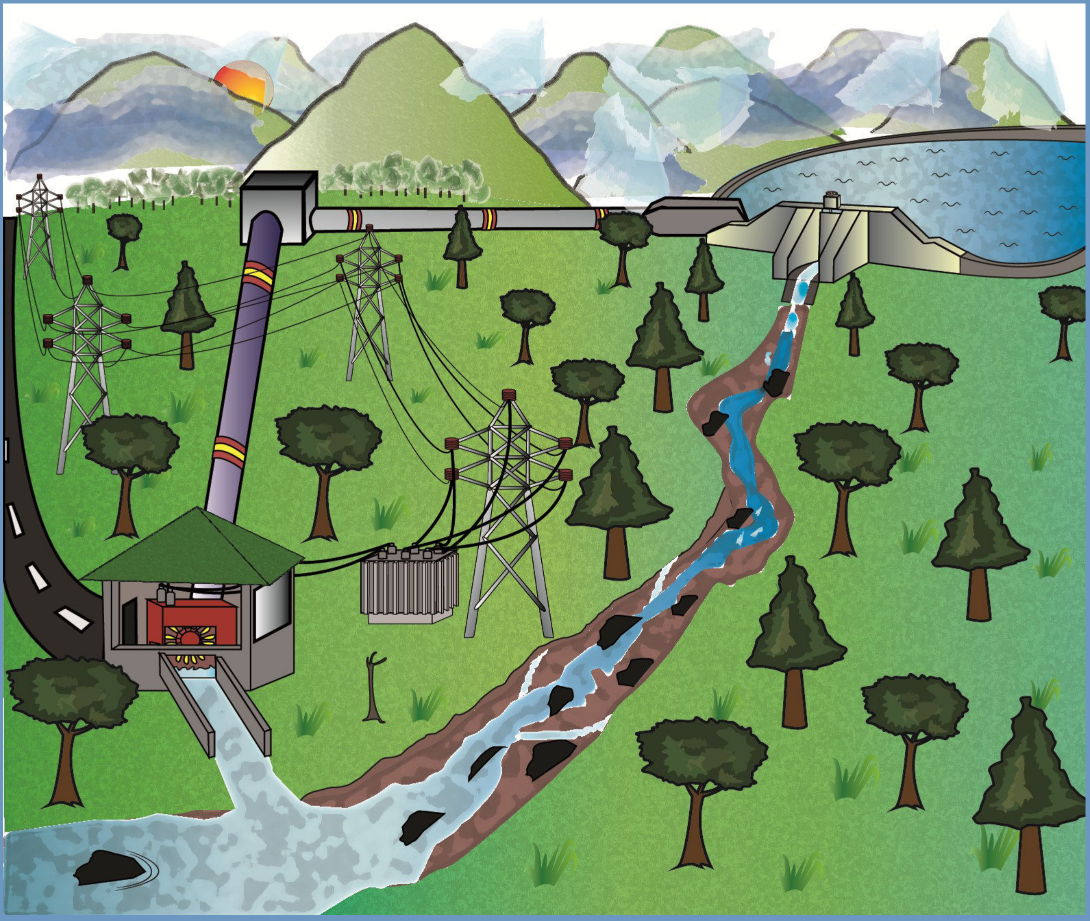
Handbook on:

# Small Hydropower Development and Environment:

## A Case Study on Sri Lanka

E.I.L Silva, E.N.S Silva



An APN funded project conducted by WRST

2016

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By

E.I.L. Silva & E.N.S. Silva

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Sponsored by Asia-Pacific Network for Global Change Research (APN)
Published by Water Resources Science and Technology (WRST)

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First Edition: 2016

ISBN: 978-955-3920-00-3
Cover Page & Illustrations: Rachana Bathika Silva
Art Work: Kanchana De Silva
Photography: Nithya Randaka, Nilanka Jayawardhana, Nishchitha Sandeepana
Formatting & Typesetting: Nishchitha Sandeepana
Sponsored by Asia-Pacific Network for Global Change Research (APN)
Publisher: Water Resources Science and Technology (WRST)

URL: www.wrst.info
77/2, Hettiyawatte, Elapitiwela, Ragama, Sri Lanka

Printed by: Tehani Printers (PVT) LTD, 584, Paradise Place, Mahabage Rd. Ragama, Sri Lanka

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## Acknowledgments

The authors are pleased to thank Asia-Pacific Network for Global Change Research (APN) for the grant awarded (CBA 2015-06NSY-Silva) for Water Resources Science and Technology (WRST) to implement several components of the ongoing research project on “Escalating Small Hydropower Development and Aquatic Biodiversity of Mountain Streams in Sri Lanka.” Many thanks are due to Dr. Herath Manthrithilake, Head, Sri Lanka Initiatives, International Water Management Institute (IWMI) for his firm interest towards WRST’s work on small hydropower. Mr. Gamini Kulasuriya and Mr. Ananda Ramanayake, of Hill Rose Estate, See Forth, Yatiyantota for the facilities provided during the field activities and for their hospitality. Nilanka Jayawardhana (Uva Wellassa University) and Dammika Pitigala (Mahaweli Authority of Sri Lanka) helped in many ways at different stages. Finally, Mr. T. Jude N. Silva, the sole proprietor of Tehani Printers, also helped in many ways to take this handbook out on art papers in four colors.

## Preface

Sri Lanka has the small hydropower potential of about 400 MW and the government encouraged and facilitated private sector entrepreneurs to undertake the development of small hydropower ventures with flexible power purchasing agreements as the country has already tapped almost every potential sites for large hydropower development. A request was made by the Mahaweli Authority of Sri Lanka (MASL) to Water Resources Science and Technology (WRST) through International Water Management Institute (IWMI) to examine whether there is a significant impact of construction and operation of small hydropower plants or so-called mini-hydro on hill stream fish fauna. The preliminary investigations revealed that there is an escalating development of mini hydro with least concern for stream environment, especially on hill stream fishes endemic to the country although, Sri Lanka is identified as a biodiversity hotspot with rich endemic fish fauna, confined to hill streams.

There are several cascades of mini-hydro in major rivers. In most cases, dead river beds occur between the weir and the powerhouse. The study was further extended to examine the entire headwater streams network of the country with the help of a competitive grant awarded to the WRST by Asia-Pacific Network for Global Change Research (APN). Among the several activities on building awareness of civil citizens and public officers on this issue, it was proposed to write a handbook entitled “Small Hydropower and Environment - A Case Study on Sri Lanka.” The handbook is compartmentalized into ten chapters and a concise glossary and a bibliography covering the reference materials. An enormous amount of literature is available on small hydropower development highlighting both financial and technical aspects. Adverse environmental impacts and social problems have also been analyzed in different angles. While there are many taboos in developed countries to restrict and regulate the establishment of small hydropower concerning the environment and social requirements, there is a rapid and shocking trend in the exploitation of hill streams in developing countries including Sri Lanka. Since it is a very lucrative venture, entrepreneurs are not reluctant to invest on small hydropower although the process is very stringent and corrupted to a greater extent.

The primary objective of this handbook is to build up the awareness of the non-subject specialists who are engaged and responsible for different activities of small power development. Further, it is anticipated that the developers also understand the importance of evolutionarily established natural processes and functions to sustain the ecosystem balance. Of course, socio-economic development to improve the quality of life and, in turn, the well-being of the human being is utmost important. Nevertheless, there is a right and necessity to protect the other living beings on this planet earth for our survival. Therefore, care should be taken when over-estimate and over-emphasis on technologically biased and politically motivated development activities are planned to over-exploit natural resources. Finally, we conclude this handbook requesting the relevant authorities and other stakeholders to adopt appropriate strategies and guidelines in par with the developed nations when physical plans are drawn to exploit hill streams for the development of small hydropower since the conservation of aquatic biodiversity and the protection of livelihoods of riparian communities is equally important.

E.I.L. Silva & E.N.S. Silva

January 2016

# Chapter 1

## Small Hydropower

### 1.1 Introduction

Sustainable electricity supply not only supports social well-being and economic progress but also regulates environmental balance and climate change in global context. Hence, it is imperative to attain Millennium Development Goals. Currently, an increasing trend is there in electricity demand in industry, household, and services sectors in developing countries to reinforce socio-economic development. If the generation of electricity is in place in an unsustainable manner and the trend is not regulated, it may lead to a chaotic stage of environmental conservation and climate change management that is the current trend prevailing in the world.

The generation of electricity by fossil fuel burning is the ever largest contributor of greenhouse gas (GHG) emission, the prime culprit of global warming or the main driving force of climate change according to the Intergovernmental Panel on Climate Change (IPCC). The contribution to global GHG emission by burning fossil fuel was about 26% in 2004, followed by forest clearing (17%), agriculture practices (13%), and automobile exhaust (13%). This condition is more predominant in the fast-growing countries in South and Southeast Asia compared with the other countries of the developing world. Nevertheless, some nations of this region altogether, do not emit a significant amount of GHG concerning global GHG emission levels. These countries are also encouraged to participate in the GHG reduction initiatives (clean renewable energy) because the reduction of GHG emission activities is synergistic with other national developmental programs such as infrastructure development, environmental health, human well-being, and collectively sustainable development programs.

### 1.2 What is Small Hydropower?

Hydropower, if the potential exists, is one of the most reliable, affordable, environment-friendly and sustainable energy sources for any nation. It is also the largest source of clean electricity at present accounting for about two-thirds of all renewable energy generation in the world. With the correct national policies in place, hydropower has the potential to expand the economy in any country where the hydropower potential exists.

Unlike large hydropower projects, small hydropower projects typically divert a small portion of a river (run-of-river system) or are constructed on pre-existing diversions, pre-existing dams, and irrigation canals. In order for a hydropower project to be deemed low-impact, it must meet certain criteria including minimum river flows (environmental flow or e-flow), water quality, fish movement, watershed protection, threatened and endangered species, recreation, and cultural resource protection.

There is no widely-accepted definition of the term "small hydropower." For this handbook, small hydropower is defined as tapping the potential energy of running water and development of a hydropower plant with generating the capacity of 10-megawatts or less.

### 1.3 Non-conventional Renewable Energy

The generation of electricity using non-conventional renewable sources, such as hydro, the wind and solar etc., is believed to be green energy production attributable to insignificant

GHG emission during the process at different levels of construction and operation. Nevertheless, generation of electricity from non-conventional renewable energy sources such as large-scale hydropower is responsible for a variety of environmental consequences to a certain extent and also to accelerate climate change due to GHG emission. Further, renewable energy resources are abundant in many regions and can be harnessed to generate the much-needed electricity and mechanical power to support development programs in developing countries in a sustainable manner, although that is not the real scenario in some developing countries. For example, small hydropower potential in Bangladesh is 0.15 MW whereas it is 15,000 MW in India. The small hydropower potentials in Bhutan, Iran, and Sri Lanka are also not high compared with other countries in South and Southeast Asia, perhaps attributable to the geomorphology of the landscape and the availability water resources

### 1.4 Large Scale Hydropower

Although hydropower is generally believed to be a renewable resource, the large-scale hydropower generation may result in environmental damage as well as social conflicts, particularly in low-head, storage reservoir-based hydropower stations. Large reservoirs constructed by damming are known to emit GHGs, especially methane ($CH_4$) and carbon dioxide ($CO_2$). Resettlements of displaced riparian human communities when constructing dams and competing demand for water usage among different sectors (power generators, farmers, household users and to sustain wildlife) are among the main social conflicts associated with this large-scale hydropower projects. Besides, some countries like Sri Lanka has harnessed almost all potential sites for large-scale hydropower generation while paying less attention to the environment and riparian communities.

### 1.5 Small Hydropower Potential

The entire installed electricity generation capacity of small hydro power for all the countries of Asia is around 112.705 gigawatt (GW) of which China has 63.429 GW (56.2%). This amount is extremely high compared with the other parts of the world; in most of the countries in the African continent, electricity generation capacities from small hydropower are less than 1000 MW, against a huge demand for domestic, service, and industrial applications. The entire installed electricity generation capacity of all the 48 countries of sub-Saharan Africa excluding the Republic of South Africa is about 30 GW that is almost equal to that of Argentina. On the other hand, potential generation capacities in those countries are not harnessed efficiently attributable to various reasons such as aging of hydro-turbines, destruction of power generating systems by means of environmental challenges such as build-up of debris dams (which clogs the generating system) and flooding of powerhouses (mainly for hydropower stations), and general plant failure resulting from limitations in plant maintenance.

### 1.6 Global Picture

Small hydropower (SHP), a mature technology that can be easily operated and maintained as a suitable energy solution for fostering industrialization, upgrading infrastructure and quality life to attain sustainable development. Its potential, primarily determined by geomorphology of the watershed, landscape of the terrain and intensity and distribution rainfall that varies from region to region, and from country to country in the world. The potential sites of small hydropower essentially have geographical boundaries than political or administrative boundaries. The SHP potential in the Middle East is zero because this region experiences least annual rainfall although mountains with steep slopes are there.

**North America:** In Canada, capacity up to 30 MW is considered to be small Hydropower plants whereas in the USA this limit is 50 MW. Further, the potential up to 10 MW has not been estimated in Canada but about 1049 MW have been tapped below 10 MW capacities. In the USA, estimated SHP potential below 10 MW is 8041 MW of which 6785 MW have been tapped. A large untapped small hydropower potential is there in North America, particularly in Canada and the USA. Information on a potential of SHP (10-MW) was not officially available for the USA as different hydropower classifications were used.

**Africa:** The African continent that is fascinated by noticeable plate tectonics features such as the Great Rift Valley, Lake Victoria and Mount Kilimanjaro and Congo Forest has 7517 MW of SHP potential to generate electricity. The potential sites in Africa are mainly confined to Eastern Africa (6262 MW), of which 209 MW has been tapped as yet. Of the twenty-three Eastern African countries, the highest potentials have been estimated for Kenya (3,000 MW), Ethiopia (1,500 MW) and Mozambique (1,000 MW).

**Southern Europe:** Southern Europe, consisting of sixteen countries has the highest SHP potential (12,239 MW) in Europe although five countries namely Andorra, Gibraltar, Holy See, Malta and San Marino do not exploit small hydropower. Eleven countries use small hydropower, including six European Union (EU) Member States (i.e., Croatia, Greece, Italy, Portugal, Slovenia and Spain) of which Italy has the highest potential of SHP (7066 MW) in Southern Europe. Besides, Italy has harnessed 16.5 % of her potential capacity. Apparently, Southern European countries have paid less attention to the development of small hydropower, perhaps attributable to environmental legislation concerning designated areas, such as Nature 2000, the EU (European Union) Water Framework Directive, among others.

**Western Europe:** Except Monaco and Liechtenstein, seven Western European countries (i.e., Austria, Belgium, France, Germany, Luxembourg, the Netherlands and Switzerland) harness SHP and they have tapped 87.4 % of the potential capacity amounts 6 644 MW. These countries especially Austria, France and Germany develop SHP technologies while manufacturing machinery and equipment need for small hydropower development. Since the EU Water Framework Directive is being implemented in all European Union Member States, these countries are strictly bound to the environmental regulations such as maintaining downstream environmental flow and facilitating fish movements in SHP systems.

**Eastern Europe:** Most of the Eastern European countries have tapped SHP, but the potential ranges from 1.30 MW in Moldova to 1300 MW in Russian Federation. 78 % of the total regional potential (3495 MW) has been harnessed (3495 MW) in the Eastern Europe with Belarus, Russian Federation and Ukraine exploiting their maximum potentials. The Russian Federation has the highest potential (1300 MW) of which 100% has been harnessed. Nevertheless, EU Member States have to bear more operational costs since they have to maintain higher residual flow conditions according to Water Framework Directive.

**Northern Europe:** Of the 18 Northern European countries, ten countries of which eight are the EU Member States (except Norway and Iceland) use SHP. Except Norway (1778 MW) and Sweden (1230 MW), the other countries are not endowed with large potentials of mountain streams. Some countries (e.g., Norway, Finland, and Denmark) have overachieved their targets. Besides, EU member states such as the United Kingdom and Sweden have slowed down the progress resulting from strong public opinion on the environment.

**Oceania:** In Oceania (mainly Australia and New Zealand), many green field sites are there, that are physically suitable for small-scale hydropower development but the industry is not encouraged much primarily attributable to potential environmental and social issues, with the main barriers to development being many protected areas, competing uses for water and a long and expensive consenting process. The correct potentials of both countries are not estimated although New Zealand has given 760 MW as a potential figure.

**Table 1.1:** Global summary of small hydropower potentials and installation

| Region | Potential (MW) | Installed (MW) | % |
|---|---|---|---|
| **Africa** | | | |
| Eastern Africa | 6262 | 208 | 3.3 |
| Middle Africa | 328 | 76 | 23.2 |
| Northern Africa | 184 | 115 | 62.5 |
| Western Africa | 743 | 83 | 11.2 |
| **Sub total** | **7517** | **482** | **6.4** |
| **America** | | | |
| North America | - | 7834 | |
| South America | 9390 | 1735 | 18.5 |
| Caribbean Countries | 252 | 124 | 49.2 |
| **Subtotal** | | **9569** | |
| **Asia** | | | |
| Central Asia | 4880 | 184 | 3.8 |
| Eastern Asia | 75196 | 40457 | 53.8 |
| Southern Asia | 20341 | 3563 | 19.7 |
| South Eastern Asia | 6682 | 1252 | 18.7 |
| Western Asia | 7752 | 488 | 6.0 |
| **Sub total** | **114,851** | **45,944** | **40.0** |
| **Oceania** | | | |
| Australia | - | 172 | - |
| New Zealand | 760 | 138 | 18.2 |
| **Sub Total** | | **310** | |
| **Europe** | | | |
| Eastern Europe | 3495 | 2735 | 78.3 |
| Northern Europe | 3841 | 3643 | 94.8 |
| Southern Europe | 12239 | 5625 | 45.9 |
| Western Europe | 6644 | 5809 | 87.4 |
| **Subtotal** | **26219** | **17,812** | **67.9** |

**Eastern Asia:** Recent reports show that Asian continent has the highest potential of SHP (114,851 MW) based on the 10-MW definition compared with other regions of the world (Tables 1.1 & 1.2). Eastern Asia (excluding North Korea) has the highest SHP potential of 75.196 GW with the installed capacity of 40.48 GW. China belongs to Eastern Asia ranked first in the world for small hydropower potential (63,429 MW) that is about 55.2 % and 36.4 % of regional and global potentials respectively (Table 1.1). Further, Eastern Asia has installed 53.8 % (40,575 MW) of total SHP potential, which is the highest in the world.

**Central Asia:** Of the Asian sub-regions, the Central Asia has the lowest SHP potential (4880 MW) with Kazakhstan having the largest potential (2707 MW) of which only 78 MW have been tapped. The overall exploitation in Central Asia is 8.4 % of the total sub-regional potential.

**Southern Asia:** Southern Asia that includes eight countries has the total SHP potential of 20,341 MW although 3563 MW (19.3%) has been tapped (Table 1.1). This is primarily attributable to relatively poor exploitation by Nepal, Afghanistan Pakistan and India (Table 1.2).The estimated SHP potential in Southern Asia ranges from 15,000 MW in India to 0.51MW in Bangladesh. Although India has the largest potential in the Southern Asian sub-regional, the country has tapped only 3,198 MW that is the third highest in the region, next to China and Japan. Sri Lanka has already tapped 86.5 % of potential small hydropower (400 MW) that is 10.8 % of the installed capacity of India. Escalating rate of SHP harnessing in Sri Lanka can be attributed to several reasons such as the government policy, private sector participation, and technology etc.

**Southeast Asia:** The total SHP potential in Southeast Asia that includes eleven countries is 6682 MW (no hydropower is used in Singapore and Brunei) and it ranges from 0.3 MW in Timor-Leste to 2205 MW in Viet Nam. Except Viet Nam, The Philippines, and Indonesia have SHP of more than 1000 MW and it was 700 MM and 300 MW in Thailand and Cambodia respectively. Myanmar has abundant small hydropower potentials. The topography of the country is suited to isolated power supply systems. At present about 3 % of the country's potential has already been developed and 26 % is under implementation. However, according to the World Small Hydropower Development Report, 21.5 % of the potential has been used (WSHPDR 2013) but still nearly 60 sites with individual capacities between 1 MW and 5 MW remain suitable and could result in around 402.20 MW of total potential capacity. Southeast Asia experiences monsoon rain but the terrain varies from country to country resulting in different potential in small Hydropower. All nine countries have harnessed 19.2 % of the total available SHP potential of 6,685 MW.

**Western Asia:** Most Western Asian countries in the Arabian Peninsula (i.e., Saudi Arabia, Bahrain, Oman, Kuwait, Yemen, United Arab Emirates, and Qatar) experience about 250 mm of annual rainfall, with Saudi Arabia receiving a minimum of 59 mm. The countries in the mountainous Caucasus sub-region (i.e., Azerbaijan, Armenia, and Georgia) experience the highest precipitation with a maximum of 4,100 mm. The SHP in this region is limited to Iraq, Jordon, Lebanon and Turkey in addition to the countries in the Caucasus sub-region, with Turkey having the highest potential of 6500 MW. The total potential in the region is 7,752 MW, but 488 MW (6.2%) have been tapped, with Turkey having a maximum installation capacity of 175MW. Information on small hydropower is contradictory in different reports perhaps due to the dearth of published data in developing countries.

In 2013, United Nations Industrial Development Organization (UNIDO) and International Center for Small Hydro Power (ICSHP) the jointly published document called World Small Hydropower Development Report (WSHPDR) compiling much information on SHP extracted from different sources, but publications exclusively devoted to mini hydropower (MHP) potentials are still lacking.

**Table 1.2:** Regional summary of small hydropower potentials and installation capacities

| Country | Area (km²) | Population (m) | Potential (MW) | Installed (MW) | % |
|---|---|---|---|---|---|
| **Central Asia** | | | | | |
| Kazakhstan | 2,724,900 | 17.55 | 2 707 | 78 | 2.8 |
| Kyrgyzstan | 199,951 | 5.49 | 275 | 32 | 11.6 |
| Tajikistan | 143,000 | 7.77 | 115 | 12 | 10.4 |
| Turkmenistan | 488,100 | 5.05 | 23 | 5 | 21.7 |
| Uzbekistan | 447,400 | 28.39 | 1760 | 56 | 3.1 |
| **Sub Total** | | | 4880 | 184 | 8.4 |
| **Eastern Asia** | | | | | |
| China | $9.600 \times 10^6$ | 1 339.61 | 63429 | 36 889 | 58.1 |
| Japan | $0.377 \times 10^6$ | 127.37 | 10267 | 3 503 | 34.1 |
| North Korea | $0.122 \times 10^6$ | 24.35 | | | |
| South Korea | $0.099 \times 10^6$ | 48.88 | 1500 | 65 | 4.3 |
| **Sub Total** | | | 75,196 | 40457 | 53.8 |
| **Southern Asia** | | | | | |
| Afghanistan | 652,000 | 30 | 1200 | 75 | 6 |
| Bangladesh | 147,570 | 161 | 0.15 | 0.01 | 7 |
| Bhutan | 38,394 | 0.71 | 8 | 8 | 100 |
| India | 3,287,263 | 1,205 | 15000 | 3198 | 21 |
| Iran | 1,648,195 | 78.86 | 38.2 | 16.5 | 43.1 |
| Nepal | 147,181 | 26 | 1430 | 70 | 5 |
| Pakistan | 796,095 | 190 | 2265 | 281 | 12 |
| Sri Lanka | 65,610 | 21 | 400 | 347 | 86.5 |
| **Sub Total** | | | 20,341 | 3996 | 19.6 |
| **Southeast Asia** | | | | | |
| Cambodia | 181,035 | 14.14 | 300 | 2 | 0.6 |
| Indonesia | 1,904,569 | 239.87 | 1267 | 99 | 7.8 |
| Lao | 236,800 | 6.48 | 50 | 11 | 22 |
| Malaysia | 329,961 | 28.4 | 117 | 88 | 75.2 |
| Myanmar | 676,578 | 47.96 | 167 | 36 | 21.5 |
| Philippines | 300,000 | 93.26 | 1876 | 248 | 13.2 |
| Thailand | 513,120 | 69.12 | 700 | 146 | 20.9 |
| Timor-Leste | 14,874 | 1.2 | 0.3 | 0.3 | 100 |
| Viet Nam | 331,051 | 86.93 | 2205 | 621 | 28.1 |
| **Sub Total** | | | 6682 | 1251 | 19.2 |
| **Western Asia** | | | | | |
| Armenia | 29,743 | 3.26 | 430 | 158 | 36.7 |
| Azerbaijan | 86,660 | 9.23 | 392 | 42 | 10.7 |
| Georgia | 69,700 | 4.63 | 286 | 67 | 23.4 |
| Iraq | 435,000 | 32.3 | 26 | 6 | 23.1 |
| Jordan | 89,342 | 6.05 | 58 | 10 | 17.2 |
| Lebanon | 10,400 | 4.23 | 60 | 30 | 50 |
| Turkey | 783,562 | 75.7 | 6500 | 175 | 2.6 |
| **Sub Total** | | | 7752 | 488 | 6.2 |
| **Total** | | | 114,851 | 46,375 | 40.5 |

Adopted from WSHPDP (2013)

### 1.7 Small Hydro Categories

Small hydropower (SHP) is a non-conventional renewable energy technology for generating electricity and mechanical power. SHP is categorized as being “small” depending on the capacity of the installed electricity. No international agreement or hard and fast rule on the limit of “small”, but Europe and other countries accept 10 MW as the upper limit. Within the

SHP category, the systems are divided into sub-categories such as pico, micro, mini, and small. Many countries and organizations recognize pico generates less than 10 kW whereas micro generates between 10 kW and 100 kW. Nevertheless, mini-hydropower plants generate more than 100 kW but less than 1 MW and the range of small hydro varies between 1 and 10 MW (Table 1.3).

These subcategories are variably used in different countries. For example, small hydropower plants that have generation capacity below 10 MW, are named as mini-hydropower plants in Sri Lanka. With such type of installed capacities, SHP is more robust than a photovoltaic (PV) system. SHP installed systems, therefore, are better placed to support diverse energy requirements for institutional, community, and small scale industries in remote locations, than either solar PV or wind power. The SHP can be of either a low-head reservoir type or run-of-river type; run-of-river type is a flow-through system has no water storage for power generation, but instead, water for power generation is diverted from the main river via a small weir but maintains downstream environmental flow.

**Table 1.3:** Subcategories of small hydropower

| Subcategory | Capacity (kW or MW) |
|---|---|
| pico | >10 kW |
| micro | 10-100 kW |
| mini | 100-1000 kW |
| small | 1-10 MW |

### 1.8 Run-of-River and Low-head Reservoir Systems

For small capacities of SHP, run-of-river types are better than low-head reservoirs because the absence of reservoirs, maintains continuous downstream flow to sustain aquatic life and investment cost per kW of electricity is relatively low. In developing countries, the main emphasis is to reduce the capital investment for SHP irrespective of sustainable environment. A typical run-of-river SHP for electricity generation is composed of the following basic components; water intake structure (e.g., weir and settling tank), forebay (optional), headrace canal, penstock, turbine, mechanical power transmission to the generator, tailrace canal, electricity transmission to load centers, and control panel. Nevertheless, the SHP maintains continuous environmental flow and devises for upstream and downstream fish movements. This aspect has neglected to a greater extent in developing countries including Sri Lanka.

### 1.9 Site-specific Technology

SHP is a site-specific technology and the potential location is determined by two main factors namely, suitable head or sloping section of the river channel and perennial river flow with sufficient water throughout the year. Accordingly, all locations on the river course are not ideal for SHP development. Therefore, long-term flow monitoring and investigation of correct geomorphologic conditions and soil properties are important during potential sites selection. In many instances, pre-feasibility studies are conducted by technologists and subject specialists. As many potential locations for SHP are found in hill streams of the mountainous terrain, care should be taken to avoid landslides and earth slips. The major natural threats on small hydropower plants are flash floods, especially in monsoon areas. Not only the site determines the magnitude of the SHP (as well as its type) but also the level of complexity of the SHP civil works and thus the investment cost per kW of installed power.

The investment cost also depends on local economies and government taxes that are imposed on system components as well as on the labor services and status of the government corruptions.

### 1.10 License and Cost

In many countries, permissions are granted to the developers after rigorous lengthy procedures of evaluation by different project approving agencies. In Sri Lanka, proposals (IEE or EIA) are opened for the public hearing and the consent of riparian communities is important when other users of water in the selected site are there. The capital investment cost for an ideal system varies from country to country depending on various factors. Nevertheless, it ranges from US$1,000 to US$20,000 per kW of installed electricity. The capital investment cost may align more towards the lower limit in developing countries, which has encouraged more foreign developers to invest in developing countries with local partners. Maintenance costs of SHP plants are relatively small in comparison to other technologies such as diesel generators. Indeed, SHP is a long-lasting and robust technology, the lifespan of a well-installed SHP systems can be last for 50 years or more without major new investments in parts, replacements (the average life considered for investment purposes is about 30 years.

Of different electricity generation systems, SHP is an efficient technology for power generation because electricity is generated directly from the shaft power. SHP for power supply is a well-matured technology when compared with solar photovoltaic (PV) and the wind energy systems. SHP technology is already being applied as one of the energy interventions in many countries of Asia (e.g., India, Sri Lanka, and Nepal) Peru, and China. In the African continent, the technology is not applied widely despite the certain regions; especially Eastern Africa has enormous SHP resources. As in Sri Lanka, the SHP technology in Africa also was first introduced by missionaries and tea planters but the development in Africa is led by international development agencies, not research-based institutions. As a result, information about SHP in Africa is restricted to certain sectors, which is also common in other developing countries. The technology and awareness seem to have penetrated into many developing countries as evidenced by the inclusion of SHP energy in rural electrification master plans throughout the developing world except in few countries in South America and Africa. An opportunity is there for the popularization of the technology because many countries in the developing world have liberalized their energy sectors, allowing for independent (private) power generation and selling it to the national grids through independent power purchase agreements. In fact, private sectors in many developing countries have started venturing into SHP generation business as early as 2006.

### 1.11 Unequal Development

The small hydropower is a suitable renewable energy technology in the context of rural electrification, energy diversification, industrial development and exploration of existing infrastructure. At the national level, small hydropower programs in developing regions and at the regional level in Western Africa, have reflected the importance given by some governments to small hydropower as an energy solution for rural electrification and productive use. Nevertheless, harnessing small hydropower primarily depends on the SHP potential of a particular territory, which varies from continent to continent, region to region within the same continent and from country to country within the same region. In addition, many other inherent barriers are there, that are responsible for the insignificant development of SHP especially in developing countries, although their willingness to harness such renewable energy resource is evident. These intrinsic barriers may vary from country to country but with some similarities intrinsic to certain regions such as Africa, South America, and Asia. The major barriers unique to different regions are highlighted below**.**

**African Region**

- Lack of government funding
- Insufficient technological know-how
- Poor private sector participation in investment for SHP development
- Inadequately developed infrastructure
- Non-availability of feed-in-tariff (FIT)
- Political unrest
- Competitive demand for water uses
- Poor awareness of general public on small hydropower
- Stringent EIA process

**Central America**

- Complex multiple administrative procedures for issuing license
- Rigorous pre-feasibility studies.
- Non-availability of feed-in tariffs
- Social-institutional barriers
- Extremely high government charges
- Poor micro financing systems and high-interest rates for bank loans

**South America**

- SHP potentials are unknown(e.g., Bolivia, Brazil, French Guiana)
- Poor government policies
- El Niño events in Colombia and French Guiana
- Local political instability (e.g., Argentina, Colombia and Chile)
- Unwillingness of foreign agencies to invest in hydropower projects
- No tax incentives in Ecuador, Brazil, and Panama
- No sufficient micro-financing institutions and power purchasing agreements

**North America**

- Developers encounter long lead times required for approvals or to obtain license
- Lengthy public participation process
- Environmental flow for fish migration
- Aesthetic intrusions
- Aquatic biodiversity conservation
- Complex regulatory processes
- Lack of integration and communication among agencies
- Lack of standards,
- Grid connection difficulties
- Limited incentives for development.
- The absence of designs specific to small hydropower.

**Eastern Europe**

- Environment concerned public opposition
- Financial constraints
- Much cheaper other energy sources (coal, nuclear)
- Non-suitable geomorphology (Hungary)
- No civil engineering work is allowed in Poland
- No responsible organizations to promote SHP in Slovakia
- Member states of the EU adhered to environmental flow regulations

**Northern Europe**

- Residual flow requirement is compulsory in EU member states
- Fish migration in mountain streams
- Grid connection can be an obstacle in some countries
- Strong angling lobby throughout the United Kingdom

**Western Europe**

- Residual flow fish bypasses, changes in Feed-in-Tariff
- Strict, administrative procedures
- Opposition among from fishermen, civil servants, and academics
- Not supported by legislative and administrative activities
- Environmental concerns remain, being voiced by various
- Environmental lobbying by. NGOs, fishing clubs and local stakeholders
- Lacking concrete information on small hydropower

**Central Asia**

- Poor public awareness
- Unavailability of institutional regulatory frameworks
- Unavailability of bank credits and technical know-how
- Operational difficulties during winter
- Low flow conditions during summer

**Eastern Asia**

- Obtaining bank loans
- Relatively low tariff receiving from the grid connections
- Minimum flow requirement and river health are major in Japan
- Social well-being of the riparian communities also very strict in Japan

**Southern Europe**

- Financial constraints in Bosnia and Herzegovina
- Environmental impact, cultural-historical heritage and landscape protection in Croatia.
- Greece, residual flow in Greece
- Suitable incentive support is not available in Italy and Macedonia
- No proper framework in Portugal

- Feed-in tariffs exist, but strict administrative procedures in Serbia, Slovenia, and Spain

**South Asia**

- No bank loans and poor private sector involvement in Afghanistan and Bangladesh
- Potential for SHP development in Bhutan is unknown
- Strict environmental regulations and remoteness of mountainous terrain in Bhutan
- No gauging stations everywhere in India,
- Lengthy procedures for project clearance and obtaining license
- Minimum flow requirement in state governments of India
- Lack of good governance and law and order in Nepal
- Remoteness and poor infrastructure problems in Pakistan
- Lack of trained local staff and low tariffs in Pakistan

Sri Lanka has almost exceeded her estimated potential of 400 MW by the end of 2014 giving grid connection to 286 MW and 37 small hydropower plants with 68.1 MW aggregation capacities are being under construction. The tremendous establishment of SHP plants in Sri Lanka can directly be attributed to the non-existence of barriers or taboos whatsoever related to legislative, financial, social or environmental issues. While there are many local investors of different elite groups, foreign investors are also active in this sector in Sri Lanka. The pattern of unprecedented growth of SHP industry in Sri Lanka will be highlighted in the next Chapter 2 of this Handbook. Most of the local entrepreneurs engaged in SHP active in Sri Lanka have their foreign counterparts and some local companies undertake the construction and development of foreign projects, especially in Africa.

The low utilization of India's SHP potential may be attributed to several factors, including challenges in setting up plants in difficult and remote terrain; delays in acquiring land and obtaining statutory clearances; inadequate grid connectivity; and high wheeling and open access charges in some States.

SHP plants have certain inherent advantages: they generate clean energy at a competitive cost; they have features that make them suitable for peaking operations; they are less affected by rehabilitation and resettlement (R&R) problems vis-à-vis large hydropower plants; they can meet the power requirements of remote and isolated areas, and they use mature and largely indigenous technology.

Small hydropower projects have been implemented in several countries in the region, but information about these projects is limited and incomplete. While some technical information on the implemented projects is available, information about the success of the implementation models is mostly unavailable.

Basic technical information about existing hydro-stations may be available from different sources, but is incomplete and inconsistent. This lack of information severely hampers the ability to learn from past experiences and creates a barrier to the uptake of the technology.

# Chapter 2

## Small Hydropower in Sri Lanka

### 2.1 Introduction

Renewable energy resources are appropriate choice in clean energy generation around the world. Unlike non-renewable energy generation, plants that have a relatively lower capital investment and a substantial operational cost, renewable energy conversion plants have negligible operational costs. This offsets the high capital cost and contributes significantly to maintaining long-term energy costs. Renewable energy production facilities are not subjected to fuel-price fluctuations but change due to environmental conditions to some extent. Hence, renewable energy should be considered to be the ultimate strategy for stabilizing energy prices in the long term. The most reliable renewable energy, except geothermal and tidal energy, comes either directly or indirectly from the sun. In addition to direct solar energy, hydro, wind and biomass are among the widely used renewable types of energy in many parts of the world depending on their availability and potentials.

By creating large upstream reservoirs and damming perennial rivers, a large amount of hydroelectric power can be generated. Most of the large rivers in the world have been tapped today generating hydro-electricity. Similar technologies were employed in minute scale to tap the potential energy of high mountain streams as small, mini or micro hydropower development. This technology has been widespread throughout the world including Sri Lanka as a lucrative private sector industry. Many governments of the developing countries enforced comfortable policies on small hydropower development while economically sound western countries exploit small hydropower carefully conserving the aquatic environment. The major conceptual issue aligned with the small hydropower development is the negative environmental impact is "small" or "insignificant" compared to large hydropower projects.

The development of the small hydropower (SHP) sector in Sri Lanka is positively considered as a success story in the energy sector. Small hydropower industry is typically characterized by projects with capacities less than 10 MW and the economically feasible small hydropower potential in Sri Lanka is estimated as 400 MW. The year 2008 has seen a growth in the non-conventional renewable energy additions surpassing 150 MW (large hydropower is considered as conventional renewable energy). Most of these capacity additions are attributed to the growth in the SHP sector. Figure 2.1 depicts the exponential growth in installed capacity of non-conventional renewable energy resources (1996-2014), where the capacity addition exceeded 150 MW in 2008.

The geo-climatic settings of Sri Lanka are particularly conducive to harnessing hydro resources: a highland mass in the south-center, surrounded by an intermediate zone of upland ridges and valleys lying at the lower elevation. Prevailing climate of Sri Lanka is largely determined by the meteorological conditions caused in the Indian sub-continent due to tropical monsoon. Two contrasting wing regimes formed as a result of the Asian monsoons is the major phenomenon caused by these conditions. The southwest monsoon prevails from May to September and the northeast monsoon occurs from December to February. These are responsible for the distinct seasonal rainfall in Sri Lanka. Nevertheless, orographic nature of the Central Highlands of the island is decisive on rainfall intensity and distribution. Given the humid conditions and the hilly terrain, the highlands of Sri Lanka offer excellent opportunities to harness hydropower for the generation of electricity.

### 2.2 Mini-hydro History in Sri Lanka

The history of harnessing hydropower in Sri Lanka dates back to the British colonial era, during which hydropower was used as the main source of energy in large tea factories located in the hilly terrain of the central highland. Since the beginning of the tea industry, small hydropower was the main source of power for the tea factories, and many factories were intentionally located closer to perennial streams or brooks to tap their gravitation energy. Initially, factories and powerhouses were placed together, as power had to be transmitted to the machinery by line shafts and belts. Later, direct current (and still later, alternating current) generators became more readily available, and powerhouses were built at further downhill from the factory to maximize the head for effective power generation.

According to available records, nearly 90 percent of the small hydropower turbines used in the plantation sector was supplied by Gilbert Gilkes and Co. Ltd., which was the oldest manufacturer of hydraulic turbines and pumps in England. The first 15 hp vortex type turbine was delivered to the country as early as 1887. Since then, there had been a steady supply of hydropower generating machinery to Sri Lanka with sales peaking around in 1930. During 1887- 1957, Gilbert Gilkes and Co.Ltd. supplied 367 SHP plants aggregating to about 10 MW installation capacity.

### 2.3 Temporary Drawback

After the World War II, the relative advantage of SHP rapidly declined owing to the installation of large-scale storage-type hydro schemes, which began to supply the first stages of a national grid. At the early stage, power supplies were in surplus, and even export to India was considered. Further, many of the mini-hydro and thermal systems were near their end of life at this time, needing extensive repairs or total replacement. These issues, together with the prospect of low-cost and reliable electricity supplies, acted as strong incentives for the tea industry to switch over to the national grid operated by the Ceylon Electricity Board (CEB). By 1975, when the tea estates were nationalized, less than one-third of them had retained their SHP systems in operational stage. The decline further continued after nationalization and by 1984, only 5 percent SHPs were in operation.

The shift from small hydro to grid-connected electricity was justified on financial grounds up to the late 1970s owing to the reliability of grid electricity and the favorable tariff schemes. Nevertheless, charges increased by 1981 with the shortage of generating capacity led the CEB to use gas turbines to meet the peak demand from 1980 onwards.

New lease of life renewed interest in SHP development emerged in the early 1980s, as by that time the adverse consequences to the tea industry; increasing costs and unreliable power supply were slowly being recognized. This renewed interest could further be attributed to the worldwide surge of harnessing renewable energy, as a response to the oil crisis in 1974. Accordingly, several estate SHP schemes were rehabilitated with the technical and financial support from the Integrated Rural Development Project (IRDP) funded by the Government of the Netherlands. The Practical Action (former Intermediate Technology Development Group), jointly with CEB, made a significant contribution to the revival of SHP development in Sri Lanka through technology development and strengthening of technical capabilities of Sri Lankan engineers and technicians.

### 2.4 Reasons for Success

At the inception, the SHP industry was not all that different from the major hydropower projects implemented in Sri Lanka, because of the turnkey contracts and consultancy inputs from foreign experts. Nevertheless, Sri Lanka achieved the following gradually.

- Gained technological know-how by local engineers
- Adaptation of low-cost engineering methods
- Engagement of local business community
- Decreased capital investment and operational cost
- Conversion of more potential sites into commercially viable projects
- Lowering cost per unit capacity (1 MW) as US$ 1 million by 2003
- Relaxed government policies on environmental issues
- Least attention on mitigation and monitoring during operation
- Standardized Power Purchase Agreement (SPPA) with CEB

The salient features of the SPPA are as follows;

- A complete avoidance of market risk: CEB assures the purchase of all electricity produced by an SHP project
- A floor price that is 90 percent of the tariff, ensuring a steady and predictable cash-flow and
- A long-term commitment, with the SPPA lasting 15 years and being based on sound legal provisions

### 2.5 Towards Small Hydro

Most of the major hydro potential has been developed and they are delivering valuable low-cost electricity to the country (Table 2.1). Since the commissioning of the first hydroelectric power plant in 1950, hydroelectricity has played a major role in power generation in Sri Lanka. The largest share of electricity generation came from major hydropower projects until the mid-1990s. The Sri Lanka's power sector was dominated by hydropower until 1996, and almost 94 percent of the annual power demand in 1995 was met via hydropower generation. Despite several hydropower capacity additions, the share of hydropower showed a reducing trend since the mid-1990s due to the non-availability of new potential sites that are economically feasible for hydropower development. Currently, hydropower stations are operated to meet both peak and base electricity generation requirements.

**Sri Lanka is endowed with several forms of renewable energy sources owing to island's natural geo-climatic settings. Biomass, solar, hydro and wind have been identified as the potential sources in this regard that have the development potential, as and when the technologies become mature and cost-effective. Solar and wind are among the best renewable energy sources compared with biomass and hydro.**

**The government has also recognized the need to harness biomass as both a commercial crop as well as the third option for electricity generation. Besides, it has declared *Gliricidia sepium* as the fourth plantation crop after tea, rubber, and coconut in 2005. Care should be taken regarding electricity generation by dendro such as *Gliricidia sepium* as burning biomass results in the emission of toxic volatile trans-boundary compounds such as dioxin and furan in addition to greenhouse gasses (GHGs).**

**Table 2.1:** Major hydropower developments in Sri Lanka

| Name of the Project | River Basin | Capacity (MW) | Year of Commissioned |
|---|---|---|---|
| Old Lakshapana | Kelani River | 53.5 | 1950 |
| Wimalasurendra | Kelani River | 50 | 1965 |
| New Lakshapana | Kelani River | 115 | 1983 |
| Canyon | Kelani River | 60 | 1983 |
| Polpithiya | Kelani River | 75 | 1974 |
| Inginiyagala | Gal Oya | 10 | 1951 |
| Udawalawe | Walawe River | 6 | 1969 |
| Samanalawewa | Walawe River | 120 | 1992 |
| Ukuwela | Mahaweli River | 40 | 1976 |
| Nilambe | Mahaweli River | 3.2 | 1988 |
| Bowetenna | Mahaweli River | 40 | 1981 |
| Kotmale | Mahaweli River | 201 | 1985 |
| Victoria | Mahaweli River | 210 | 1984 |
| Randenigala | Mahaweli River | 122 | 1986 |
| Rantambe | Mahaweli River | 49 | 1990 |
| Upper Kotamale | Mahaweli River | 150 | 2011 |
| Kukule Ganga | Kalu Ganga | 75 | 2003 |
| Deduru Oya | Deduru Oya | 1.5 | 2014 |
| **Total** | | **1381.2** | |
| Moragahakanda | Mahaweli River | 10 | **Under Construction** |
| Kalu Ganga | Mahaweli River | 15 | |
| Moragolla | Mahaweli River | 30.2 | |
| Broadlands | Kelani River | 35 | |

It is anticipated to develop biofuels, as a key constituent of the transport energy and contribute a share of 20 % by 2020. Energy sector should pay attention to extracting bio-diesel from invasive plants including planktonic algae, which is abundant in hyper-eutrophic water bodies such as Beira Lake.

Unavailability of potential sites for major hydropower development, associated inflation and high labor cost and environmental issues has led to exploring the potential of small hydropower in the country. Risk analyzes, risk mediation measures, low-cost developments, selective procurement etc., adopted by engineers resulted in achieving positive results. Nevertheless, the major assumption forwarded in engineering context on small hydropower development was that small hydropower results in no adverse environmental and social issues, which is an incorrect and bias assumption to a greater extent.

Small hydropower sector and its potential in Sri Lanka have been overviewed and the country adheres to the small hydropower definition of 10 MW as the upper limit. By the end of 2014, 143 small hydropower plants are connected to the national grid and in operation in Sri Lanka, with an aggregated installed capacity of 287 MW. The most of them are owned by Independent Power Producers (IPPs). According to Sri Lanka's Sustainable Energy Authority (SLSEA), the total economically feasible small hydropower potential in Sri Lanka is 400 MW with 600 potential sites. On the contrarily, the latest release (on 16 October 2015) of the Public Utility Commission of Sri Lanka (PUCSL), permission have granted for another 87 projects with installation capacity of about 139 MW.

Figure 2.1 depicts the grid connection since 2000 to 2014 with aggregation of capacity to the national grid as reported by Ceylon Electricity Board in January 2015. The acceleration can be attributed to the transparent resource allocation process introduced by SLSEA which is based on a 20-year permit to use a particular new renewable energy source granted to private sector developers through a 'first come first served' principle.

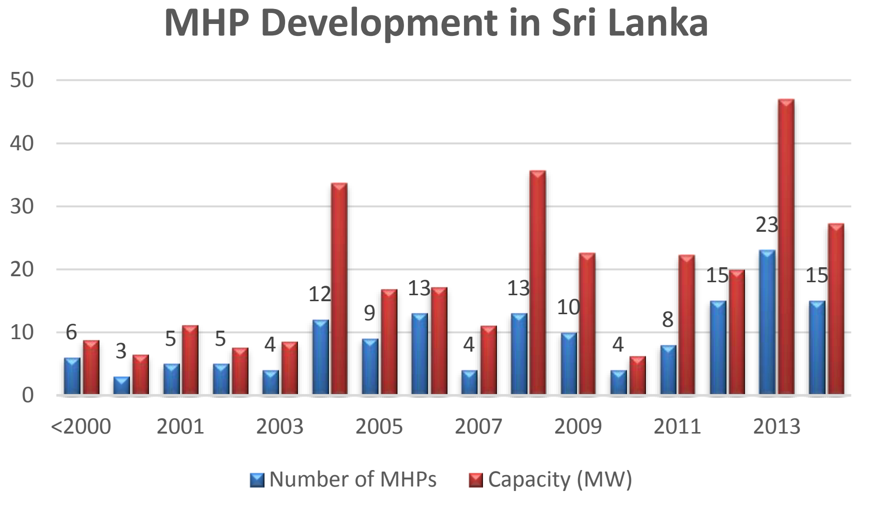



**Figure 2.1:** Development of Small Hydro in Sri Lanka from 2000 to 2014

Sri Lanka's small hydropower sector has shown a gradual evolution with an accelerated growth up to 2015, with no formal policy framework and enthusiasm. Remarkably escalating growth of the establishment of small hydropower projects in Sri Lanka since early 2000 may be attributed to following factors;

- Willingness of entrepreneurs to engage in this lucrative business
- Poor lobbying of environment conservationists under civil war in the country
- Poor knowledge of riparian communities on stream ecology and livelihood threats
- Lack of high caliber stream ecologists in Sri Lanka to conduct IEEs or EIAs
- Non-availability of an expert panel to evaluate proposed projects
- Lack of knowledgeable stream ecologists in relevant government sector organizations
- Consideration of construction and operation of SHP as zero GHG emission activities
- Ability of entrepreneurs to manipulate the situation as the need arises
- Political biases and enthusiasm to become self-sufficient in power generation

As a result, the tariff on offer was based on avoided costs, and escalating oil prices forced the small hydropower tariff to climb up towards an almost unsustainable level. Although the small hydropower in Sri Lanka has created a conducive market enterprise within certain legal frameworks and financing mechanisms in place, an escalating development with poor concern on environment and livelihood impacts on riparian communities will certainly create devastating negative effects in the time to come. Apparently, the Sri Lankan Government has lavishly provided policy support to the entrepreneurs over the last decade, creating an encouraging environment for the construction and operation of small hydropower in the country based on the recommendations forwarded by the energy sector.

Sustainable Energy Authority of Sri Lana has identified the following as the potential barriers to small hydropower development although the sector has reached its peak by establishing 143 grids connected mini hydropower projects while issuing about 180 licenses by the end of 2014.

The small hydropower sector in Sri Lanka has reached its maturity state; however, the industry is still experiencing barriers to implementation in the following areas:

- Absence of a dedicated transmission solution for uptake of power from small hydropower plants
- Limitations at local grid sub-station level and at national power system level for adding more small hydropower to the grid
- Public opposition at regional level arising out of conflicting use of water resources
- The absence of dispatch control strategies such as advanced forecasting and on-line monitoring and regression.

The biggest risk elements in the SHP sector are the social issues and easy land issues. The

***Misleading statements***

*1. Almost all hydro installations were, and still are, run-of-river schemes without storage facilities.*
*2. Eco-friendly power generation with zero GHG emission*

policy document “National Energy Policies and Strategies (2008)” of the government creates an environment conducive to develop non-conventional renewable energy inclusive of small hydropower.

Nevertheless, later still, local engineers together with the local business community – who became investors in the industry – made bold decisions with high risks to promote local engineering know-how and low-cost engineering methods. These changes dramatically decreased the investment costs, converting more sites into commercially viable projects. Further, the efforts of the local engineers to bring down the investment cost per unit capacity to as low as US$1 million per MW by 2003, in spite of inflation and high labor cost, have resulted in a notable increase in investment in the SHP sector.

In 1990, the first attempt of using small hydropower plants to export energy to the national grid experimented. Success was achieved in 1996, with the commissioning of the first grid-connected power plant (namely, Dickoya). This set stage for the development of a Standardized Power Purchase Agreement (SPPA), which turned a new leaf by streamlining the process of selling power to CEB, the operator of the national grid.

The SPPA is considered the focal point in the successful development of the SHP sector in Sri Lanka. It is applicable for power plants with capacities less than 10 MW based on renewable sources, waste or co-generation facilities. The power plant could be either connected to the grid and deliver electricity fully to the grid or connected and deliver electricity to the grid while a part of the electricity generated is used by the developer. Grid-connected projects are commercial initiatives carried out by the private developers. The salient features of the SPPA are as follows;

- A complete avoidance of market risk: CEB assures the purchase of all what is produced by an SHP project
- A floor price that is 90 percent of the tariff, ensuring a steady and predictable cash-flow; and
- A long-term commitment, with the SPPA lasting 15 years and being based on sound legal provisions

In Sri Lanka, energy is consumed in three forms – electricity, petroleum products and biomass (fuelwood). Nevertheless, only electricity and petroleum products are considered the major commercial forms of energy. The total electrical energy generated during the year 2007 was 9,901 GWh of which 59.55 percent came from oil-burning thermal power plants while 40.45 per cent was from hydropower. The highest demand for energy is from households and the commercial sector (49 per cent) followed by industries (26 percent) and transport (25 percent).

Electricity generation in Sri Lanka can be broadly divided into two parts based on whether they are connected to the national grid or run as stand-alone units. The national grid dominates the electrical energy supply in Sri Lanka, wherein, the country has the main grid that covers almost all parts of the country. Stand-alone power generation facilities have been made available in some locations that are not penetrated by the national grid. Additionally, standby power supplies are also available in most industries and commercial facilities, although their generation is very minimal due to the short-term nature of the operation.

The demand for electricity is growing at an average rate of around 8-9 percent annually. Electricity consumers in Sri Lanka are categorized into groups based on the usage type – domestic, religious institutions, industrial, commercial and street lighting. The highest demand for electricity among these groups is in the industrial (37.7 percent) and domestic (39.2 percent) sectors, followed by the commercial sector (20.9 per cent). Street lighting (1.6 percent) and religious institutions (0.6 percent) come next according to Sustainable Energy Authority.

The National Energy Policy and Strategies (2008), developed by the Ministry of Power and Energy (MP&E), places a strong emphasis on energy security, from both national strategic and an individual's perspectives. The policy envisions a situation where reliable, affordable and clean energy is made available to all the citizens at all times. Ministry of Power and Energy states that his requires an energy resource base, or resources, available a plenty at all times.

The growing electricity demand can be met only by adding adequate installation capacities, employing the most appropriate technologies in the most economical manner. The present energy resources in Sri Lanka, however, fail to meet these criteria and hence, the requirement for several resources or an energy mix arises. The government, therefore, foresees the gradual increase of non-conventional renewable energy resources to provide the right mix to generate electric power.

The government envisages reaching a 100 per cent target in electrification by 2016. Herein, the government has to increase the stake of the off-grid renewable energy by 10-12 percent by 2015, and 4 per cent of this is to be derived from the small hydropower industry. The government has also recognized the need to elevate biomass as both a commercial crop as well as the third option for electricity generation. Accordingly, it has declared *Gliricedia sepium* as the fourth plantation crop after tea, rubber, and coconut in 2005.

Biofuels, as a key constituent of the transport energy, will be developed to claim a 20 percent share by 2020 according to SLSEA. The acceleration of renewable energy development needs to be a key strategy in a broad-based energy mix to provide high-quality and affordable energy to the people while contributing maximum effort to minimize environmental impact and lowering GHG emissions. The vast untapped potential of renewable energy and the diversity of the array of possibilities allow Sri Lanka to benefit and to deviate from an economic calamity, like the one stimulated by the oil crisis in the recent past. Sri Lanka is endowed with many forms of renewable energy sources due to her natural geo-climatic settings. Biomass, solar, hydro and the wind have been identified as the potential sources available adequately. These have the potential of value addition, as and when the technologies become sound and cost-effective for deployment on a commercial scale. Biomass, a bulk of the firewood and other biomass resources are used for cooking in rural households, irrespective of their access to grid electricity. Even though the majority of energy needs of the rural population are fulfilled by firewood, its application in electricity generation is not yet widespread. But, the utilization of biomass for electricity generation is gaining momentum in Sri Lanka according to the energy sector.

Most of the major hydro potential has been developed and they are delivering valuable low-cost electricity to the country. Since the commissioning of the first hydroelectric power plant in 1950, hydroelectricity generation has played a major role in power generation in Sri Lanka. The largest share of electricity generation came from major hydropower projects until the mid-1990s. The Sri Lanka's power sector was dominated by hydropower until 1996, and almost 94 percent of the annual power demand in 1995 was met by hydropower generation. Despite several hydropower capacity additions, though, the share of hydropower showed a reducing trend since the mid-90s due to the non-availability of more potential sites that are economically feasible for hydropower development. At present, hydropower stations are operated to meet both peak and base electricity generation requirements

Energy supply in Sri Lanka is mainly based on three primary resources, namely, biomass, petroleum, and hydroelectricity. In 2004, hydroelectricity production in the country accounted for 706.9 kTOE (thousand tons of oil equivalents) while the biomass-based energy supply was 4,494.4 kTOE. Approximately 4,304.2 kTOE was provided by imported crude oil and finished petroleum products such as diesel and liquefied petroleum gas (LPG). Additionally, the non-conventional resources (mainly wind) provided 3.5 kTOE of primary energy, giving an aggregate primary energy supply of approximately 9,509.1 kTOE. The 2004 primary energy contributions to national energy supply were 47.3% from biomass, 45.3% from crude oil and petroleum products and 7.4% from hydroelectricity. The use of non-conventional energy resources in Sri Lanka is of a relatively smaller scale and, therefore, its contribution is presently of low significance in the macro energy picture.

The installed electricity generation capacity in Sri Lanka reached 3,141 MW in 2011, where 66 percent is owned by the state and 34 percent is in possession of independent power producers. Gross electricity generation in Sri Lanka was 11,528 GWh in 2011. 3 Figure 1 below depicts the breakdown of the different energy sources used.

Sri Lanka's electricity demand increases by about 7% every year, to serve new consumers connected through the rapidly expanding electrification network, and to serve the growing industrial and commercial sectors of the economy. The demand for petroleum products too increases by about 5% per year, with the industrial and commercial sectors being increasingly used fuel oil and liquefied petroleum gas. The potential for energy efficiency (EE) improvement in the power transmission and distribution network is estimated to be about 5% while the potential to save electricity and petroleum use across all the consuming sectors is estimated to be about 10%. In managing losses in the electricity network, improved demand management is a key strategy, owing to the high evening lighting peak that exists in Sri Lanka

**2.6 MHP in Tea Estates**

A large number of recurrent and non-recurrent activities under the establishment of estate micro-hydro (below 1 MW) are presently not covered by the National Environmental Act (NEA). The SLSEA has identified that there are approximately 200 sites in the estate sector in 20-200 kW range with the potential for rehabilitation with an estimated total capacity of 30 MW. Recent changes in government regulation allow connection of small embedded generation plants to the grid with an export capacity of less than 42 kW on a so-called "Net Metering" basis with minimal administrative requirements.

This project will provide financial assistance, administered by the SLSEA, to 19 such micro-hydropower plants in tea estates to facilitate the rehabilitation and repowering. The project will comprise the following components:

Consulting support to develop a detailed technical specification and funding eligibility criteria for micro-hydro rehabilitation and grid connection;

Consulting support for providing engineering assessment and monitoring of projects for the duration of the pilot project;

Funding has been approved about 19 projects producing approximately 1.3 MW of grid-connected capacity.

The project implementation will lead to better energy efficiency at the tea estates and supply of net 1.3 MW energy to the grid during off-peak hours. Mini-hydropower is considered as one of the clean electricity generation technologies since the process causes little impacts to the environment during the generation when compared to the other modes of electricity generation sing conventional fuels. Table 2.2 summarizes projects that are being considered for funding.

**Table 2.2:** Tea estates based micro-hydro power plants currently in operation

| Tea Estate | District | Tributary of | Capacity (kW) |
|---|---|---|---|
| Glassaugh | Nuwara Eliya | Nanu Oya | 40 |
| Edinburgh | | Nanu Oya | 55 |
| Talawakelle | | Nanu Oya | 112 |
| Tillyrie | | Kelani River | 45 |
| Meddacombra | | Kotmale | 285 |
| Diagama West | | Agra Oya | 225 |
| Waverley | | Agra Oya | 30 |
| Mahauva | | Kurundu Oya | 152 |
| Moray | | Kelani | 80 |
| Pitarathmalie | Badulla | Uma Oya | 32 |
| Demodara | | Badulu Oya | 65 |
| Mool Oya | Kandy | Maha Oya | 120 |
| Hunugala | Matale | Rattota | 20 |
| Kelani | Kegalle | Kelani River | 40 |

### 2.7 Recent Study in Mahaweli Areas

In 2012, Mahaweli Authority of Sri Lanka (MASL) requested the International Water Management Institute (IWMI) to conduct a study on the impacts of dams and weirs and other physical structures in designated Mahaweli areas on freshwater fish fauna. The IWMI hired Water Resources Science and Technology (WRST) to carry out the study. The study was confined to designated Mahaweli areas under the purview of Mahaweli Development Program, which falls within Mahaweli River, a part of Kala Oya (System H), a major portion of Maduru Oya (System B), Udawalawa Scheme falls within the central and southern lowlands of the Walawe River basin and Yan Oya basin. The study was primarily focused on hydrological networks of respective basins and their associated flow-regulatory structures in order to emphasize the present status of freshwater fish fauna, native and endemic to Sri Lanka.

This survey provided an opportunity to examine most of the stream regulatory structures (e.g., ancient anicuts, weirs constructed by British, modern dams, barrages, impoundments, embankments, interlinking tunnels, diversion channels, major reservoirs) weirs including mini-hydropower plants in the Mahaweli areas. Besides, more emphasis was paid on the mini-hydropower plants that are connected to the national grid; those are at different construction stage and sites that have been approved for the construction. At each site, topographical features (coordinates, elevations, slopes, river bottom features etc.,) were recorded in addition to riparian vegetation and land use forms along the river banks of respective stream stretches. The said features were compared with recent satellite images of Google Earth Pro and 1:50,000 topographic sheets for comparison. Further, observations were made on fish fauna and the information on fish inhabiting the stream stretch was gathered from the people living in the area whenever it is possible. Desk studies were carried out to collect the physical features flow-regulatory structures and the details of project designs in relation to environmental aspects in the case of mini-hydropower plants.

### 2.7.1 MHPs in Mahaweli River Basin

There are 57 mini-hydropower plants in operation in the Mahaweli River basin while another few are under construction. Table 2.3 shows the number of MHPs in operation within each sub-watershed of the Mahaweli basin. Two cascades on Sudu Ganga and Hatton Oya are prominent in the Mahaweli River basin and the highest number of MHPs is in operation on the Hatton Oya followed by Atabage Oya, Hulu Ganga, and Nanu Oya sub-watersheds. The total disrupted or affected stream stretch (ASS) within the Mahaweli basin were estimated as 77.3 kilometers while generating 113 MW. In contrast, loss of stream stretches due to major hydropower schemes (i.e., Upper Kotmale, Kotmale, Randenigala-Rantambe, Ukuwela, and Bowetenna on the Mahaweli River is 33.3 km which generates 810 MW. The distribution pattern of mini hydropower plants in the Mahaweli river basin is shown in Figure 2.2. Three major hydropower schemes namely Moragahakanda, Kalu Ganga, and Uma Oya are under construction in the Mahaweli River basin. (Table 2.1)

**Table 2.3:** Number of mini hydro power plants, their installation capacity, and estimated stream lost in different sub-watersheds of the Mahaweli River basin

| Sub-watershed | Number of Plants | Installation Capacity (MW) | Affected Stream Stretch (km) |
|---|---|---|---|
| Agra Oya | 4 | 7.200 | 4.35 |
| Atabage Oya | 5 | 5.950 | 2.48 |
| Amban Ganga | 2 | 2.300 | 1.00 |
| Badulu Oya | 2 | 8.300 | 6.16 |
| Belihul Oya | 1 | 1.500 | 4.32 |
| Galatha Oya | 2 | 2.800 | 2.60 |
| Galmal Oya | 1 | 2.400 | 1.73 |
| Guruk Oya | 3 | 2.500 | 2.32 |
| Hangaran Oya | 2 | 6.000 | 2.78 |
| Hatton Oya | 6 | 13.920 | 9.14 |
| Hulu Ganga | 5 | 12.000 | 7.21 |
| Kahawathura Ganga | 1 | 0.750 | 1.00 |
| Kotlmale Oya | 1 | 4.300 | 2.20 |
| Loggal Oya | 1 | 5.000 | 2.23 |
| Maha Oya | 3 | 8.000 | 2.20 |
| Nanu Oya | 5 | 4.560 | 2.31 |
| Nilambe Oya | 2 | 3.947 | 3.28 |
| Pundalu Oya | 3 | 4.160 | 2.86 |
| Sudu Ganga | 3 | 13.500 | 14.0 |
| Uma Oya | 1 | 0.800 | 0.46 |
| Minor Tributaries | 4 | 3.500 | 2.40 |
| **Mini hydropower** | **57** | **113.387** | **77.3** |
| **Major hydropower** | **7** | **812.00** | **33.3** |

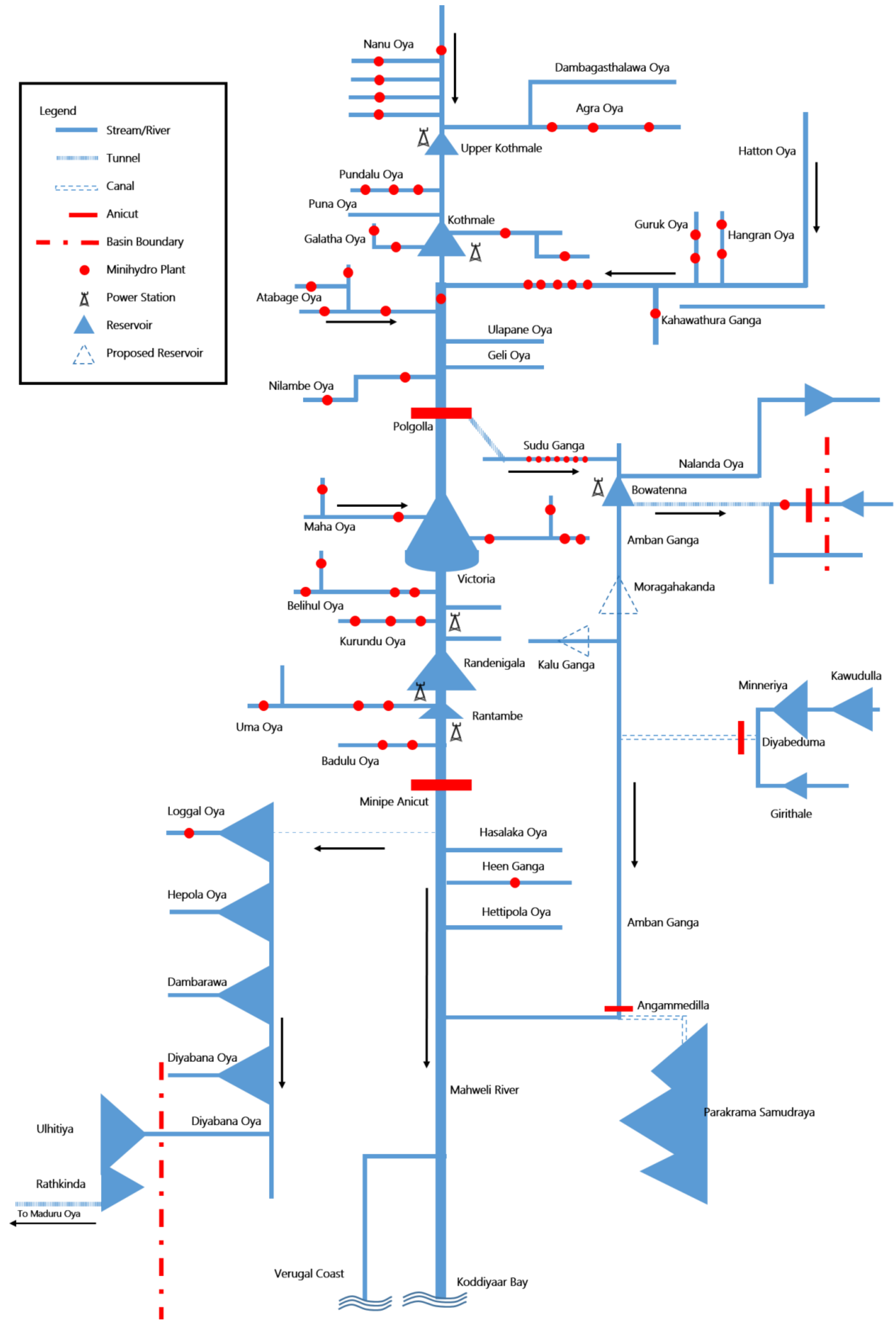



**Figure 2.2:** Schematic diagram of Mahaweli River basin depicting sites for mini-hydropower plants and other regulatory structures

### 2.7.2 MHPs in Kelani River Basin

Thirty-two mini hydro power plants with 55.61 MW generation capacities are in operation on the Kelani River basin of which 12 are located on the Seethawaka Ganga (Figure 2.3 & Table 2.4), the major tributary of the Kelani River whose headwater tributaries drain Kithulgala-Maliboda range. The power generation capacity of these MHPs ranges from 0.060 MW (Indurana MHP) to 9.928 MW (Magal GangaMHP). In Seethawa Ganga sub-watershed, seven MHPs have the capacity of less than 1.00 MW. Besides, the total lengths of affected stream stretch (ASS) in the Kelani River basin is 47 km where 32 MHPs are in operation to generate 55.61 MW. In contrast, the affected stream stretch is 47.3 km resulting from five major hydropower schemes (i.e., Wilmasurendra, Old Lakshapana, Canyon, New Lakshapana and Polpitiya) that are in operation while generating 353MW. Nevertheless, the Kehelguamu Oya and Maskeliya Oya have the longest affected stream stretches in the Kelani River basin (Table 2.4). None of these hydropower schemes neither major nor are facilitated with downstream environmental flow in between the weir/reservoir and powerhouse release

**Table2.7:** Number of mini hydro power plants, their installation capacity, and affected stream stretch

| Sub-watershed | Number of Plants | Installation Capacity (MW) | Affected Stream Stretch (km) |
|---|---|---|---|
| Gorugoda Oya | 4 | 6.70 | 4.61 |
| Kehelgamuwa Oya | 3 | 7.10 | 7.52 |
| Maskeliya Oya | 4 | 7.35 | 3.36 |
| Ritigaha Oya | 3 | 1.84 | 2.87 |
| Seethawaka Ganga | 12 | 19.96 | 20.14 |
| Wee Oya | 4 | 11.80 | 7.80 |
| Minor Tributaries | 2 | 0.86 | 1.04 |
| **Mini hydropower plants** | **32** | **55.61** | **47.34** |
| **Major hydropower** | **5** | **353** | **41.92** |

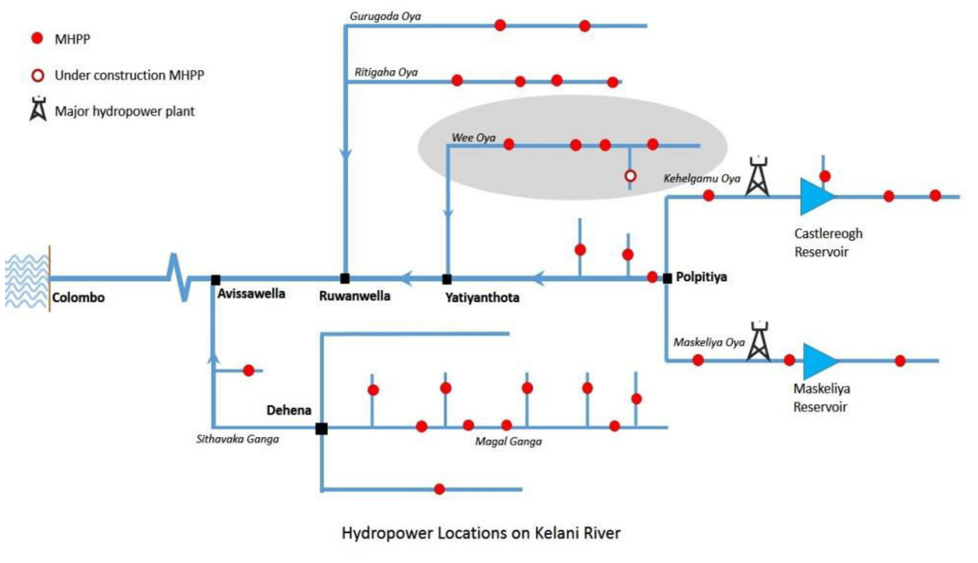



**Figure 2.3:** Schematic diagram of Kelani River basin depicting site for mini-hydropower plants and other regulatory structures

### 2.7.3 MHPs in Kalu Ganga basin

Twenty-eight mini hydro-power plants of about 70 MW generation capacity are in operation on the Kalu River basin of which eight are located on Denawaka Ganga (Fig. 2. 4 and Table 2.5). While headwater tributaries of Kalu Ganga rise from the foothills of Sri Pada mountain having two MHP plants, Kukule Ganga and Rath Ganga whose headwaters are confined to the Sinharaja Rain Forest and Peak Wilderness respectively have six and five mini-hydro power plants with more or less similar generation capacity, which is also similar to Wey Ganga that has only two MHP plants (Table 2.5). The total length of affected stream stretch (ASS) in the Kalu Ganga basin is 29.0 km when major hydropower projects are also taken into consideration (i.e., Kukule Ganga Hydropower Project), The Denawaka Ganga has the longest affected stream stretch (5.41 km) due to the establishment of seven mini hydro-power plants whereas more or less similar stream stretches have been disrupted in Kukule Ganga (4.21 km) and Kuru Ganga (4.04 km). Although Rath Ganga has five mini-hydropower plants the affected stream stretch is 3.3 km. As in Mahaweli and Kelani River basins, hydropower schemes in the Kalu Ganga basin too are not facilitated with the downstream environmental flow in between the weir/reservoir and powerhouse release.

**Table 2.8:** Number of mini hydro-power plants, their installation capacity, and estimated

| Sub-watershed | Number of Plants | Installation Capacity (MW) | Affected Stream Stretch (km) |
|---|---|---|---|
| **Denawaka Ganga** | 7 | 21.334 | 5.41 |
| **Kalu Ganga** | 2 | 4.000 | 1.24 |
| **Kukule Ganga** | 6 | 10.50 | 4.21 |
| **Kuru Ganga** | 3 | 10.500 | 4.04 |
| **Niriella Ganga** | 2 | 4.200 | 0.82 |
| **Rath Ganga** | 5 | 8.969 | 3.30 |
| **Wey Ganga** | 2 | 10.225 | 1.20 |
| **Minor Tributaries** | 1 | 0.180 | 0.60 |
| **Mini hydropower plants** | 28 | 69.914 | 20.82 |
| **Major hydropower** | 1 | 80.0 | 8.18 |

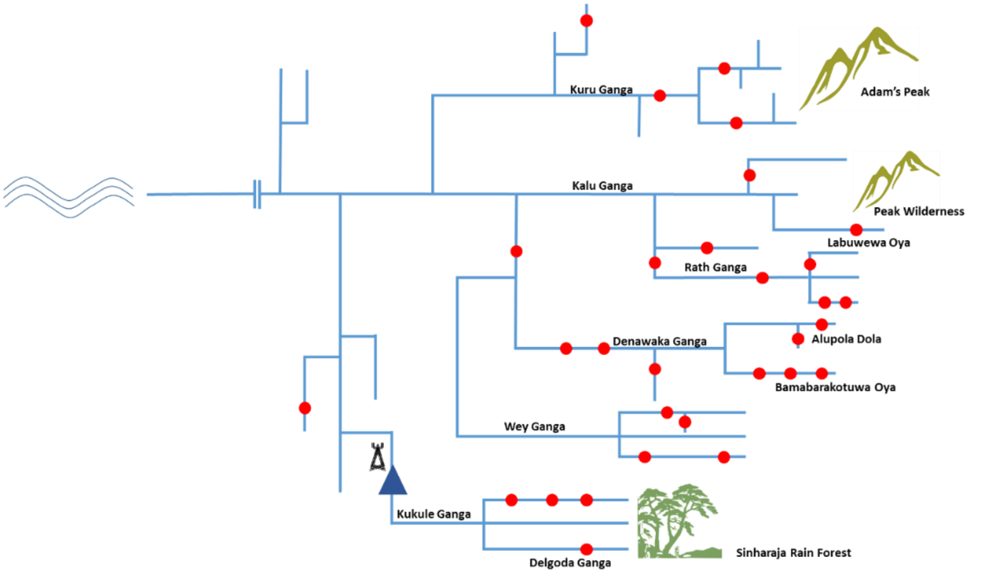



**Figure 2.4:** Schematic diagram of Kalu Ganga basin depicting sites for mini hydro-power plants and other regulatory structures

### 2.7.4 MHPs in Walawe River basin

Fourteen mini-hydropower plants having 26.84 MW generation capacity are in operation on the Walawe River (Table 2.6 and Fig. 2.4). The oldest mini-hydropower plants are located on the Rakwana Ganga sub-watershed and generation capacity ranges from 0.500 MW in Ranmudu Oya MHP plant to 5.00 MW of Bogandana MHP plant. In addition, Samanalawewa hydropower scheme generates 120 MW whereas 3.0 x 2 MW are generated by RB and LB releases of Udawalawa irrigation reservoir. There are no cascade mini-hydropower plants in the Walawe River basin perhaps due to shorter tributary lengths and the steepness of the upper basin. The total length of affected stream stretch (ASS) in the Walawe Ganga is 17.3 km because the major hydropower reservoir (Samanalawewa) has a continuous downstream flow due the leakage of water/ the downstream leakage water has been tapped at Mulgama by Mulgama mini-hydropower plant. In addition, another mini-hydropower plant is under construction at the immediate downstream of the Samanalawewa reservoirs to tap leakage water.

**Table 2.9:** Mini-hydropower plants, their installation capacity, year of commissioned and affected stream stretch

| Sub-watershed | Capacity (MW) | Year of Commissioned | Affected Stream Stretch (km) |
|---|---|---|---|
| Belihul Oya | 2.500 | 2002 | 1.71 |
| Bogandana | 5.000 | 2009 | 3.40 |
| Bulathwattha | 3.800 | 2014 | 2.34 |
| Kalupahana | 0.800 | 2005 | 0.46 |
| Kalupahana (Lower) | 2.500 | 2011 | 1.82 |
| Kolonna | 0.780 | 1999 | 0.64 |
| Kuburutheniwela | 2.800 | 2005 | 1.00 |
| Lemastota | 1.300 | 2011 | 0.81 |
| Mulgama | 2.800 | 2013 | 2.41 |
| Pathaha Oya | 1.500 | 2009 | 0.72 |
| Rakwana Ganga I | 1.000 | 1998 | 0.82 |
| Rakwana Ganga II | 0.760 | 1998 | 0.45 |
| Ranmudu Oya | 0.500 | 2014 | 0.31 |
| Seethagala | 0.800 | 2004 | 0.42 |
| | 26.840 | | 17.31 |

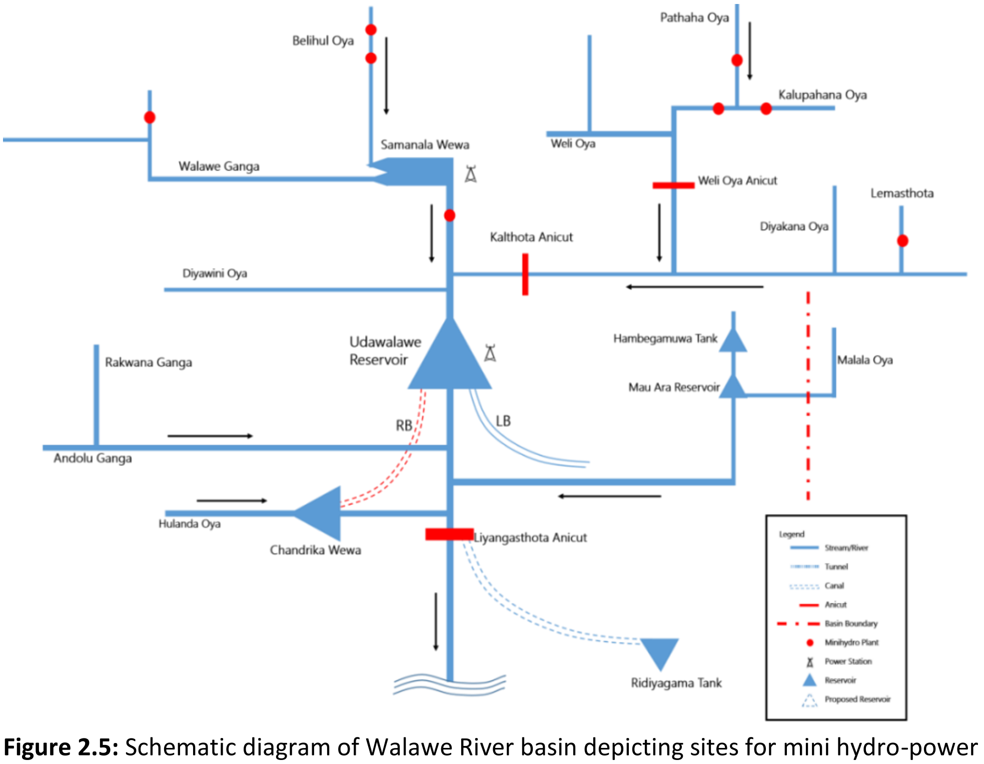



**Figure 2.5:** Schematic diagram of Walawe River basin depicting sites for mini hydro-power plants and other regulatory structures

### 2.7.5 MHPs in Other River Basins

Twelve MHPs are in operation in the other river basins (i.e.; Gin Ganga, Kirindi Oya, Maa Oya Maduru Oya and Nilwala Ganga), by the end of 2014 generating 21.95 MW within the range of 0.250 MW (Kiriwenwela and Kandadola) and 5.00 MW at Maduru Oya LB release (Table 2.7). Nevertheless, there are no major hydropower schemes on these river basins. Maduru Oya II is on the LB irrigation canal at Drop 9. Another mini-hydropower plant is under construction on the same irrigational canal at Drop 10. The link canal between Bowatenna and Kala Oya has been augmented at Lenadora to generate hydropower constructing mini-hydropower plant in 2012. Generation power of mini-hydropower plants constructed on Nilwala Ganga is relatively low compared to that of Gin Ganga and Maa Oya.

**Table 2.10:** Number of mini hydro-power plants, their installation capacity, year of commissioned and affected stream stretch in different other river basins

| River Basin | MHP | Capacity (MW) | Year of Commissioned | Affected Stream Stretch (km) |
|---|---|---|---|---|
| Gin Ganga | Lower Neluwa | 1.450 | 2007 | N/A |
| | Madugeta | 2.500 | 2013 | N/A |
| Kirindi Oya | Mille Oya | 1.200 | 2013 | N/A |
| | Wallawaya | 1.200 | 2014 | N/A |
| Maa Oya | Assupiniella | 4.000 | 2005 | N/A |
| | Deiyanwela | 1.500 | 2002 | N/A |
| | Salawa | 2.000 | 2006 | N/A |
| Maduru Oya | Maduru Oya | 5.000 | 2011 | 00 |
| | Maduru Oya II | 2.000 | 2014 | 00 |
| Nilwala | Green Energy (Kiriwenwela) | 0.250 | 2013 | N/A |
| | Kandadola | 0.250 | 2013 | N/A |
| | Kotapola | 0.600 | 2005 | N/A |
| Kala Oya | Bowetenna-Kala Oya link Canal | 1.500 | | 00 |
| **Total** | | 23.45 | | |

The overall picture of mini-hydropower distribution in Sri Lanka is amazing (Figure 2.6). The entire hydrological network of the Central Highland has dramatically changed. Sri Lanka Government still did not understand the gravity of the problem with respect to Ecohydrology of the mountain landscape, which also provides many services in addition to cash crops. It is well-known that the mountain landscape of the island is the water tower, which supplies water to the other parts of the island via surface and underground. The natural hydrological network plays a vital role shaping the entire landscape including its flora and fauna. Devastating disruption of natural system at unwarranted magnitude may lead to unprecedented consequences. Therefore, it is extremely important to pay equitable consideration on environment not in a superficial manner for the sake of doing but in realistic and in-depth ecological and geomorphologic understanding

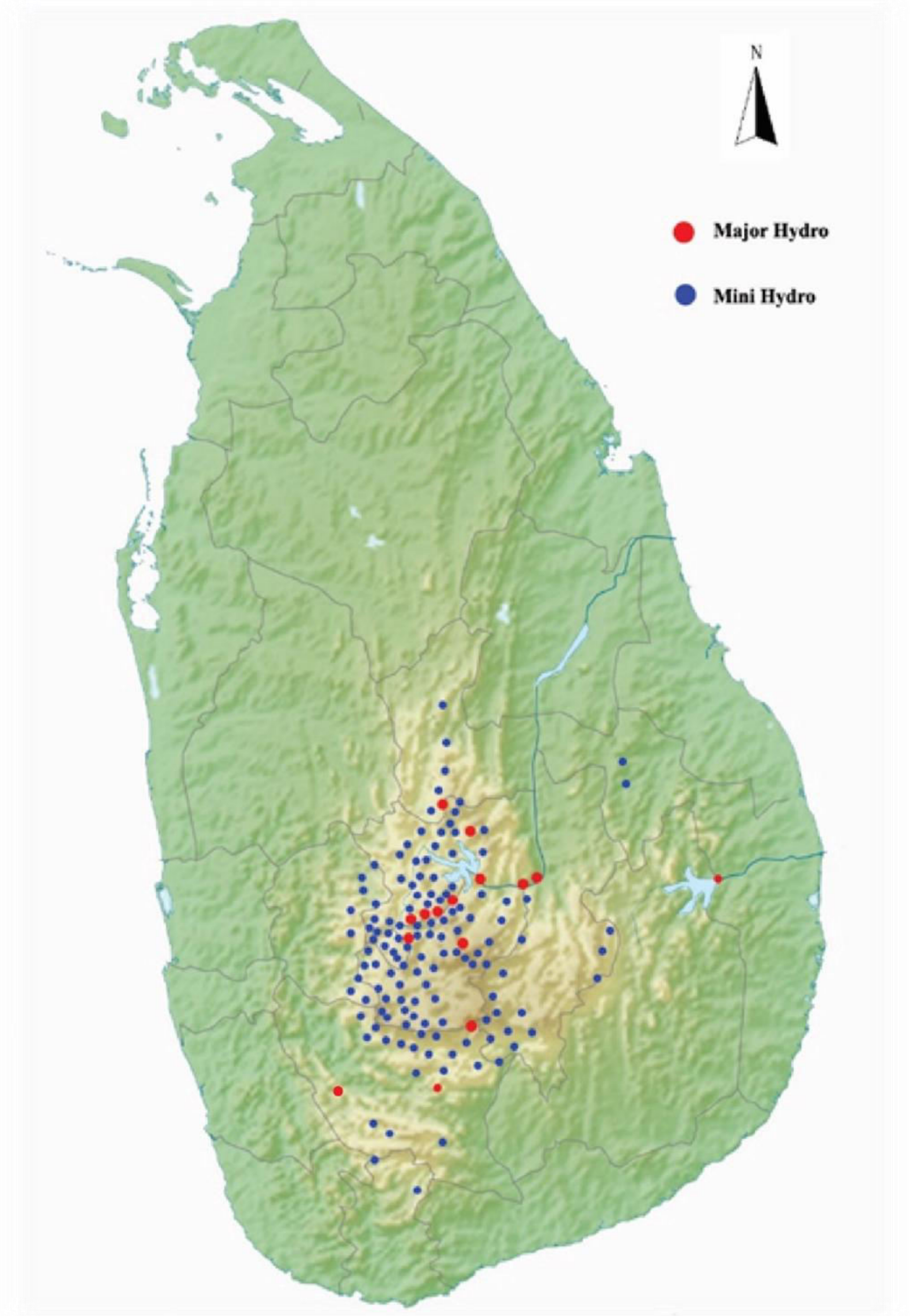



**Figure 2.2:** Present Distribution of mini-hydropower plants in Sri Lanka

# Chapter 3

## Approvals to Develop a Mini-hydropower Project

### 3.1 Introduction

A guide to project approval process for on-grid renewable energy project development, published by the Sustainable Energy Authority in Sri Lanka in 2011 provides details policies and procedures to secure approvals to develop a mini-hydropower project that can provide electricity to the national grid. This guide describes the details on how to get provisional approval, reasons for granting or refusal of provisional approval or energy permit, the meaning of the Standardized Power Purchasing Agreement (SPPA), and the events of cancelation of provisional approval energy permit. Besides, this Guide also provides a reference to institutions that would be reviewing applications or project approving agencies in the process of issuing permits and approvals for the development of all types of small scale power development projects such as biomass, the wind, and solar. Therefore, the objective of this chapter is to present this information in a simple way enabling a layman to understand and procedures to be followed if there is a necessity.

### 3.2 Sustainable Energy Authority

The Sri Lanka Sustainable Energy Authority (SLSEA) established by the Act No 35 of 2007 is the custodian of the renewable resources. Now it is necessary to get a permit for utilization of renewable energy resources (i.e., solar, the wind, biomass and hydro), just like any other natural resource, by any person according to this Act. Apart from her statutory obligations, SLSEA will also function as the facilitator for implementation of projects using new renewable energy (NRE) previously referred to as non-conventional renewable energy resources (NCRE).

National Energy Policy of Sri Lanka, established in 2006 emphasizes the Government's policy of ensuring energy security and promoting the development of indigenous resources. Promoting the development of economically viable NRE sources is a key strategy of the national energy policy. The Government has expressed its desire of meeting 10% of electricity served in the national grid, from NRE resources. The most recent revision of National Energy Policy in Sri Lanka (2011) states that the Government of Sri Lanka requires 20% of electricity generation from NRE by 2020, with the target of 10% reached by end 2016.

At present, the Power Purchasing Branch of Ceylon Electricity Board (CEB) operates an administrative arrangement to grant resource development rights to private sector investors through a Letter of Intent (LoI) due to the absence of a well-defined legal framework or a duly appointed custodian of renewable energy resources in the country. This document, which is an assurance to purchase electricity produced by a particular resource by a person on a first come first served basis also was accepted by all concerned as a granting of resource rights to that person. Most of the NRE projects including small hydropower projects are registered with the Sustainable Energy Authority.

### 3.3 Provisional Approval

New applicants for NRE projects are encouraged by the government for the establishment of any type of renewable energy projects, which are capable of generating electricity that can be provided to the national grid. Applicants will be either granted or refused Provisional

Approval depending on their capability and suitability. The main categories of NRE sources were identified as the wind, solar, biomass, and small hydro and treated individually in tariff setting exercises undertaken by the Ministry of Power and Energy (MP&E) and the Public Utilities Commission of Sri Lanka (PUCSL).

Mini-hydropower plants converting the gravitational energy of water using locally manufactured turbine equipment are encouraged with a higher tariff by the MP&E and PUCSL

**Public Utilities Commission of Sri Lanka (PUCSL):** The PUCSL is a government body that regulates all the utilities within the purview of the Public Utilities Commission of Sri Lanka, to ensure safe, reliable and reasonably priced infrastructure services for existing as well as future consumers in the most equitable and sustainable manner.

### 3.4 Submission of an Application

Any citizen or person or a local company may apply for a mini-hydropower project anytime, irrespective of whether the person holds any rights to the water or land resource. The SLSEA will entertain the application depending on the availability of NRE sites. A formal application, accompanied by a pre-feasibility study report prepared by a consultant accredited by the SLSEA will be processed after receiving the due application fee. A period of three months is granted for preparation of pre-feasibility report, which includes;

a. One page summary
b. A map of geographical location of the proposed site
c. Brief description of the project including power generation
d. Total estimated cost and financial model
e. Proof of availability of adequate finances
f. Schematic diagram of the project and a list of equipment to be used
g. Mode of grid connection
h. Copy of the receipt of payment to SLSEA

All duly furnished applications that have been accepted will be registered under the SLSEA with a registration number unique to the project. An opportunity is given to the applicants who are faced with a cancelation of a Provisional Approval granted by SLSEA to seek a fresh Provisional Approval.

All successful applicants with Provisional Approval will be invited to submit an application to gain an extended period to meet the conditions required for an issuance of an Energy Permit, after payment of the due application fee.

The following aspects will be investigated by the Director General of SLSEA before providing a recommendation on the re-application to the Provisional Application Committee (PAC).

**Feasibility Studies:** Whether a report on a comprehensive feasibility study carried out for the project including but not limited to an analysis of the availability of the renewable energy resource during a period in excess of a 12 month period, prepared by a consultant accredited by the Authority is submitted or not.

**Access to Land Resources**: A tenement list of land resources required for project implementation and a survey plan of the renewable energy resource site, prepared by a licensed surveyor registered with the Authority to be submitted.

**Status of Statutory Approvals**: Whether a status report on statutory approvals with proof of application for all such relevant approvals including but not limited to receipts of payment of such application fees payable to other approving authorities including but not limited to;

- A copy of the Letter of Intent (LoI) issued by the Ceylon Electricity Board
- Divisional Secretary's Approval
- Approval for construction granted by the Urban Development Authority (UDA) or the local authority designated by UDA
- Approvals from other relevant line agencies

**Environmental Clearance**: Documents in proof of progress achieved in realizing the environmental approval from the relevant designated approving agencies are required. Nevertheless, a transparent marking scheme will be used to carry out the above investigation in an objective manner.

It is important to include the following aspects in the application correctly and precisely.

- Name of Applicant
- Completeness of the Application
- Correct Installed Capacity and Energy Output
- Concurrence of the CEB to the Grid Connection
- Resources Allocated to Other Parties if any
- Alternative Approaches to Development
- Capacities not Greater than 10MW
- Excluded Areas (e.g., natural reserves, such as Conservation Forests and Wildlife Sanctuaries)

### 3.5 Pre-feasibility Study

The pre-feasibility study report to be attached to the application shall cover the main topics given in the list of contents given in the section on how to submit an application relevant to a mini-hydropower project. Any additional information that would reinforce the project analysis from the technical and financial point of view, and the technical and financial capability of the Applicant to develop the project, may have added advantages. Three major items of the pre-feasibility study report are as follows:

- Summary of the pre-feasibility study
- Certification by the accredited consultant
- Study report based on the list of contents

The pre-feasibility study should be conducted by a consultant accredited by SLSEA. An updated list of accredited consultants published by SLSEA will be given to the each applicant when an application form is issued. The applicant can select the consultant as he/her wishes.

### 3.6 Success or Failure in Provisional Approval

Depending on the information furnished in the pre-feasibility report, all applications received by the SLSEA will be evaluated in consultation with the CEB to find out the possibility of accommodating grid connection. Besides, all the relevant line agencies will be prompted to indicate the concern of their approval for proposed projects at the first Provisional Approval Committee (PAC) meeting. If any line agency is indicating that a particular project is not within their purview, such agencies will be relaxed from the approvals required for granting of the Energy Permit. Only the relevant agencies will be handed over a scrutiny paper on each project, in the preparation of granting Provisional Approval at the next PAC meeting and Energy Permit at an appropriate PAC meeting respectively.

Irrespective of the nature of response obtained from the CEB all projects for which the CEB was consulted will be tabled with the recommendations of the Director General at the following meeting of the PAC. There is a possibility that the Director General may invite the Applicant to make a presentation of the proposed project before an internal committee supported by external experts to evaluate the project and may also request a site inspection by a team of officers nominated by him to gather information to make his recommendation before the PAC. The Applicant will be required to pay for such evaluations and site inspections on a case by case basis, which will be notified in advance to the Applicant.

If any other omissions were found in the preliminary screening of the application carried out by the Director-General under the provisions of the Section 17(1) of the Act, the Director General will notify the PAC accordingly, which will lead to the refusal to grant Provisional Approval to the project under the provisions of Section 17(3) of the Act. In the event of a project is refused to grant a Provisional Approval by the PAC, the Applicants of such projects will be notified immediately after the PAC meeting. The time period for processing an application for Provisional Approval by SLSEA will be not more than three months.

### 3.7 Recommendation of the Director General

The recommendations of Director General to the PAC will be based on the following principles.

a) Whether the application is complete in every sense, as per requirements of Section 16(2) of the Act and On-grid Renewable Energy Projects Regulation 2011,
b) Whether the amount of power proposed to be produced by the Applicant is representative of the available resource,
c) Whether the CEB has granted its concurrence to consider the proposed capacity or part thereof for grid connection as required under Section 17(1) of the Act,
d) Whether there is any operational power plant in the same location or using the same resource area or part of the resource area required by the Applicant for the proposed project,
e) Whether SLSEA has issued a Provisional Approval or an Energy Permit to another Applicant for the same site or the resource or part of the resource area required by the Applicant for the proposed project,
f) Whether SLSEA or the Government of Sri Lanka has plans of their own to develop the site through a different mechanism,
g) Whether a specific written policy directive from the Ministry of Power and Energy is available to consider a project with an installed capacity greater than 10MW, in the event of an application is received for a project of capacity greater than 10MW,
h) Whether the project is impacting on any excluded area.

Based on the recommendation of the Director General made on the above grounds, initial scrutiny of the project by relevant line agencies and observations of such agencies, the PAC will move to either grant or refuse Provisional Approval for projects. All projects which are at various stages of appraisal and queued behind a pioneering Applicant will be presented to the PAC to clear the backlog of projects held in abeyance, pending approval or refusal of the PAC. Provisional Approvals will be issued within 2 weeks of the relevant PAC and refusal to grant Provisional Approval will be notified to Applicants immediately after the relevant PAC meeting.

The Provisional Approval recognizes the exclusive rights available to an Applicant to develop a particular NRE resource site, but it is valid only for an initial period of six months, which can be extended for an another six months. Within this maximum period of twelve months, the Applicant should obtain the following permits and approvals;

- The Letter of Intent to purchase electricity from the CEB
- Electricity Generating License from the PUCSL
- Environmental Approval
- Approvals required from other relevant line agencies
- Land rights and
- Letters of consents from equity partners and lenders

Otherwise, the Provisional Approval will be canceled. Once the Applicant is in the process to fulfill the requirements for the issuance of Energy Permit, he has to report the progress of the project at the end of each quarter to the SLSEA. Once all the requirements stated in the Provisional Approval is fulfilled and submitted with the application for the final approval, the Director General will submit the application to the next available meeting of the PAC for its consideration. The PAC will make the final decision either to grant or to refuse the Energy Permit within a month of giving such consideration while recording the reasons for arriving at such decisions.

### 3.8 Validity of Energy Permit

The Energy Permit is valid for a period of twenty years from the date of commercial operation of the project. Once issued with an Energy Permit the status of the Applicant is changed to that of a Developer, a person having permission to develop an NRE project at the proposed site. A period of two years is allowed to the Developer for construction, from the date of the Energy Permit is issued. At the end of the twenty year period, the permit is extendable for another maximum period of twenty more years, provided the relevant power purchase agreements are extendable based on the conditions stipulated in such agreements or other guidelines effective at that time. A power purchase agreement should be signed for the sale of electricity to the grid within one month from the date of the Permit is issued.

**Permit fee**: The onetime non-refundable permit fee payable at the time of issuing the Permit is Rs. 500,000 per 1 MW of capacity for projects up to 10 MW. For the projects larger than 10 MW capacities, the one-time permit fee is Rs 1,000,000 per MW. These amounts can also be paid on an installment basis over the project period. In addition, there is an annual royalty to be paid by the Developer.

### 3.9 Power Purchase Agreements and Tariff

**For projects up to 10 MW:** SLSEA and CEB offer a Standardized Power Purchase Agreement (SPPA) for approved mini-hydropower projects, with an installed capacity up to 10 MW. The SPPA is standardized, non-negotiable, and is valid for twenty years from the date of grid connection under the Small Power Purchase Tariff (SPPT).

There will be an annual tariff review process conducted by the PUCSL considering;

- Types of projects to be offered the SPPT
- Tariffs to be offered to Developers entering into an SPPA in the coming year

### 3.10 Malpractices and Illegal Operations

Well written and systematic procedures are followed by the SLSEA, CEA, and PUCSL for the development of mini-hydropower projects in Sri Lanka. As a result, there is a remarkable development in small hydropower ventures with many success stories in Sri Lanka compared to the other countries in the region. This achievement in Sri Lanka to be appreciated to a greater extent as socio-economic upgrading improves the quality of life. Nevertheless, there are incidents of malpractices and illegal activities during both construction and operational phases of small hydropower projects. Most of them are related to environmental issues, associated with stream ecology and endemic fishes.

Further, people have sought legislative assistance in some instances to sort out certain problems related to small hydropower schemes. For example, approval given to construct a 0.6 MW installation capacity mini-hydropower plant on Koskulana River, which demarcates the northern boundary of Sinharaja World Heritage Site, has become a critical issue during the recent past.

Wallawaya mini-hydropower project is exclusively confined to the strict forest reserve of Kirindi Oya basin. Further, approvals have been granted to establish seven mini-hydropower power plants on Sudu Ganga (main headwater stream of the Amban Ganga) within 23.4 km of which three of them are in operation. Furthermore, ecological aspects have been totally ignored when permissions were granted to establish six mini-hydropower plants on the trunk stream of the Hatton Oya, between Watawala and Nawalapitiya within 14 river kilometers (Figure 3.1). This stream section, one of the most likely breeding grounds of Mahseer, the largest carp native to Sri Lanka, can be ranked as the most disrupted stream stretch of the Upper Mahaweli Hills.

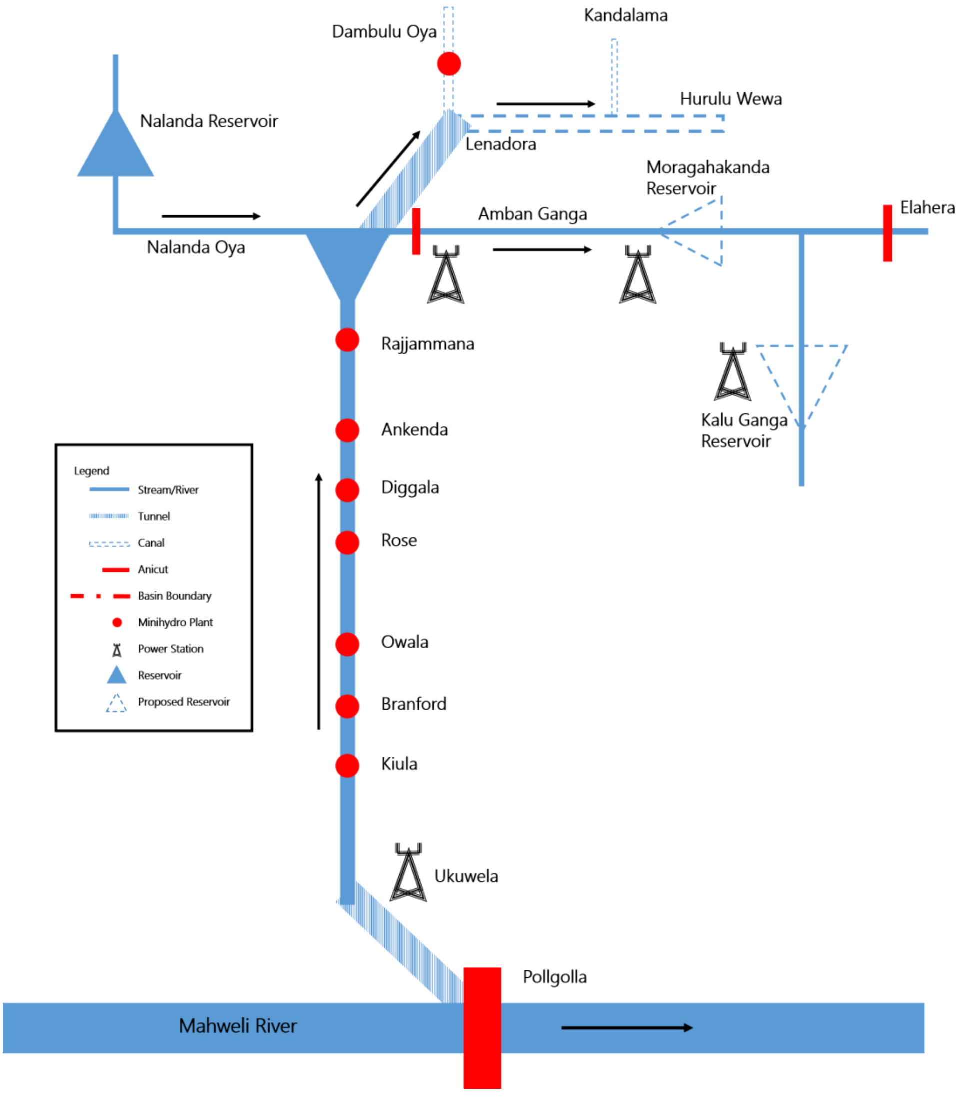



**Figure 3.1:** Schematic diagram depicting the sites of operational and approved mini-hydropower plants on Sudu Ganga

**Wallawaya MHP**: Situated in Koslanda valley in the Kirindi Oya basin of the Uva Province, Wallawaya Small Hydro Power Project is located exclusively in a Forest Reserve closer to the village Dehilanda, approximately 10 km away from Koslanda town. It is mentioned in the project report that the main design of the project was focused on limiting impacts to the surrounding environment and to provide free animal moments inside the forest and also to provide the forest to grow back to its original stage after construction. In order to achieve the above objectives, the entire conveyance path of the project was designed below ground (as advised by the Forest Department Sri Lanka). HOBAS CC GRP pipes were used for the 600 m long Low-pressure line and 800m long high-pressure line. Due to the fact that the entire conveyance path is buried in the ground, the natural vegetation is slowly growing back across the pipe path and in another few years. This is completely a misleading statement because deep-rooted forest trees cannot penetrate through buried huge pipes. But one can see a growth of wild grasses ("mana") along the pipelines. Further, it should be noted that the riparian forest vegetation along the stream banks of Kuda Oya (the headwater stream of Krindi Oya) will affect badly due to the diversion and conveying water through conduit for nearly 1 km.

**3.11 Promised Social Benefits and Donations**

Although not included in the ToR, the following information is available in different reports as the social benefits for the respective local communities that are associated with the development of hydropower projects.

- During the construction phase of all of the plants (which is typically about one-two years) the civil engineering firms undertaking the construction of the plants hire a large number of skilled and unskilled workers from the nearby communities, thereby providing additional employment during the period.

With respect to hiring labor during construction, it is important to understand that most of the construction companies have their own skilled labor fleets specialized for different tasks. Nevertheless, there may be opportunities for unskilled casual hands on temporary basis.

- After commissioning the plants typically have a small complement of staff of 10-15 persons including plant operators, laborers, security staff, etc. Over 50% of these persons are typically hired from the nearby communities.

It is very unlikely to have a 10-15 workforce in a small hydropower scheme. The developers employ only least number of workers. There are cases that local people work in small hydropower schemes as a result of pre-negotiation based on some transactions, for examples land acquisition for headrace channel, power lines etc.

- In most of the plants, additional roads have to build by the developers to access the powerhouse or the weir, transport material. These roads are available for use by the local people and in some cases provide motorable access to their homes where there were only footpaths before.

Of course, the developers have to build access roads for various purposes, but they maintain only the access road to the powerhouse to some extent after commissioning. There are instances that the accesses road to the powerhouse is fairly well maintained when the developer also use the powerhouse area as a small holiday resort.

- During the construction phase, various additional works beneficial to the local communities is carried out by the developers free of charge.

The Developers offer different types benefits to the local communities including financial donations during the construction and operational phases to mediate the agitations of local communities against small hydropower development.

# Chapter 4

## Environmental Clearance

### 4.1 Introduction

National Environmental (Amended) Act No 58 of 1988 of Sri Lanka stipulates Initial Environmental Examination (IEE) or Environmental Impact Assessment (EIA) as a mandatory requirement for establishment of various development projects depending on their magnitudes and assigns regulatory functions to the Central Environmental Authority (CEA). According to the Part IV C of the above Act, all "prescribed" development projects are subjected to IEE or EIA. National Environmental Act further stipulates that approval for all prescribed projects shall have to be obtained from the appropriate Project Approving Agencies (PAA) concerned or connected with such prescribed project with the concurrence of the CEA. EIA provisions are also included in the Flora and Fauna (Amended) Act No 49 of 1993. According to this Act, any development activity of any description whatsoever proposed to be established within one mile from the boundary of any Nature Reserve, is required to be subjected to an EIA and written approval should be obtained from the Director-General of the Department of Wildlife Conservation prior to implementation of such projects.

**Legislation on small hydropower:** The primary legislation on small hydropower sector in Sri Lanka is incorporated in Sustainable Energy Authority (SLSEA) Act No.35 of 2007. The provisions of this Act are resource neutral and apply not only to small hydropower but equally on all renewable energy resources. The primary legislation is supported by subsidiary legislation identified as 'regulations' with the publication of Energy Development Areas through a regulation where the SLSEA can exercise control over the hydropower resource, land requirement for the project and access.

Renewable Energy is a form of an energy resource that is replaced by a natural process at a rate that is equal to or faster than the rate at which that resource is being consumed. Following are the main sources of renewable energy in Sri Lanka; biomass (Dendro), hydropower, solar energy and the wind, of which the country is heavily dependent on hydropower. Sri Lanka was harnessing small hydropower since late eighteenth century as a source of energy for tea factories. Following the independence in 1948, the country began to develop major hydropower projects of which most of them are above the capacity of 10 MW. By early 21st century, Sri Lanka has tapped all most all potential sites for major hydropower projects. When looked at alternative sources, the country identified the potential of small streams flowing over cascades as potential sites for hydropower generation.

Now, however, the capacity of such large schemes is nearing their end. Therefore, the country has to resort to other means of generating power, among which the grid connection of small hydropower, wind power generation schemes, and solar projects more attractive. Such technologies are called non-conventional renewable energy (NCRE) technologies, as they were not used in the past in conventional grid power generation. Nevertheless, the priority was given to small hydropower generation as solar PV and the wind technologies were not very familiar with Sri Lanka's energy sector and there are certain uncertainties.

### 4.2 Mini-hydropower Plants

At present, the Sri Lankan Government is giving high priority to further exploiting the potential of its running water resources generating hydropower to reduce dependence on costly fossil fuel imports with a view to earning carbon credits as an initiative to reduce the effects GHGs on global warming. The private sector entrepreneurs are encouraged to invest on mini-hydropower projects under an ambitious plan of the Ceylon Electricity Board (CEB). According to the CEB around 600 potential sites have been already identified to establish small-scale hydropower projects which are capable of adding around 500 MW of hydropower to the national grid. According to this plan, it was anticipated to add 320 MW to the national grid by commissioning 140 mini-hydropower plants by the end of 2015. At present 143 mini-hydropower plants with 286 MW generation capacity have been connected to the national grid and provisional approvals to develop further 87 plants with 140 MW generation capacity had been already issued according to the latest list of the licensees dated on 1.10.2015 released by the Public Utilities Commission in Sri Lanka. The capacity of already established hydropower sites ranges from a few hundred kW to 10 MW. Most of the power from mini-hydro plants is also generated during the wet season when the utility is least dependent on thermal power. The development of energy from renewable resources is indeed a very important step in the reduction of $CO_2$ emissions. Electricity production from hydropower has been, and still is today, the first renewable source used to generate electricity.

Given a more favorable regulatory environment, it is assumed that a fair amount of electricity can be achieved by small hydropower plants next to the wind-power. The large majority of small hydro plants are “run-of-river” systems, meaning that they have no or relatively small water storage capability. The turbine only produces power when the water is available and provided by the river. Medium and high head schemes use weirs to divert water to an intake; it is then conveyed to the turbines via a pressure pipe or penstock. Therefore, a dam should be constructed to create a weir changing natural running water system into a pseudo lotic-lentic system behind the dam and almost dead aquatic ecosystem immediate downstream if an appropriate amount of water not released as the environmental flow. An alternative is to convey the water by a low-slope canal, running alongside the river contour to the pressure intake or forebay and then in a short penstock to the turbines. If the topography and morphology of the terrain do not permit the easy layout of a canal, a low-pressure pipe can be an economical option. At the outlet of the turbines, the water is discharged to the river via a tailrace.

In the case of low-head projects, either the water is diverted to a power intake with a short penstock, as in the high-head schemes, or the head is created by a small dam, provided with sector gates and an integrated intake powerhouse and fish ladder. Nevertheless, fish ladder is a must in hydropower plants as an ecological requirement.

When reservoirs are built for other purposes, such as flood control, irrigation, water abstraction for a big city, recreation area etc. - it may be possible to generate electricity using the discharge compatible with its fundamental use or the ecological flow of the reservoir. Accordantly, ecological flow also equally important as fish ladders when dams are built across rivers. Besides, the existing irrigation canals also can modify to establish min-hydropower plants by exploiting irrigation canals. The canal is enlarged to accommodate the intake, the power station, the tailrace and the lateral bypass. To safeguard the water supply for irrigation, the scheme should include a lateral bypass, in a case of shutdown of the turbine. This kind of scheme must be designed at the same time as the canal, as additional works whilst the canal is in full operation can be a very expensive option.

**4.3 Environmental Issues**

Environmental clearance is a must to obtain Provisional Approval from the Project Approving Committee, Energy Permit from the Public Utility Commission of Sri Lanka and to sign the Standardized Power Purchasing Agreement with the Ceylon Electricity Board as described in the previous chapter. An Initial Environment Examination (IEE) or Environment Impact Assessment (EIA) is compulsory to make sure that environmental issues are raised when a project or plan is first discussed and that all concerns are addressed as a project gains momentum through to implementation. The recommendations made by the IEE or EIA may necessitate the redesign of some project components, require further studies, and suggest changes which alter the economic viability, environmental sustainability, and social stability.

The project implementation must also adhere to proposed time frame. To be a success, it is essential that an environmental assessment is carried out to determine significant negative impacts during the construction and operational phases in order to implement correct mitigation measures. To be effective, once implementation has commenced, the EIA should lead to a mechanism whereby adequate monitoring is undertaken to realize environmental management or least or no impairment to the ecosystem components required for ecological integrity and sustainability. An important output from the IEE/EIA process should be the explanation of enabling mechanisms for such effective management of the project according to the Central Environmental Authority.

The way in which an IEE/EIA is carried out is not rigid; it is a process comprising a series of steps. These steps are outlined below and the techniques more commonly used in IEE/EIA are described in some details in many texts. The main steps in the IEE/EIA process are:

- Screening
- Scoping
- Prediction and mitigation
- Management and monitoring
- Audit

**4.4 IEE/EIA Process**

- It is an effective tool for the purpose of integrating environmental considerations into development planning and highly recognized in Sri Lanka
- It helps to identify the likely effects of a particular development activity on the environment and finds ways and means to reduce unacceptable impacts in order to shape the activity, well-suited to the local environment.
- It helps project approving agencies s to make decisions about the activity while directing the project proponent to achieve his targets more successfully.
- It is a major planning tool and one of the key techniques to achieve the sustainable development.
- It is a mandatory requirement for establishment of development projects in Sri Lanka under the National Environmental Act as well as under few other legislations

### 4.4.1 EIA in the National Environmental Act

The National Environmental (Amended) Act No. 56 of 1988 introduced EIA, as a part of the strategy to achieve sustainable development for the entire country and the Central Environmental Authority, was assigned as the regulatory body.

Only large-scale development projects that are likely to have significant impacts on the environment are listed as “prescribed projects”.

In addition, "prescribed projects" if located within "environment sensitive areas" are required to undergo EIA irrespective of their magnitude.

### 4.4.2 Stepwise Procedure

**Step 1: Preliminary Information**

A project proponent is required to provide the CEA with preliminary information on the proposed project, in order to initiate the EIA process by the CEA.

**Step 2: Environmental Scoping**

When a prescribed project is referred to CEA, the CEA will decide a suitable Project Approving Agency (PAA).

Then the PAA will carry out scoping and Terms of Reference (ToR) for the EIA/IEE will be issued to the project proponent.

**Step 3: EIA/IEE Report Preparation**

Project Proponent has to prepare the EIA /IEE report and to submit it to the PAA for evaluation.

Preparation of EIA reports may require the services of a team of consultants or subject specialists as many specialized areas have to be covered.

A list of consulting firms who prepare EIA reports is available at the CEA.

Project Proponents may use the services of suitably qualified consultants who may not have registered in the CEA.

Project Proponent should obtain the services of reliable and adequately qualified experts in the relevant fields, in order to ensure that the EIA report will be of the required standard

**Step 4: Public Participation & Evaluation of the Report**

EIA report will be subjected to an adequacy check in order to ensure that the ToR issued by the PAA has been met.

It will then be opened for public inspection/comments for a period of 30 working days.

(If there are any public comments on the EIA report, they will be sent to the project proponent for response.)

Subsequent to the public commenting period the PAA will appoint a Technical Evaluation Committee (TEC) to evaluate the EIA report and make its recommendations.

IEE reports are not required to be opened for public comments and are thus subjected to technical evaluation only.

**Step 5: Decision Making**

Based on the recommendations of the TEC, the PAA makes its decision on whether to grant approval for the project or not.

(If the PAA is not the CEA, it should obtain the concurrence of the CEA prior to granting approval.)

N.B. If the project proponent doesn't agree with the decision he has a right to appeal to the Secretary to the Ministry of Environment. The decision of the Secretary to the Ministry of Environment is the final.

**Step 6: Compliance Monitoring**

EIA/IEE approval is generally given with conditions that the project proponent is expected to meet.

The CEA or the PAA will monitor the implementation of conditions/ mitigation measures. If the project proponent violates the conditions, the approval may be revoked.

**EIA regulations are published in following Gazette notifications;**

- **Gazette Extra Ordinary No. 772/22 dated 24.06.93**
- **Gazette Extra Ordinary No. 1159/22 dated 22.11.2000**

#### 4.4.3 Prescribed Projects

Only “prescribed projects” are required to be subjected to IEE/EIA. The list of prescribed projects requiring an IEE/EIA under the provisions of the National Environmental Act is given in the following Gazette notifications.

- **772/22 of 24th June 1993**
- **1104/22 of the 5th November 1999**
- **1108/1 of the 29th November 1999**

Accordingly, **power generation and transmission** are prescribed projects.

#### 4.4.4 Project Approving Agencies

1. The respective ministries to which the following subjects are assigned: - National Planning, Irrigation. Energy, Agriculture, Lands, Forests, Industries, Housing, Construction, Transport, Highways, Fisheries, Aquatic Resources, Plantation Industries
2. The Department of Coast Conservation
3. The Department of Wildlife Conservation
4. The Department of Forest
5. The Central Environmental Authority

6. The Urban Development Authority
7. The Geological Survey and Mines Bureau
8. The Ceylon Tourist Board
9. The Mahaweli Authority of Sri Lanka
10. The Board of Investment of Sri Lanka

#### 4.4.5 Obstacles During Construction

- Unavailability of access roads
- Long distance transport of building materials (sometimes to be airlifted)
- Disposal of excavated materials and other debris
- Lack of labor in some instances
- Financial constraints
- Flash floods
- Invasion of elephants when constructed in forest reserves
- Protest by people when sites are located in sensitive areas

#### 4.4.6 Composition of the EIA team

Mini-hydropower projects are essentially prescribed projects falling under the category of power generation. Project proponents have to conduct IEE/EIAs very stringently depending on the nature of the project. Therefore, an EIA team for a mini-hydropower projects is compulsory to be composed the following expertise;

- Hydrologist/drainage engineer
- Stream ecologist
- Fish ecologist and;

The other subject specialists are, for example, an agronomist/pesticide expert, a soil conservation expert, a biological/environmental scientist, an economist, a social scientist and a health scientist, preferably an epidemiologist. Nevertheless, the final composition of the team will vary depending on the nature of the project.

Specialists may also be required to conduct fieldwork, laboratory testing, library research, data processing, surveys, and modeling. The team leader of the IEE/EIA processes must have significant management skill to co-ordinate the work of the team with diverse skills and knowledge.

Unfortunately, in the case of mini-hydropower projects, more than 90 % of IEE/EIA reports approved by the Project Approving Agencies, the EIA teams did not have the correct composition and required competence for conducting IEE/EIAs stringently. Most of the reports are bulky meaningless and deliberately misleading documents. Ecological assessments included therein were vague, trackless, and ambiguous. Very hardly one can find correct subject specialists listed in the team although CEA has very correctly defined the composition. This clearly demonstrates the weakness of the TEC appointed by the PAA. The content includes lengthy jargons on carbon trade and engineering mathematics rather than immediate local and social issues. Recent studies have highlighted the impacts on native and endemic fish fauna and human-elephant conflict a grave problem in the Walawe River basin as a result of the construction of MHPs below the Samanalawewa.

### 4.4.7 Public Comments

Public participation, which has a provision in the National Environmental Act is an important component in the EIA Process in Sri Lanka. Once the EIA report is submitted to the Project Approving Agency (PAA), the report will be opened for the comments of the public by a newspaper advertisement highlighting where and when the EIA report can be inspected. At this stage, EIA reports are available in three languages (i.e., Sinhala, English, and Tamil) at relevant government organizations, including Pradeshiya Shaba, Divisional Secretariat, Central Environmental Authority, and the Project Approving Agency. Any member of the public may send their comments either to the Head of the respective PAA or the Director General of the CEA within 30 working days. Further, public have the right to obtain the copy of the report from the PAA by paying due copying charges.

A public hearing may also be held at the discretion of the PAA when it is though that it would be in the public interest to do so. Public comments received by the PAA must send to the Project Proponent for immediate response. It is the responsibility of the Project Proponent to respond to the comments by making every effort to improve the project. IEE reports are not required to open for public comments for a mandatory period of 30 days. Nevertheless, an IEE report shall be deemed to be a public document and shall open for public inspection on request.

In addition to mandatory requirements, the Project Proponents are always advised to have informal dialogues/consultation with the local community during the process of IEE/EIA study. The project proponent must ensure that the local people get correct information about the project. If the local community is negatively affected by the project activities it is the responsibility of the Project Proponent to negotiate with them for conflict resolution in order to minimize the negative impacts by implementing appropriate mitigation measures.

Public participation is an excellent strategy to identify the negative impacts on riparian communities and common environmental issues arising mainly during the construction phase. Nevertheless, the public is not aware of real ecological problems such as disruption of evolutionarily established ecological processes and functions and, in turn, alteration of eco-hydrology and bio-diversity within the watersheds when mini-hydropower plants emerge like mushrooms.

## 4.5 Clean Development Mechanisms (CDM)

Sri Lanka is a signatory to United Nation Framework Convention on Climate Change (UNFCCC) has ratified the Kyoto Protocol on climate change by a cabinet decision in November 1993 and is among the first 50 countries that have ratified it. Therefore, under its obligations to contribute to efforts to mitigate climate change, Sri Lanka made its initial communication in October 2000. In keeping with this convention's obligations, this project has been launched in 2000. The climate change division of Ministry of Environment was assigned to prepare the Second National Communication (SNC) by 2010. The largest contributors to GHG emission in Sri Lanka are;

- changes in forest and woody biomass stocks
- forest, and grassland conversion and liming and
- organically amended soils

The largest source of methane is the treatment and handling of waste while energy sector also contributes on a small scale through the incomplete burning of fossil fuel. The primary energy sources in the country are biomass (43.5%), petroleum (45.3%) coal (3.9%), major hydropower (5.7%) and new renewable energy (1.6%) as reported in 2012.

Sri Lanka has initiated strategies to reduce GHG through afforestation, reforestation, and development of sustainable energy including the establishment of smaller hydropower plants, solar cells, and windmills. Apart from the initial national communication, Sri Lanka has also developed a Clean Development Mechanism (CDM) policy and strategy following the Kyoto Protocol.

The national policy on CDM is to contribute to sustainable development through developing and establishing the institutional, financial, human resources and legislative framework necessary to participate in Clean Development Mechanism (CDM) activities under the Kyoto Protocol while developing a mechanism for trading "Certified Emissions Reductions" (CER) and "Removal Units" (RMU) earned through CDM activities. The CDM was designed to meet a dual objective; to help developed countries to fulfill their commitments to reduce emissions, and to assist developing countries in achieving sustainable development. CDM projects earn tradable, saleable certified emission reduction (CER) credits that can be used by industrialized countries to meet a part of their emission reduction targets under the Kyoto Protocol. The benefits of CDM projects include investment in climate change mitigation projects in developing countries, transfer or diffusion of technology in the host countries, as well as improvement in the livelihood of communities through the creation of employment or increased economic activity.

The Ministry of Environment & Natural Resources is the National Focal Point for UNFCCC and the Kyoto Protocol while Climate Change Secretariat (CCS) is the Designated National Authority (DNA) for CDM activities. A National Experts Committee (NEC) comprising representatives from relevant ministries and universities and private sector and NGO representatives evaluate CDM projects and make recommendations to the Authority. CDM projects shall be subjected to the Environment Impact Assessment (EIA) or Initial Environment Examination (IEE) process and other applicable laws as relevant. Nevertheless, following challenges exist for CDM registration in Sri Lanka.

- Overestimating the CDM potential.
- Overestimating the CDM revenue
- No market access
- Approval procedures not acceptable to private sector
- Lack of knowledge.
- No easy access to new information.
- Fear of adopting new technologies

For example, in the case of generation of electricity by construction and operation of mini-hydropower project, CDM demonstrates only the amount of $CO_2$ emission to generate an equivalent amount of electricity by burning fossil fuels. GHG emissions (viz., $CO_2$, $CH_4$, and NOx) during the construction and operation of small hydropower plants are not in cooperated. Therefore, it is imperative to estimate GHG emission in the case of electricity generation by small hydropower projects. Mini-hydropower projects at Alupola and Badulu Oya were the first projects registered under the Clean Development Mechanism (CDM) in Sri Lanka, in 2005. Since then, thirteen such projects (viz, Denawak Ganga, Delta, Sanqhuar, Magal Ganga, Hapugastenna I & II, Hulu Ganga I & II, Atabage, Kirkoswald, Gantuna Udagama. Sheen, Ethamala Ella) have been registered for CDM.

**The CDM project has five stages:**

1. Identification and formulation
2. National approval
3. Validation and registration
4. Monitoring
5. Verification/certification

The first three stages occur during pre-implementation of the project while the last two are during the lifetime of the project.

Apart from minor emissions during the construction phase and those associated with maintenance and monitoring, the Sanquhar and Delta plants will supply greenhouse emission free electricity to the Sri Lankan grid, at a time when the grid is connected otherwise becoming increasingly reliant on fossil fuels.

# Chapter 5

## Designing and Physical Structures

### 5.1 Introduction

Following the "Third Conference of the Parties to the United Nations Framework Convention on Climate Change" held in Kyoto in December 1997, the European Union has recognized the urgent need to tackle the climate change issue. It has also adopted a target to reduce greenhouse gas emissions by 8 % by 2010 from 1990 levels, whereas, for other industrialized countries, the target was 5 %. To facilitate the Member States achieving this objective, the Commission identified a series of actions, focusing on reducing energy consumption and greenhouse gas (GHG) emissions.

The development of energy from renewable resources (e.g., solar, wind and hydro) is a very important step in the reduction of GHG emissions. Therefore, "Directives" were forwarded for the promotion of electricity produced from renewable energy resources. Electricity production from hydropower has been, and still is today, the first renewable source used to generate electricity throughout the world. Nevertheless, the conventional large scale hydro requires the flooding of large areas of land that create environmental and social issues. Therefore, it was assumed that the properly designed small hydro schemes are more flexible and easily integrated into local ecosystems.

In 2001, electricity generation in the European Union from small hydro plants accounted for 8.4% of installed capacity (9.9 GW) but they were operated under more favorable regulatory environmental conditions. The large majority of small hydro plants are "run-of-river" schemes, meaning that they have no or relatively small water storage capability or no reservoir behind the weir. The turbine only produces power when the water is available and provided by the river.

### 5.2 Site Configurations

The objective of a hydropower scheme is to convert the gravitational energy of a mass of water, flowing in a stream with a certain fall to the turbine (termed the "head"), into electric energy at the lower end of the scheme, where the powerhouse is located. The power output from the scheme is proportional to the flow and to the head.

Schemes are generally classified according to the "Head":

- High-head: 100 m and above
- Medium-head: 30 - 100 m
- Low-head: 2 - 30 m

NB: The above ranges are not rigid but are merely means of categorizing sites.

Schemes can also be defined as:

- Run-of-river schemes
- Schemes with the powerhouse located at the base of a dam
- Schemes integrated on a canal or in a water supply pipe

### 5.2.1 Run-of -river schemes

Run-of-river schemes are where the turbine generates electricity as and when the water is available and provided by the river. When the river dries up and the flow falls below some predetermined level (environmental flow or e-flow) or the minimum technical flow for the turbine, generation ceases.

Medium and high head schemes use weirs to divert water to the intake, it is then conveyed to the turbines via a pressure pipe or penstock. Penstocks are expensive and consequently this design is usually uneconomic. An alternative (Figure 5.1) is to convey the water by a low-slope canal (headrace canal), running alongside the river to the pressure intake or forebay and then in a short penstock to the turbines. If the topography and morphology of the terrain do not permit the easy layout of a canal a low-pressure pipe, can be an economical option. At the outlet of the turbines, the water is discharged to the river via a tailrace.

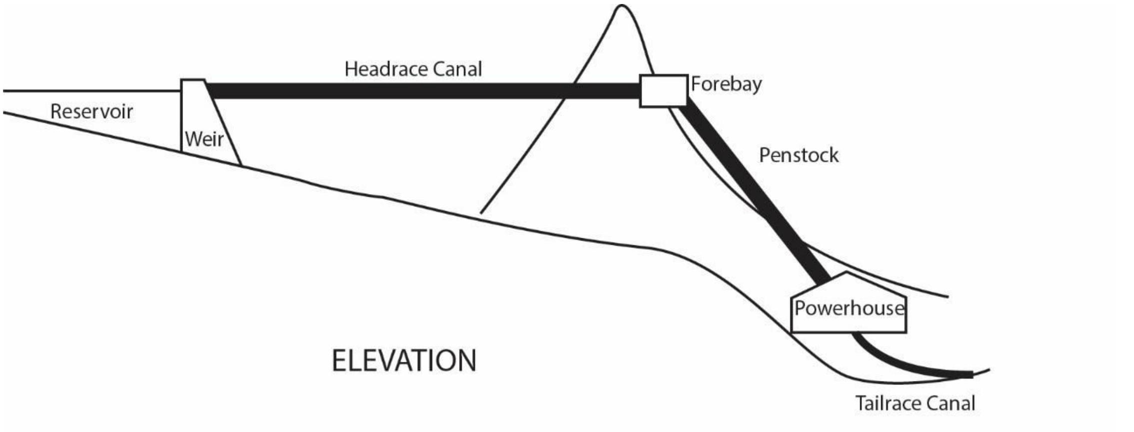



**Figure 5.1:** High-head scheme

Low-head schemes are typically built in river valleys (e.g., Branford and Rajjammana mini-hydropower plants on Sudu Ganga in the Mahaweli River basin).

**Two technological options can be selected.**

Either water is diverted to a power intake with a short penstock as shown in Figure 5.2 as in the high head schemes,

OR

The head is created by a small dam, provided with sector gates and an integrated intake as shown in Figure 5.2

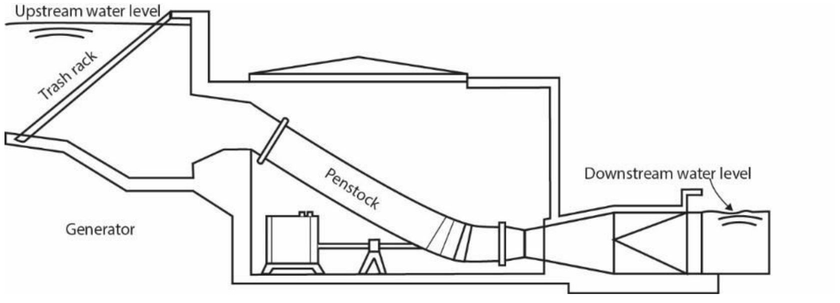



**Figure5.2:** Low head scheme with penstock

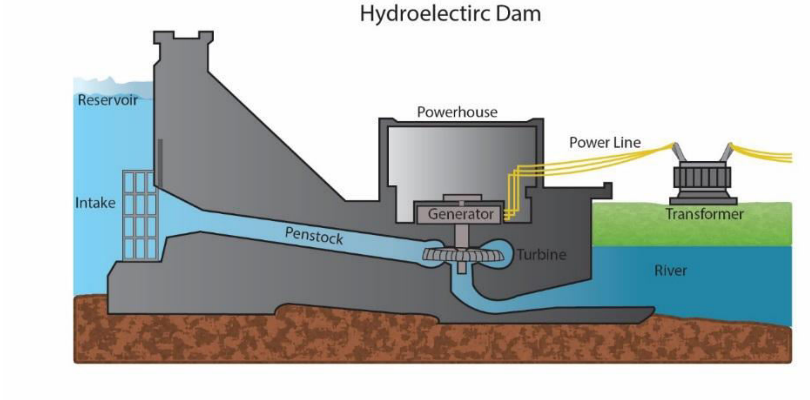



**Figure 5.3:** Low head scheme integrated into the dam

### 5.2.2 Schemes with the powerhouse at the base of a dam

A small hydropower scheme cannot afford a large reservoir to operate the plant when it is most convenient, the cost of a relatively large dam and its hydraulic appurtenances would be too high to make it economically viable. But if the reservoir has already been built for other purposes, such as, irrigation (e.g. Senanayake Samudra, Maduru Oya, Uda Walawe), water storage for diversion (e.g., Bowetenna reservoir) etc., it may be possible to generate electricity using the discharge compatible with its fundamental use or the ecological flow of the reservoir. But unfortunately, either large irrigation reservoirs or hydropower reservoirs in Sri Lanka do not maintain ecological flows. The main issue is how to link headwater and tailwater by a waterway and how to fit the turbine in this waterway. If the dam already has a bottom outlet (see Figure 5.4) for a possible solution.

Provided the dam is not too high, a siphon intake can be installed. Integral siphon intakes as shown in Figure 5.5 provide an elegant solution in schemes, generally, with heads up to 10 meters and for units up to about 1000 kW, although there are examples of siphon intakes with an installed power up to 11MW (Sweden) and heads up to 30.5 meters (USA).

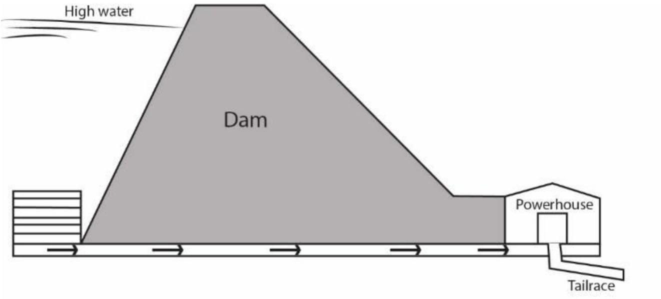



**Figure 5.4:** Low-head scheme using an existing dam

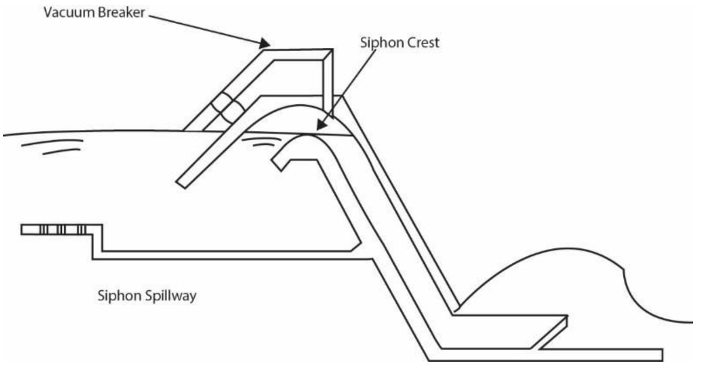



**Figure 5.5:** Low head scheme – siphon intake

### 5.2.3 Schemes integrated within an irrigation canal

Two types of schemes can be designed to exploit irrigation canal:

**Type I.** The canal is enlarged to accommodate the intake, the power station, the tailrace and the lateral bypass as shown in Figure 5.6 with a submerged powerhouse equipped with a right angle drive Kaplan turbine. To safeguard the water supply for irrigation, the scheme should include a lateral bypass, as in the figure, in the case of shutdown of the turbine. This kind of scheme must be designed at the same time as the canal, as additional works whilst the canal is in full operation can be a very expensive option.

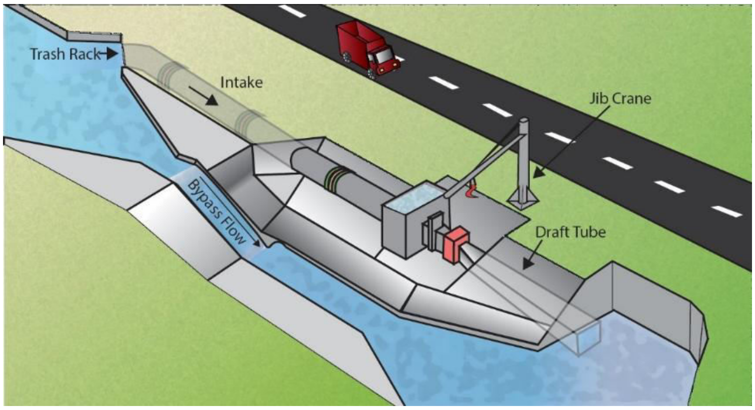



**Figure 5.13:** Integrated scheme using an irrigation canal

**Type II.** If the canal already exists, a scheme like the one shown in Figure 5.7 is a suitable option (e.g., Maduru Oya LB Canal, Drop 9 and Drop 10). The canal should be slightly enlarged to include the intake and the spillway. To reduce the width of the intake to a minimum, an elongated spillway should be installed. From the intake, a penstock running along the canal brings the water under pressure to the turbine. The water passes through the turbine and is returned to the river via a short tailrace. Fish ladders or bypasses are not necessary under both type I and II.

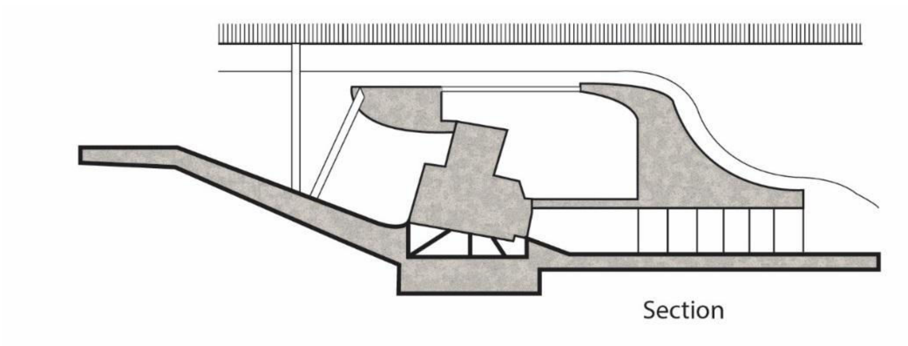



**Figure 5.14:** Elongated spillway scheme using an irrigation canal

### 5.2.4 Schemes integrated into a water abstraction system

The drinking water is supplied to a city by conveying the water from a headwater reservoir via a pressure pipe. Usually in this type of installation, the dissipation of energy at the lower end of the pipe at the entrance to the Water Treatment Plant is achieved through the use of special valves. Nevertheless, this type of schemes is not in operation in Sri Lanka.

## 5.3 Planning and designing a mini hydropower scheme

The project planning and designing in small hydropower schemes is a complex and iterative process, where consideration is given to the environmental impact assessment, mitigation programs, and different technological options. These are then budgeted and an economic evaluation will be carried out.

Although it is not an easy task to provide a comprehensive guide on how to design and evaluate an SHP scheme, the fundamental steps to be followed have been forwarded by various organizations, before deciding if one should proceed to a detailed feasibility study or

**Box 5.1**

- Topography, geomorphology and pedology of the site
- Hydrology of the water resource and its generating potential
- Site selection and basic layout
- Hydraulic turbines and generators and their control
- Environmental assessment with special emphasis on fish
- Monitoring and mitigation measures
- Economic evaluation of the project and financing potential
- Institutional framework and administrative procedures

not. A list of the studies that should be undertaken during the process of small hydropower development is given in the Box 5.1.

The viability of the scheme is also determined by:

- The availability of water resource
- The product of the flow and the head (= potential)
- Constant gross head
- The most appropriate hydraulic equipment
- Flow-duration curve (needs gauged stream site)

**Gross head**: The gross head is the vertical distance that the water falls through in giving up its potential energy (i.e. between the upper and lower water surface levels). Accurate measurements of the gross head can be made by a tachometer or less accurately by a clinometer or Abney level. At present, with digital theodolites, electronic digital, and laser levels are being used. The modern electronic digital levels provide an automatic display of height and distance within a few seconds with a height measurement accuracy of 0.4 mm, and the internal memory that can store approximately 2,400 data points. Surveying by Global Positioning Systems (GPS) is now used widely and a handheld GPS receiver is ideal for field positioning, and rough mapping.

**Nethead**: The potential energy is lost due to trash racks, pipe friction, bends, and valves. In addition, to these losses, certain types of turbines need to discharge their water to the atmosphere, above the level of the tail water (the lower surface level). The gross head minus the sum of all the losses equals the net head, which is available to drive the turbine. The net head can be estimated using the mathematical formula.

**Streamflow:** Stream flow time series data gathered regularly over several years is needed for the preparation of flow-distribution curve. Unfortunately, it is rather unusual for regular gauging to have been carried out in the stretch of river where the development of a small hydro scheme is proposed. In Sri Lanka, gauging stations are hardly fixed in hill streams, but there are several in the trunk stream of major rivers.

The upstream water level may vary with flow. If the intake pond is regulated by an overtopping weir without any gates, the water level will rise with the flow. Nevertheless, if the intake pond is regulated by gates in order to operate at a desired reservoir level, the water level may remain constant even during high flow periods. During low flow periods, the upstream water level may also be lower due to the drawdown of the reservoir.

The downstream water level may also vary with the flow. This depends on the water body into which the water is released. If discharging directly into a headwater pond controlled by gates in a downstream development, the water levels may remain almost constant even for higher flows. If the water is discharged into a natural stream, the water levels again may vary considerably**.**

**Flood**: The stream flow is the fuel of the plant, but stream flow in the form of floods is also a potential threat to all structures built in rivers. Therefore, the hydrological investigation must address not only water availability for production but also frequency and severity of floods so as to design flood protection and control into the scheme. The design flood is not only characterized by its peak value of flow, but a hydrograph flood flows should show the distribution of the flow over time. The flood flows have washed away the weir and other physical structures of Branford and Ross Estate mini-hydropower plants located on Sudu Ganga in Matale District in 2012 and Giddawa mini hydropower plant operating on the Hulu Ganga was inundated during the rainy season in 2012 reducing its generation capacity.

For weirs with large reservoirs are at risk of high floodwaters and therefore, it is necessary to design the system to avoid flooding damage. Two criteria have been proposed to overcome flood hazards. Further, care should be taken when mini-hydropower plants are planned to establish downstream of major hydropower plants when the landscape has the lesser gradient between two sites.

**Maximum Inflow Design Flood** - that the facilities should be able to accommodate the floodwater, without unacceptable risk of a dam failure or other serious damages to the structures. This flood is normally defined as the PMF, (Probable Maximum Flood) or similar.

**Normal Operation Design Flood** - that the facilities should be able to accommodate floodwater without exceeding normal conditions of operation. This flood is usually defined as a flood with a specific return period.

### 5.4 Site Evaluation

Sufficient head and flow are necessary requirements for hydropower generation. Consequently, these two parameters are important determinants in site selection. Nevertheless, the selection of the most appropriate technical solution for the site will be the result of a long-lasting, safe process, where the topography and the environmental issues for a particular site, are most important. That is why a thorough knowledge of the principles is needed to avoid dangerous failures during the construction and in the operation of the plant.

### 5.4.1 Maps and aerial photographs

Scaled maps are importation to study the site. In developed countries 1:5,000 maps are available for their territories, some of them are already digitized. On the other hand, in the developing countries, especially in Africa and South America the developers will be fortunate if they can find maps at 1:25000. In Sri Lanka available map scale is 1: 50,000 for the entire country, but 1:10,000 maps are also available for certain areas. Aerial photographs of topography can be substituted for maps to some extent if they cannot be found at the required scale. Further, aerial photographs can be viewed stereoscopically or in three dimensions. The stereoscopic effect enables the geologist to identify rock types, determine geologic structures, and detect slope instability and the engineer is able to gather data necessary for a dam, open channels, and penstock construction. Nowadays, Google images and GPS devices are available to get more landscape features of the selected site.

With these maps, it is possible to locate suitable sites for;

- Intake weir
- Headrace channel
- Forebay
- Penstock
- Powerhouse

### 5.4.2 Detailed geological studies

In many developing countries, detailed geological studies of a site are avoided as a cost reduction method. Nevertheless, it is necessary to conduct detailed geological studies to determine the safety of the dam foundations, the stability of the slopes and the permeability of the terrain. Besides, sometimes this information should be complemented, with fieldwork particularly, drilling and sampling.

Hydraulic structures should be founded on level foundations, with adequate side slopes and widths, not subjected to stability problems.

Along the open channel, many geomorphologic features can adversely affect its selected line, which, together with a steep slope of the terrain, may lead to potential instability.

**Techniques used in detailed geological studies**

- Photogeology
- Geomorphologic maps
- Laboratory analysis
- Geophysical studies
- Structural geological analysis
- Borehole drilling

The detailed geological studies will help to identify;

- Correct weir location and reinforcement requirements for the weir foundation
- Stability and permeability of headrace channel
- Requirements for tunnel constructions if necessary
- Suitability of powerhouse location

A number of small hydro plants have failed because they were poorly designed, built or operated. Three examples are given below to show the schemes that failed in the commissioning of the plant or later in the operation and produced considerable loss of money and dramatic delays.

- Ruahihi canal failure in New Zealand
- La Marea canal failure in Spain
- Seepage under a weir in France

### 5.5 Hydraulic Structures

A hydropower development includes a number of physical structures, the design of which will be dependent upon the type of scheme, local conditions, access to construction material and also local building traditions in the country or region. The structures that are common in a hydro scheme can be categorized into two groups namely diversion structures (viz., dams, weirs and, spillways, energy dissipation arrangements, residual flow arrangements and fish bypasses) and water conveyance systems (viz., intake, canals, tunnels, penstock, and powerhouse).

#### 5.5.1 Dams

Dams and weirs are primarily intended to divert the river flow into the water conveyance system leading to the powerhouse. Dams and weirs also produce additional head and provide storage capacity. The choice of dam type depends largely on local topographical and geotechnical conditions. For example, if sound bedrock is not available within reasonable excavation depth, rigid structures such as concrete dams are difficult. Conversely, for narrow valleys, it can be difficult to find space for separate spillways, and concrete dams can be the natural choice with their inherent possibilities to integrate spillways etc. in the dam body.

**Small dam**: A dam is considered "small" when its height, measured from its foundation level to the crest, does not exceed 15 m, the crest length is less than 500 m and the stored water is less than 1 million cubic meters.

The vast majority of dams are embankment dams with a central core of moraine. The embankment dams are the more common throughout the world partly owing to the following characteristics, which they possess:

- Can be adapted to a wide range of foundation conditions.
- Construction uses natural materials, which can often be found locally, limiting needs for
- Long transportation.
- The construction process can be continuous and highly mechanized.
- The design is extremely flexible in accommodating different fill materials.

Disadvantages with embankment dams are;

- They are sensitive to overtopping and leakage
- Erosion in the dam body and its foundation

There is a higher mortality rate among embankment dams as compared to concrete dams. They are often categorized according to the main fill material, for example, rock-fill dams, or earth-fill dams and can be further divided into;

- Homogeneous dams (low embankments less than 4m)
- Zoned embankment dams (high embankments more than 4m)
- Embankments dams with membrane made of concrete, asphalt or other materials

**Concrete dams:** Generally, concrete dams are categorized according to how they function statically and fall into one of the following groups.

- **Gravity dams**: Their cross-section is basically triangular in order to provide adequate stability with their own mass and stress distribution across the foundation plane. The upper part is normally rectangular in order to provide adequate crest width for installation and transportation
- **Buttress dams**: These dams consist of a continuous upstream face that is supported by buttresses at regular intervals. The upstream face is normally divided into vertical sections by dilatation joints, each section being supported by a buttress. Cross-sections are similar to those of gravitation dams.
- **Arch and Cupola dams**: These dams function structurally as horizontally laid out arches that transfer the water pressure on the upstream face into the abutments rather than into the foundation. Arch dams can be designed with a constant radius of the dam height, or with varying radii (Cupola dams).

Concrete dams, on the other hand, have drawbacks compared with the embankment dams:

- Require certain conditions with respect to the foundations.
- Require processing of natural materials for aggregate at the site,
- Hauling of large quantities of cement
- Has a labor intensive
- Discontinuous construction process,
- Large unit costs.

On the other hand, concrete dams have several advantages:

- Suitable for a wide range of topography
- that is for wide and narrow valleys,
- Provided that foundation conditions are right.
- Not very sensitive to overtopping.
- A spillway can be placed at the crest or else over the entire length of the dam.
- Chambers or galleries for drainage can be housed
- Tubing and ancillary works can be included
- Powerhouses can be placed right at the toe of the dam

**Dam safety**: Dams have been identified as “the single man-made structures capable of causing most deaths.” because of their susceptibility to failure. Depending on localization and circumstances even smaller and medium sized dams can be potentially dangerous, and considering their large number they do pose a significant threat to human health and the environment. In order to identify potentially hazardous dams, most countries including Sri Lanka now employ a classification system for dams, requiring dam owners to classify their dams. The hazard level is described and identified subjectively using terms such as low, significant and high. Dam safety can be improved by the installation of monitoring systems, performing reviews and undertaking dam inspections on a regular basis.

### 5.5.2 Weirs and spillways

In order to avoid dam failures, carefully designed overflow passages called spillways are incorporated in dams or weirs as part of the structure. Owing to the high velocities of the spilling water, some form of energy dissipation is usually provided at the base of the spillway. The large majority of small hydropower plants are of the run-of-river type, where electricity is generated from discharges larger than the minimum required to operate the turbine. In these plants, a low diversion structure is built on the streambed to divert the required flow whilst the rest of the water continues to flow over it. Such a structure is called a **weir**, whose role is not to store the water but to increase the level of the water surface so the flow can enter into the intake.

**Weirs:** Weirs are smaller fixed, storage, cost-effective structures. They cannot regulate the water level and thus, both the water level and energy production fluctuates as a function of discharge. Weirs can be constructed perpendicular, angular or lateral compared to the river axis. Most often the weir crest is rectilinear and perpendicular to the river axis. For relatively low downstream water levels, the weir controls the flow and defines the relationship between the upstream water level and the discharge. In general weirs are three types (Figure 5.8);

- Sharp-crested weir
- Broad-crested weir
- Ogee weir

The sharp-crested weir is easy to construct and relatively cost-effective whereas the broad-crested weir is often constructed for temporary structures or for structures of secondary importance, such as in the case of temporary flow diversion. The ogee weir is hydraulically an ideal type giving the highest discharge coefficient. Its curved shape is defined by the jet trajectory that would appear for the design discharge. The construction of Ogee weir is more expensive than both the sharp-crested and broad-crested weirs.

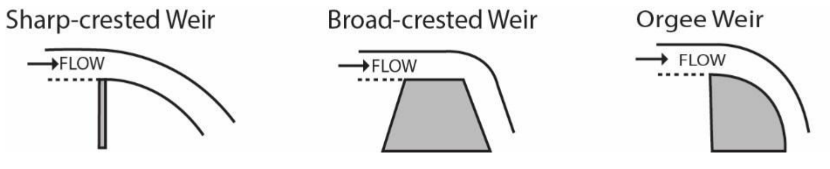



**Figure 5.15:** Three types of weir

**Spillways**: Unlike weirs, spillways are large structures. They are often divided into ungated and gated spillways, corresponding to fixed and mobile structures, the ungated spillway, in fact, being a large-scale weir.

**Gated spillways**: The gated spillway is a mobile storage structure that can regulate the water level such that it stays more or less constant for most incoming flow. This is performed by means of gates, which are designed such way that, when the gate is fully open (and the structure functions as if it were fixed) the discharge has to pass the structure without noticeable water level increase upstream. Depending on gate configuration and discharge capacity they may also be able to flush accumulated sediment downstream. These structures are generally more expensive than fixed structures, for both construction and maintenance, and their functioning is more complicated.

**Flashboards**: In order to raise the water level slightly behind the weir ensuring an adequate depth of water at the intake, without endangering the flooding of the upstream terrain, flashboards may be installed on the crest of the weir. They are commonly made of wood and reinforced with steel pins embedded in steel sockets in the spillway crest. The flashboards have to be removed manually during flood flows so that high water levels do not flood the upstream terrain.

**Inflatable weirs**: Inflatable weir is a reinforced rubber bladder which can be incorporated to the weir instead of concrete, steel or wood flashboards. Inflatable weirs are flexible gates in the form of a reinforced, sheet-rubber bladder inflated by air or water, anchored to a concrete foundation by anchor bolts embedded into the foundation. Like any other gate, the inflatable weir needs a mechanism by which it is opened and closed.

### 5.6. Energy Dissipating Structures

The water discharge from the aforementioned fixed or mobile hydraulic structures is usually super critical at the outlet. The corresponding high flow velocities and turbulence may produce severe erosion at the toe of the structure, especially if the riverbed is not erosion resistant, such as for example in the case of silt, clay, loose sand, gravel or even fractured rock. In order to avoid such damage, the following structural solutions may be applied, although some of them being very costly.

- Stilling basin
- Baffled apron drop
- Plunge pool
- Chute cascades

Most of the above structures dissipate the flow energy by the formation of a hydraulic jump, which dissipates a lot of energy over a relatively short distance. The design and construction of energy dissipating structures are quite complex and vast and the reader is encouraged to contact specialized engineers.

### 5.7 Intake Structures

A water intake must be able to divert the required amount of water into a headrace canal or into a penstock without producing a negative impact on the local environment and with the minimum possible head losses. Also, a major challenge consists of handling debris and sediment transport.

The intake serves as a transition between a stream that can vary from a trickle to a raging torrent, and a controlled flow of water both in quality and quantity. Its design, based on geological, hydraulic, structural and economic considerations, requires special care to avoid unnecessary maintenance and operational problems that cannot be easily remedied and would have to be tolerated for the life of the project.

The location of the intake depends on a number of factors, such as submergence, geotechnical conditions, environmental considerations (especially those related to fish life) sediment exclusion and ice formation in temperate countries, where necessary. The orientation of the intake entrance to the flow is a crucial factor in minimizing debris clogging on the trash rack, a source of possible future maintenance problems. The best disposition of the intake is with the screen at right angles to the spillway so, that during flood seasons, the flow pushes the debris over its crest. The intake should not be located in an area of still water, far from the spillway, because the eddy currents common in such waters will accumulate trash at the entrance. Intakes are primarily two types;

**Power intake**: The power intake converts water directly to the turbine via a penstock. These intakes are often incorporated with reservoirs (e.g., Senanayake Samudra, Maduru Oya, Uda Walawe and Bowetenna) and transfer the water as pressurized flow.

**Conveyance intake**: The intake supplies water to other waterways (headrace canal, flume, tunnel, aqueduct etc.) that usually end in a power intake. These are most frequently encountered along rivers and waterways and generally transfer the water as free surface flow.

Conveyance intakes along rivers are further divided into lateral, frontal and drop intakes based on slope, width, and plan view of the river and sediment transport. The lateral intake functions by using a river bend or by using a gravel deposition channel. The frontal intake is always equipped with a gravel deposition tunnel and is well adapted for rectilinear river reaches. The drop intake is generally used in steep-sloped rivers or irrigation canals, such as torrents, and for rectilinear reaches.

**Head losses:** For small hydro plants, head losses can be of significant importance to the feasibility of the project and should thus be minimized as much as possible. The following can be implemented to minimize the head losses.

- Approach walls to the trash rack designed to minimize flow separation and head losses
- Piers to support mechanical equipment including trash racks, and service gates
- Guide vanes to distribute flow uniformly
- Vortex suppression devices
- Appropriate trash rack design

**Trash racks**: Trash racks are placed at the entrance to the intake to prevent the ingress of floating debris and large stones, a major function of the intake to minimize the amount of debris and sediment carried by the incoming water.

### 5.8 Sediment Traps

Conveyance intakes are designed on rivers in order to eliminate possible floating debris and bed load transport. However, they cannot prevent the entrance of suspended sediment transport. For this, a sediment trap is projected downstream of an intake. The main objective of such a trap is to avoid sedimentation of downstream structures (canals, shafts, etc.) as well as to limit the possible damage of sediments on the hydro-mechanical equipment.

A sediment trap is based on the principle of diminishing the flow velocities and turbulence. This results in a decantation of suspended sediments in the trap. This diminishing is obtained by an enlargement of the canal, controlled by a downstream weir. The efficiency of the sediment trap is determined by the grain diameter that deposits in the trap.

### 5.9 Open Channels

The flow conveyed by a canal is a function of its cross-sectional profile, slope, and bed roughness. River channels are normally very irregular in bottom topography and their surface roughness changes with distance and time. In contrast, in artificial channels, the cross-section is regular in shape and the surface roughness of the construction materials - earth, concrete, steel or wood - is well documented, so that the application of hydraulic theories yields reasonably accurate results compared with river channels.

In conventional hydropower schemes and in some of the small ones, especially those located in wide valleys where the channels must transport large discharges, the channels are designed in the manner shown in Figure 5.9. According to this profile, the excavated ground is used to build the embankments, not only up to the designed height but to provide the freeboard, the extra height necessary to account for the height increase produced by a sudden gate closing, waves or the excess arising in the canal itself under heavy storms. These embankment channels are easy to construct but difficult to maintain, owing to wall erosion and aquatic plant growth.

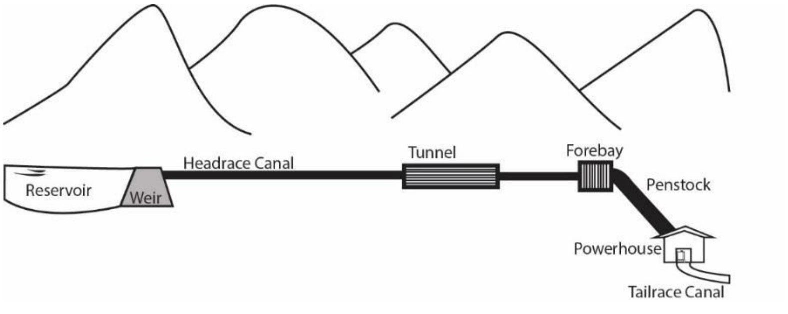



**Figure 5.16:** Channel design

**Circumventing obstacles:** Along the alignment of a canal obstacles may be encountered, and to bypass them it will be necessary to go over, around or under them. The crossing of a stream or a ravine requires the provision of an aqueduct (e.g. Monera Ela mini hydropower plant on Wee Oya), a kind of prolongation of the canal, with the same slope, supported on concrete or steel piles or spanning as a bridge. Steel pipes are often the best solution because a pipe may be used as the chord of a truss, fabricated in the field. The only potential problem is the difficulty of removing sediment deposited when the canal is full of still water.

**5.10 Penstocks**

The task of the penstock is to convey water from the intake to the powerhouse. Although it does not appear a difficult task, deciding the most cost-effective arrangement for a penstock is not that easy. Penstocks can be installed over or under the ground, depending on factors such as the nature of the ground itself, the penstock material, the ambient temperatures and the environmental requirements. A flexible and small diameter PVC penstock, for instance, can be laid on the ground, following its outline with sand and gravel surrounding the pipe to provide good insulation. Small pipes installed in this way do not need anchor blocks and expansion joints. Larger penstocks are usually buried, as long as there is only a minimum of rock excavation required. From the environmental point of view, the solution is not optimal because the ground cannot be returned to its original condition with respect to vegetation growth but the penstock does not constitute a barrier to the movement of wildlife. Usually, the penstock is built in straight or nearly straight lines, with concrete anchor blocks at each bend and with an expansion joint between each set of anchors.

### 5.11 Tailraces

After passing through the turbine, the water returns to the river trough a short canal called a tailrace. Impulse turbines can have relatively high release velocities, so the tailrace should be designed to ensure that the powerhouse would not be undermined. Protection with rock riprap or concrete aprons should be provided between the powerhouse and the stream. The design should also ensure that during relatively high flows the water in the tailrace does not rise so far that it interferes with the turbine runner. With a reaction turbine, the level of the water in the tailrace influences the operation of the turbine and more specifically the onset of cavitations. This level also determines the available net head and in low head systems may have a decisive influence on the economic results.

### 5.12 Grid Connection

The Developers, those who hold Standardized Power Purchasing Agreement are eligible to apply for the grid connection when the project construction is completed. The “CEB Guide for Grid Interconnection of Embedded Generators, Sri Lanka” provides the requirements and procedures for the plant design, testing, commissioning and operation of the interconnection with the CEB network. The developer must sign the Standard Power Purchasing Agreement (SPPA) with CEB within the validity period of the LoI and, until such time, submit a monthly report of progress to CEB. SPPA is a standardized, non-negotiable, 15-year contract.

# Chapter 6

## Construction, Operation, and Management

### 6.1 Introduction

A hydropower scheme primarily contains three phases, namely water diversion, generation, and grid connection. Water diversion means changing the flow direction of a stream or river towards the powerhouse whereas the generation means how to transform the gravitational energy of flowing water into electricity. There are various methods to generate electricity. The basic principle is similar to the mechanism of a bicycle dynamo. When electricity is generated it will be transferred to the grid by means of a transformer and power lines. As we know that the hydropower scheme is defined as the place where hydroelectricity is generated from flowing water, so as the source is hydro, normally it is called a **hydropower plant**. Hydropower plants are e called “small” when their generation capacities are less than 10 MW. The content of this chapter is mainly devoted to the construction, operation, and management of small hydropower plants.

### 6.2 Three phases

Massive physical constructions of hydropower schemes are involved in the three phases i.e., water diversion, generation and grid connection. For the construction of hydropower plant first, it is necessary to identify a site where the water is sufficient to reserve and no any crisis of water and suitable to build a diversion weir. The purpose of the construction of a weir is to retain the flow of water and reserve the water in the reservoir behind the dam. The weir should be situated at a sufficient height to maximize the gravitational force of water. Nevertheless, it must be facilitated with an outlet to maintain the downstream flow, which is sufficient to sustain the aquatic flora and fauna including fish. If the selected site is a breeding or spawning ground of fish or a stream stretch with obvious fish movements, there should be a mechanism for the fish to bypass the weir. Besides, spillways and sediment and debris removal facilities as associated with the diversion weirs.

In order to undertake the construction of a weir, the site should be accessible to transport materials and necessary machinery. In most cases, the developers have to construct the access roads, some are several kilometers long (e.g. access road to Mulgama mini-hydropower plant in the Walawe River basin, immediately downstream of Samanalawewa dam). Most of the access roads constructed for the weir sites are temporary and they are not maintained after commissioning of the power plants. Nevertheless, accesses roads to the powerhouses are fairly maintained primarily for owner's visits. In some cases, developers build small holiday resorts near the powerhouse. The construction of water conveying canal or headrace channel is extremely difficult depending on the geomorphology of the terrain. Convey canal in Badulu Oya MHP is more than 5 km and can be seen when traveling on the Mahiyangana-Badulla main road.

Water conveying canal and penstocks are buried underground to hide the structures, as in Wellawaya MHP constructed in a forest reserve on Kudawa Oya of the Kirindi Oya in order to facilitate the movements of wild animals including elephants according to the developers. But it is obvious they have done so to hide the massive concrete and metal structures in the forest reserve. The buried track can easily be noticed as only a wild grasses are grooving along the buried tracks. When there are deep gorges on the track of the convey canals, they construct aqueducts to bypass them as done in Monaraela mini hydropower scheme in the Wee Oya of the Kelani river basin. Drilling, blasting, and excavations using heavy machinery are involved during the construction.

### 6.2.1 Water diversion

Any hydraulic structure which supplies water to the off-taking canal is called a headwork. Headworks are two types namely storage headwork and diversion headwork. A storage headwork comprises the construction of a dam on the river that stores water during the period of excess supplies and releases it when demand overtakes available supplies whereas a diversion headwork serves to divert the required supply to the canal from the river.

**Diversion Headwork**

- A diversion headwork is a structure constructed across a river for the purpose of raising the water level in the river so that it can be diverted into the off-taking canal.
- Diversion headworks are generally constructed on perennial streams/rivers, which have adequate flow throughout the year and therefore, there is no necessity of creating a storage reservoir.
- A diversion headwork differs from a storage work or a dam. A dam is constructed on the river for the purpose of creating a large storage reservoir. The storage works are required for the storage of water on a non-perennial river or on a river with inadequate flow throughout the year.
- On the other hand, in a diversion headwork, there is very little storage, if any.
- If the storage on the upstream of a diversion headworks is significant, it is called a storage weir.
- If a diversion headwork is constructed on the downstream of a dam for the purpose of diverting water released from the upstream dam into the off-taking canals, it is called a pickup weir.

- Generally, the dam is constructed in the rocky or the mountainous reach of the river where the conditions are suitable for a dam, and a pickup weir is constructed near the commanded area in the alluvial reach of the river.

**Functions**

- It raises the water level on its upstream side.
- It regulates the supply of water into canals.
- It controls the entry of silt into canals
- It creates a small pond (not reservoir) on its upstream and provides some pondage.
- It helps in controlling the fluctuations of the river

**Under-sluice**

- Under-sluice sections are provided adjacent to the canal head regulators.
- The under-sluices should be able to pass fair weather flow for which the crest shutters on the weir proper need not be dropped.
- The crest level of the under-sluices is generally kept at the average bed level of the river

**Divide Wall**

A divide wall is constructed parallel to the direction of flow of the river to separate the weir section and the under-sluices section to avoid cross flows.

If there are under-sluices at both the sides, there are two divide walls

**Fish Ladder**

- A fish ladder is a passage provided adjacent to the divide wall on the weir side for the fish to travel from upstream to downstream and vice versa.
- Fish migrate upstream or downstream in search of food or to reach their sprawling sites.
- In a fish ladder, the head is gradually dissipated so as to provide smooth flow at sufficiently low velocity.
- Suitable baffles are provided in the fish passage to reduce the flow velocity

Figure 6.1 Diversion Weir

Figure 6.2 Fish Ladder

**Weir or Barrage**

- A weir is a raised concrete crest wall constructed across the river
- It may be provided with small shutters (gates) on its top
- In the case of weir, most of the raising of water level or ponding is done by the solid weir wall and little with by the shutters
- A barrage has a low crest wall with high gates.

- As the height of the crest above the river bed is low most of the ponding is done by gates.
  During the floods, the gates are opened so efflux is very small
- A weir maintains a constant pond level on its upstream side so that the water can flow into the canals with the full supply level

Disadvantages of a weir:

- There is a large efflux during floods which causes large submergence. 9Because the crest is at high level, there is great silting problem
- The raising and lowering of shutters on the crest is not convenient. Moreover, it requires considerable time and labor
- The weir lacks an effective control on the river during floods
- A roadway cannot be conveniently provided over the weir

The failures of weirs constructed on the permeable foundation may occur due to;

- Failure due to- subsurface flow
- Failure due to surface flow

The failure due to subsurface flow may occur by;

- Piping due to Exit Gradient
- Rupture of floor due to uplift

### 6.2.2 Generation

In hydropower plants, gravitational force or potential energy of fluid water is used to run the turbines which are coupled to an electric generator to produce electricity (conversion of mechanical energy into electric energy under a magnetic field). Water at a higher elevation flows downward through large piles or tunnels (penstocks). The falling water rotates turbines, which drive the generators, which converts turbines mechanical energy into electricity as it rotates under a magnetic field. The advantage of hydroelectric power over such other sources as fossil fuels and nuclear fission are that it is continually renewable and produces no greenhouse gasses Hydroelectric plants are specially used for producing electricity during periods when it is in great demand because they can be the turn on and off rapidly. Further, it is a cost-effective process if the resource is plenty.

**Powerhouse**

The powerhouse of a small hydropower plant located at the lowest elevation of the site adjacent to the stream is designed to protect the electromechanical equipment that converts the potential energy of water into electricity, under prevailing conditions. The number, type and power of the turbo-generators, their configuration, the scheme head and the geomorphology of the site determine the shape and size of the building. In order to mitigate the environmental impact, the powerhouse can be entirely submerged. The powerhouse can also be at the base of an existing dam as in Maduru Oya MHP, where the water arrives via an existing bottom outlet or an intake tower.

Electromechanical equipment in the power house are;

- Inlet gate or valve
- Turbine
- Speed increaser (optional)
- Generator
- Control panel
- Condenser, switchgear
- Protection systems
- DC emergency supply
- Power and current transformers

**Turbine**

The potential energy in water is converted into mechanical energy in the turbine, by one of two fundamental and basically different mechanisms:

- The water pressure can apply a force on the face of the runner blades, which decreases as it proceeds through the turbine. Turbines that operate in this way are called **reaction turbines**. The turbine casing, with the runner fully immersed in water, must be strong enough to withstand the operating pressure. Francis and Kaplan turbines belong to this category.
- The water pressure is converted into kinetic energy before entering the runner. The kinetic energy is in the form of a high-speed jet that strikes the buckets, mounted on the periphery of the runner. Turbines that operate in this way are called **impulse turbines**. The most usual impulse turbine is the Pelton.

**Speed increasers**

When the turbine and the generator operate at the same speed and can be placed so that their shafts are in line, direct coupling is the right solution; virtually no power losses are incurred and maintenance is minimal. Turbine manufacturers will recommend the type of coupling to be used, either rigid or flexible although a flexible coupling that can tolerate certain misalignment is usually recommended.

In many instances, particularly in low-head schemes, turbines run at less than 400 rpm, requiring a speed increaser to meet the 750-1000 rpm of standard alternators. In the range of powers contemplated in small hydro schemes, this solution is often more economical than the use of a custom made alternator.

**Generators**

Generators transform mechanical energy into electrical energy. Although most early hydroelectric systems were of the direct current variety to match early commercial electrical systems, nowadays only three-phase alternating current generators are used in normal practice. Depending on the characteristics of the network supplied, the producer can choose between:

**Synchronous generators**: They are equipped with a DC electric or permanent magnet excitation system (rotating or static) associated with a voltage regulator to control the output voltage before the generator is connected to the grid. They supply the reactive energy required by the power system when the generator is connected to the grid.

Synchronous generators can run isolated from the grid and produce power since excitation is not grid-dependent

**Asynchronous generators**: They are simple squirrel-cage induction motors with no possibility of voltage regulation and running at a speed directly related to system frequency. They draw their excitation current from the grid, absorbing reactive energy by their own magnetism. Adding a bank of capacitors can compensate for the absorbed reactive energy. They cannot generate when disconnected from the grid because are incapable of providing their own excitation current. However, they are used in very small stand-alone applications as a cheap solution when the required quality of the electricity supply is not very high.

**Switchgear equipment**

It is a statutory obligation on the electric utilities to maintain the safety and quality of electricity supply within defined limits. The independent producer must operate his plant in such a way that the utility is able to fulfill its obligations. Therefore, various associated electrical devices are required inside the powerhouse for the safety and protection of the equipment.

Switchgear must be installed to control the generators and to interface them with the grid or with an isolated load. It must provide protection for the generators, main transformer, and station service transformer. The generator breaker, either air, magnetic or vacuum operated, is used to connect or disconnect the generator from the power grid. Instrument transformers, both power transformers (PTs) and current transformers (CTs) are used to transform high voltages and currents down to more manageable levels for metering. The generator control equipment is used to control the generator voltage, power factor, and circuit breakers.

### 6.2.3 Logistics of grid connection

Some knowledge of regulatory issues and solutions (relating to the grid connection process) are required to facilitate hydro generator connections. Two major requirements include:

1. A review of Embedded Generation and connection principles and background
2. The requirements for and examples of British Standards

The regulations and guide developed in Sri Lanka to be used as an example.

**Embedded Generation**

The four main principles of an embedded generator connection are:

1. The prime Distribution Network Operator (DNO) requirement and responsibility is that the distribution network should not be unacceptably affected by the generator in order to maintain the quality of supply to customers.
2. The generating equipment must not be damaged by the distribution system
3. The generator can operate, and export, as needed
4. Safety should be maintained – for the generator, distribution system and customers

**NB. Embedded generation** is the term used to describe the process of **generating** electricity at a specific location and then connecting that supply into the electricity network. There are a number of different **generator** types that can be connected to the distribution network.

**Standards**

To facilitate the connection of embedded generation Standards is required to define:

1. The connection application and specification process
2. The interconnection protection requirements for the particular situation
3. The types of protection that may be used and their implementation
4. Long term maintenance and re-testing requirements
5. Quality of supply issues

**Sri Lanka Guide**

The Sri Lanka Guide is used as an example of a recent document designed to facilitate embedded generation that has been successfully implemented and used. Sri Lanka has a relatively small grid system – approximately 2,500 MW total capacity. The grid system is subject to frequency variations, voltage disturbances, and load shedding. Embedded generator capacity increasing, primarily hydro in the range 100 – 10,000 kW. The British standard G59 had been used as a basis for interconnection protection requirements.

Application and implementation process were not clear for all parties – leading to delays in some cases. Embedded generators experiencing frequent nuisance tripping. In 2000, the World Bank funded a program through the Ceylon Electricity Board (CEB) to develop standards and procedures designed to suit the Sri Lankan situation. The outcome was the Guide for Grid Interconnection of Embedded Generation, December 2000. The work was undertaken by a combination of Sri Lankan and British consultants working with the CEB and developers in Sri Lanka.

The Guide is available from the CEB in 2 parts which include the following:

- Introduction to Embedded Generation
- Context in terms of grid capacity and stability
- Procedures for Application and Exchange of Information
- Costs, studies, and metering
- Interconnection Certificate
- Testing and Acceptance Procedures
- Fault levels
- Voltage regulation
- Earthing
- Synchronization
- Interconnection protection requirements and Islanding
- Implementation of Protection
- Surge Protection
- Forms and explanatory notes

Prior to allowing a new generator connection, the CEB must study the effect of a new generator connection and any particular requirements for that connection. The studies include:

- Grid stability and security
- Fault Level
- Grid protection

- Voltage levels
- Earthing
- Load flow
- Grid operation, protection, and safety

The CEB may require more detailed information on particular sites or types of generating or protection systems. This information shall be provided by the Generating Company

- Synchronous Generators with a capacity above 500 kW
- Site Name ………………………………………
- Location...……………….……………………
- Site Reference Number.....………………………
- Generating Company Name…………………….
- Contact ………………………………………
- Point of Supply (location) ……………………….
- Maximum export capacity …………………………
- Maximum import capacity ………….…………..
- Power factor operating range ……….…………
- Generator (for each synchronous generator):
- Terminal voltage (kV) ……………………..
- Machine rating (MVA) …………………….
- Stator resistance (pu) …………… ……….tolerance % …….
- Sub-transient reactance (pu) ……………. tolerance % …….
- Transient reactance (pu) …………. ……..tolerance % …….
- Synchronous reactance (pu) ……. ……….tolerance % …….
- Sub-transient time constant (ms) ...... ……tolerance(ms) …..
- Transient time constant (ms) ……. ………tolerance (ms) ….
- Transformer (for each generator transformer);
- Rating (MVA) ……………………..
- Reactance (pu) …………………………… tolerance % …….
- Resistance (pu) …………………….. …….tolerance % …….
- Voltage Ratio …………….. Vector group
- Cable or Line between the Generator and Point of Common Coupling where this cabling
- distance exceeds 50 meters
- Voltage (V) …………..
- Reactance (Ohm) ………
- Resistance (Ohm) ………

Where a total generating capacity is less than 500 kW there is a reduced requirement for information from the Generating Company. The CEB may require more detailed information on particular sites or types of generating or protection systems.

**Studies review**

Following is a review of the typical studies that will be required by the network operator. These studies are required to enable the network operator to assess the possibility of allowing a new generator connection and the appropriate interconnection protection requirements.

**Stability:** The effect on the local stability of new embedded generation capacity should be analyzed when the capacity of the new plant exceeds 5MW, or when the total capacity on a single distribution line exceeds 5MW. For small generators, typically less than 1MW, the requirement for stability information from the Generating Company may be waived. The Generating Company shall provide a model of the AVR of the proposed generators where the capacity exceeds 5MW.

**Fault Level:** The cumulative effect of the embedded generator(s) on the design fault level for the distribution system shall be assessed by the Network Operator. A study should be undertaken when the cumulative fault level reaches 90% of the rating of the associated switchgear or the design fault level. The Network Operator may require more detailed information from the generator than that specified in the standard forms of information exchange.

**Distribution System Protection:** The effect on the distribution system protection ratings and settings shall be studied if any of the following apply:

1. the proposed generating site maximum short circuit current is greater than 20% of the distribution system short circuit current
2. the cumulative short circuit current from all embedded generators on a distribution line will exceed 30% of the distribution system short circuit current
3. there will be a net export of power from the distribution system to the 132 kV transmission system.

**Voltage Levels:** The nominal voltage at the Point of Supply (POS) shall be stated by the Network Operator in the LOI (Letter of Intent). The voltage rise at the POS must be within operational limits. A

two-stage approach shall be made to studies:

1. Exclude load connections

2. Include load connections

The stage 2 study is required when the stage 1 study indicates a potential problem. Voltage rise at remote locations is often the main limiting factor for the connection of embedded generation capacity.

**Earthing:** The Guide provides information on acceptable earthing practices and earthing requirements for a variety of situations. An Annex on earthing is included to provide background information on earthing. The Generating Company shall provide information about the proposed earthing arrangement to the CEB. It is the responsibility of the Generating Company to provide adequate earthing at a generating site. The interconnection of generating site and CEB earth systems should be considered for each site situation with reference to the Guide

# Chapter 7

## Hill Stream Fishes

### 7.1 Introduction

The number of freshwater fish species native and endemic to Sri Lanka has changed vigorously over the last two decades. According to the latest publication in 2015 by Wildlife Conservation Society, Galle (sponsored by Nations' Trust Bank) on freshwater fishes in Sri Lanka, there are about 93 freshwater fish species belonging to 22 families that need freshwater habitats to complete their life-cycle. After the publication of Pethiyagoda's text on Freshwater Fishes of Sri Lanka published in 1991, two new genera of freshwater fishes were described (e.g. *Dawkinsia* and *Pethia*) while introducing sixteen new cyprinids (viz., *Dawkinsia singhala, Dawkinsia srilankensis Devario pathirana, Laubuca insularis, Laubuca ruhuna, Laubuca varuna, Pethia banduala, Pethia reval, Puntius kamalika, Puntius kelumi, Rasbora armitagei, Rasbora naggisi, Rasbora wilpita, Rasboroides rohani, Systomus asoka, Systomus martenstyni)* and two gobids *Schismatogobius deraniyagalai* and *Stiphodon martenstyni*). This has led to a great confusion among most of the local and international scientists those who study freshwater fish and their biology. Most of the freshwater hill stream fishes endemic to Sri Lanka had been described by early workers.

Of the 93 species, about 54 are endemic but a majority of them are confined to the hill streams of the wet zone of the country. Of the freshwater fishes native to Sri Lanka 47 are cyprinids belong to the Family Cyprinidae. The dominants among the cyprinids are small carplets (Genus*: Puntius*), of which 7 out of 9 are endemic. *Puntius sarana* and *P. dorsalis* are important food fish whereas *Tor khudree* and *Labeo dussumieri* are among the other cyprinids which are important as a protein source for the rural riparian communities. Besides, several cyprinids and loaches are among the important aquarium fish in the export market. *Garra ceylonensis* (stone sucker), the most abundant endemic cyprinid in Sri Lanka was the largely exported freshwater fish from Sri Lanka during the recent past. Two catadromous eels inhabiting freshwater (*Anguilla bicolor* and *Anguilla bengalensis*) migrate to the sea for spawning.

Eels and some snakeheads are also important as food fish. Two silurids (*Ompok bimaculatus* and *Wallago attu*) inhabiting both riverine and lacustrine habitats were among the major constituents in inland fish production prior to the introduction of exotic cichlids into inland water bodies, *Glossogobius giuris*, a widely distributed gobid was also more popular as a food fish among the peasants compared with the other two species of common gobies (*Sicyopterus griseus* and *Sicyopterus halei*). The indigenous loaches are not consumed as food fish.

**Table 7.1:** Twenty-two families of fish reported from freshwaters of Sri Lanka

| Family | Common Name | Number | Endemic |
|---|---|---|---|
| Adrianichthyidae | Rice Fishes | 2 | - |
| Anabantidae | Climbing Perches | 1 | - |
| Anguillidae | Eels | 2 | - |
| Aplocheilidae | Rivulines | 3 | 2 |
| Bagridae | Bagrid Catfishes | 4 | 2 |
| Balitoridae | Hillstream Loaches | 2 | 2 |
| Belonidae | Needle Fishes | 1 | - |
| Belontiidae | Labyrinth Fishes | 3 | 2 |
| Channidae | Snakeheads | 5 | 2 |
| Cichlidae | Cichlids | 2 | - |
| Clariidae | Walking Catfishes | 1 | 1 |
| Clupeidae | Shads | 1 | - |
| Cobitidae | Loaches | 2 | 1 |
| Cyprinidae | Carps | 47 | 38 |
| Eleotridae | Sleepers | 2 | - |
| Gobiidae | Gobies | 7 | 4 |
| Hemiramphidae | Halfbeaks | 1 | - |
| Heteropneustidae | Airsac Catfishes | 1 | - |
| Mastacembelidae | Spiny Eels | 2 | - |
| Siluridae | Sheat Catfishes | 1 | - |
| Syngnathidae | Pipe Fishes | 1 | - |
| Synbranchidae | Asian Swamp Eels | 2 | - |
| | | **93** | **54** |

### 7.2 Salt Water Colonizers

Of the four brackish water species transplanted in inland waters (viz., *Etroplus maculatus*, *Etroplus suratensis*, *Hyporhamphus limbatus* and *Ehirava fluviatilis*), *E. suratensis*, *H. limbatus* are important in commercial fishery of certain reservoirs in the dry zone *Ehirava fluviatilis*, the Malabar Sprat, found in the rivers and coastal lagoons and estuaries of southern India and Sri Lanka also play an important role with respect to subsistence fishery in certain reservoirs namely Rajangana tank, Parakrama Samudra, Kaudulla reservoir etc., in the dry zone (personal observations). Apparently these brackish water species have colonized inland water bodies of the island long before the constructions of high dams across the rivers. In fact, there were about twelve freshwater species consumed by peasants before the establishment of self-breeding exotic cichlids and stocking of fingerlings of Chinese and Indian carps.

### 7.3 Exotic Fishes

In addition, 23 species of exotic species belonging to nine families have been introduced to Sri Lankan water since 1882. Of these introduced exotic species, with a view to increasing the commercial fish production, only three species of African cichlids (*Oreochromis mossambicus*, *Oreochromis niloticus* and *Tilapia rendalli*) and four gouramies (*Trichogaster pectoralis*, *Trichogaster trichopterus, Helostoma temminckii* and *Osphronemus goramy*) were established self-breeding populations. Although gouramies breed in Sri Lanka's freshwaters, their populations are not very high. The rainbow trout (*Oncorhynchus mykiss*) introduced to high mountain streams; above 2000 m for sport fishing, also breeds streams in Horton

Plains. Two species of larvivorous ornamental fish namely guppy (*Poecilia reticulata*) and mosquito fish (*Gambusia affinis*) introduced for mosquito control have successfully colonized inland waters. It has been noted that the tank cleaner (*Pterygoplichthys multiradiatus*) and clown knife fish (*Chitala ornata*) escaped from aquariums are encroaching freshwater habitats whereas Green Sword Tail (*Xiphophorus helleri*) and Platy (*Poecilia reticulata*) are also common in some hill streams. The common carp (*Cyprinus carpio*), Chinese carps (*Aristichthys nobilis, Ctenopharyngodon idella, Hypophthalmichthys molitrix*) and Indian carps (*Catla catla*, *Cirrhinus mrigala*, *Labeo rohita*) thrive well in Sri Lankan freshwaters but no evidence is available for their breeding in the wild. Many speculate that *Cyprinus carpio* and *Catla catla* breed in Udawalawe reservoir and Senanayake Samudra.

### 7.4 Endemic Fishes

The latest compilation of fishes of Sri Lanka in 2015 included most of the newly described species after Pethiyagoda (1991) irrespective of previously defined three ichthyological provinces namely Southwestern Ichthyological Province, Mahaweli Ichthyological Province and Dry Zone Ichthyological Province. Nevertheless, the highest number of endemic freshwater fish species is found in the wet zone of the island, especially in mountain streams. There are four endemic species in the Dry zone, which form only 7.4 % of the total number of endemic freshwater fish species in Sri Lanka. Apparently, the concept of Ichthyological Provinces in Sri Lanka is questionable when it is viewed on the basis of the comprehensive account by different authors since 1990s.

### 7.5 Hill Stream Endemics

Most of these endemic freshwater fishes inhabit hill country forested streams in the wet zone. There are complex interactions between and among fish species in a fish community and its environment for food, space and/or spawning. As evident from the biology of cyprinids in hill streams in Sri Lanka, most of the endemic freshwater fish species tend to show well-defined niche segregation and ecological adaptations. But, several anthropogenic activities such as deforestation, gem mining and uncontrolled use of agrochemicals, an ornamental fish trade that pose significant threats to the survival of many endemic freshwater fish species in Sri Lanka. Further, escapees from aquarium industry namely clown knife fish *(Chitala ornata)* and tank cleaner (*Pterygoplichthys multiradiatus*) may pose threats to the diversity of freshwater fishes in Sri Lanka, which is an indirect adverse effect on ornamental fish trade. Ironically, hitherto no one has addressed the adverse impact of the establishment of mini-hydropower plants in hill country streams on fish fauna endemic to Sri Lanka despite the very recent publications appeared in the although the mini-hydropower industry showed a mushroom development since the early 1990s. As much endemic fish are confined to hill streams as their native type habitats, the adverse impacts of the construction and operation of mini-hydropower plants on stream-dwelling fish are inevitable.

The number of fish species reported from mountain streams of Sri Lanka is about 54 belonging to eleven families of which 33 are cyprinids with 28 endemic species (Table 7.2). Of the five non-endemic species, except *Tor khudree the other four namely Devario malabaricus*, *Labeo dussumieri*, *Puntius bimaculatus*, and *Puntius dorsalis* have successfully colonized downstream reservoirs but spawning grounds are never reported from lacustrine habitats.

Gobiids (Family Gobiidae) are the next important group of fish species inhabiting mountain streams in Sri Lanka although they are sedentary species, habitats are critical to sustaining their populations. Of the seven species of gobies reported from Sri Lanka's mountain streams, only two are endemics (viz., *Sicyopus jonklaasi* and *Stiphodon martenstyni*) and found only in the riverine habitats. Nevertheless, except *Glossogobius giuris* and *Awaous melanocephalus* other three indigenous species of gobies (viz., *Schismatogobius deraniyagalai, Sicyopterus griseus* and *Sicyopterus halei*) are also restricted to mountain stream habitats indicating the importance of riverine habitats to sustain their populations. Of the seven gobiids found in Sri Lanka, two indigenous species of subfamily Sicydiinae (*Sicyopterus griseus* and *Sicyopterus halei*) are reported as critically endangered. Whereas two endemics namely *Sicyopus jonklaasi* and. *Stiphodon martenstyni* as endangered and critically endangered respectively according to Red data book. Mountain loaches in Sri Lanka represent two families (i.e., Cobitidae and Nemacheilidae) having three endemic species confined exclusively to headwater streams. Of the three mountain loaches endemic to Sri Lanka *Lepidocephalichthys jonklaasi* is ranked as critically endangered species while *Acanthocobitis urophthalmus* and *Schistura notostigma* as endangered and near threatened species respectively.

Two eels (Family: Anguillidae) reported from Sri Lanka (*Anguilla bicolor* and *Anguilla bengalensis*) are essentially catadromous migratory species whose elvers swim upstream and reported even above 700 m msl then migrate back to the sea for spawning. Their populations have declined dramatically following the construction of high dams across major rivers such as Mahaweli, Kelani, Walawe etc. Two species of endemic kili fishes, not restricted to mountain streams, namely *Aplocheilus dayi* and *Aplocheilus werneri* have also been reported from upland streams, former being endangered whereas the latter is identified as a non-rare species. Dwarf catfish (*Mystus ankutta*) belongs to the family Bagridae, which is also endemic to Sri Lanka has been reported from upland streams and categorized as endangered. Two endemic species, *Channa orientalis* (Family: Channidae) and *Clarias brachysoma* (Family: Clariidae) whose habitats are not restricted to mountain streams are categorized as vulnerable and near threatened species respectively. Stinging catfish (*Heteropneustes fossilis*) in the family Heteropneustidae is an indigenous species recorded also from mountain streams but common in occurrence.

**Table 7.2:** Hillstream fishes in Sri Lanka

| Family | Common name | Number | *Endemics* | Only in hill streams |
|---|---|---|---|---|
| Anguillidae | Eels | 02 | 00 | 00 |
| Aplocheilidae | Kili fish | 02 | 02 | 00 |
| Bagridae | Dwarf catfish | 01 | 01 | 00 |
| Channidae | Snakehead | 01 | 01 | 00 |
| Clariidae | Walking catfish | 01 | 01 | 00 |
| Cobitidae | Loaches | 02 | 01 | 01 |
| Cyprinidae | Carps/Barbs | 33 | 29 | 27 |
| Gobiidae | Gobies | 07 | 02 | 05 |
| Heteropneustidae | Stinging catfish | 01 | 00 | 00 |
| Nemacheilidae | Mountain loaches | 02 | 02 | 02 |
| Osphronemidae | Comb-tail/Paradise Fish | 02 | 02 | 02 |
| | | 54 | 41 | 39 |

### 7.6 Biogeographic Distribution

With a view to simply, the distribution of endemic fishes in the upland, hill stream watersheds above 200 m amsl, are arbitrarily grouped into seven categories (i.e., 1. Knuckles 2. Central Mahaweli Hills 3. Kelani 4. Kalu 5. Gin 6. Nilwala and 7. Walawe) based on their geomorphologic and climatic features. These biogeographic regions are distinctly separated by landscape geomorphology and experience different climatic and weather patterns resulting in rather dissimilar vegetation patterns.

Of the 54 indigenous species inhabiting hill streams and rivers in Sri Lanka 41 species are endemic to the island and 34 of them are found only in the hill streams (Table 7.3). Twelve endemic species inhabiting hill streams are critically endangered (CR) while fourteen are endangered (EN) and the many of the other endemics are either near threatened (NT) or vulnerable (VU) according to IUCN Red Data Book (Table 7.3). Nevertheless, seven species described as endemic during the recent past have not been subjected to IUCN evaluation yet. Of the 41 endemic fish species reported from hill streams six species (*Schistura notostigma*, *Belontia signata*, *Channa ara*, *Clarias brachysoma*, *Dawkinsia sinhala* and *Garra ceylonensis*) belonging to five families inhabit all seven types of biogeographic regions irrespective of the landscape, hydrology, elevation and relief of respective biogeographic region (Table 7.3). Their widespread distribution indicates that they are generalists evolved in the central highlands above 300 m elevation or in other words in the second peneplane.

Freshwater fishes of Sri Lanka are hardly found above 1000 m amsl. Only *G. ceylonensis* and *S. notostigmata* have reported above 1000 m amsl in the Walawe River basin. *Poecilia reticulata* (an exotic species) and *Lepidocephalichthys thernnalis*, native common spiny loach, have also reported above 1000 m amsl. The rainbow trout (*Oncorhynchus mykiss*) introduced to high mountain streams; above 2000 m for sport fishing have been established their breeding population. The Green Sword Tail (*Xiphophorus hellerii*) and Platy (*Poecilia reticulata*), perhaps escapees from aquariums are also common in hill streams in the Central Mahaweli basin.

In addition to six common endemic fish species, six endemic cyprinids (viz., *Dawkinsia srilankensis*, *Garra cf. phillipsi*, *Labeo lankae*, *Laubuca insularis*, *Systomus martenstyn* and *Systomus Sp. Richmondi*) have been reported only from the Knuckles biogeographic region. There are only three endemic species (viz., *Devario Sp Altus*, *Labeo fisheri,* and *Pethia bandula*) exclusively restricted to the Central Mahaweli Hills whereas *Aplocheilus dayi*, *Pethia cumingii* and *Pethia reval* and *Systomus asoka* were reported only from the headwater streams of the Kelani River basin. *Malpulutta kretseri* and *Rasboroides nigromarginatus* have been reported only from the Kalu River. Besides, two cyprinids with no species authorships (*Devario* Sp *Natalie* and *Devario* Sp *Processus*), Sri Lanka Armitagi Rasbora (*Rasbora armitagei*) and Sri Lanka Naggsi Rasbora (*Rasbora naggsi*) and *Sicyopterus halei* (Red-tailed Goby) have been reported from the upper parts of the Gin River. In addition, *Aplocheilus werneri*, *Lepidocephalichthys jonklaasi* and *Devario pathirana* were reported from the upper reaches of the Nilawala River. According to recent literature, Sri Lanka Varuna Laubuca (*Laubuca varuna*) has reported from the Sooriya Kanda area as newly found endemic fish restricted to the Walawe River basin. Of the two endemic gobies (viz., *Sicyopus jonklaasi* and *Sicyopterus halei*) *Sicyopterus halei* is found only in headwaters of Gin Ganga whereas the other species have been reported from Kelani, Kau and Nilwala rivers.

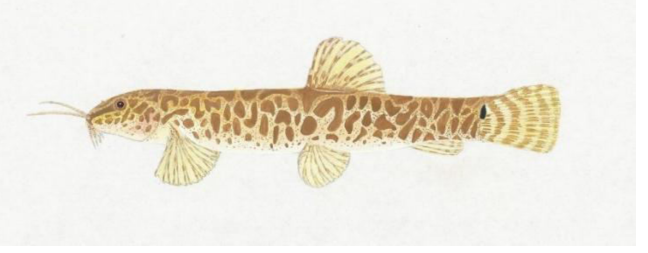
**Table 7.3:** Endemic fishes inhabiting hill streams in Sri Lanka; KN, Knuckles; MW Central Mahaweli Hills; KL, Kelani; KU, Kalu; GN, Gin; NL, Nilwala, and WL, Walawe; CR, Critically Endangered; EN, Endangered; NT, Near Threatened; VU, Vulnerable; LC, Least Concerned; DD, Data Deficient; NE, Not Evaluated.

| Endemic Fish Species | KN | MW | KL | KU | GN | NL | WL | IUCN Status |
|---|---|---|---|---|---|---|---|---|
| **01. Family Aplocheilidae** | | | | | | | | |
| ***Aplocheilus dayi*** | | | √ | | | | | EN |
| ***Aplocheilus werneri*** | | | | | | √ | | EN |
| **02. Family Bagridae** | | | | | | | | |
| ***Mystus ankutta*** | | | √ | √ | √ | √ | | EN |
| **03.Family: Balitoridae** | | | | | | | | |
| ***Acanthocobitis urophthalmus*** | | | √ | √ | | | | EN |
| ***Schistura notostigma*** | √ | √ | √ | √ | √ | √ | √ | NT |
| **04. Family: Belontiidae** | | | | | | | | |
| ***Belontia signata*** | √ | √ | √ | √ | √ | √ | √ | NT |
| ***Malpulutta kretseri*** | | | | √ | | | | CR |
| **05. Family Channidae** | | | | | | | | |
| ***Channa ara*** | √ | √ | √ | √ | √ | √ | √ | EN |
| ***Channa orientalis*** | | | | √ | | √ | | VU |
| **06. Family Clariidae** | | | | | | | | |
| ***Clarias brachysoma*** | √ | √ | √ | √ | √ | √ | √ | NT |
| **07. Family Cobitidae** | | | | | | | | |
| ***Lepidocephalichthys jonklaasi*** | | | | | | √ | | CR |
| **08. Family: Cyprinidae** | | | | | | | | |
| ***Dawkinsia sinhala*** | √ | √ | √ | √ | √ | √ | √ | LC |
| ***Dawkinsia srilankensis*** | √ | | | | | | | EN |
| ***Devario pathirana*** | | | | | | √ | | CR |
| ***Devario Sp* Altus**** | | √ | | | | | | NE |
| ***Devario Sp* Natalei**** | | | | | | | | NE |
| ***Devario Sp* Processus**** | | | | | √ | | | NE |
| ***Garra ceylonensis*** | √ | √ | √ | √ | √ | √ | √ | VU |
| ***Garra cf.phillipsi*** | √ | | | | | | | DD |
| ***Labeo fisheri*** | | √ | | | | | | VU |
| ***Labeo lankae*** | √ | | | | | | | CR |
| ***Laubuca insularis*** | √ | | | | | | | CR |
| ***Laubuca varuna*** | | | | | | | √ | CR |
| ***Pethiya bandula*** | | √ | | | | | | CR |
| ***Pethia cumingii*** | | | √ | | | | | EN |
| ***Pethia nigrofasciata*** | | | √ | √ | | | | EN |
| ***Pethia reval*** | | | √ | | | | | EN |
| ***Puntius titteya*** | | | √ | √ | √ | √ | √ | EN |
| ***Rasbora armitagei**** | | | | | √ | | | CR |
| ***Rasbora naggsi***** | | | | | √ | | | NE |
| ***Rasbora wilpita*** | | | | | √ | √ | | EN |
| ***Rasboroides nigromarginatus*** | | | | √ | | | | CR |
| ***Rasboroides pallidus***** | | | | √ | √ | √ | | NE |
| ***Rasboroides rohani***** | | | | | √ | | | NE |
| ***Rasboroides vaterifloris*** | | | √ | √ | √ | | | EN |
| ***Systomus asoka*** | | | √ | | | | | CR |
| ***Systomus martenstyni*** | √ | | | | | | | CR |
| ***Systomus pleurotaenia*** | | | √ | √ | √ | √ | | EN |
| **Systomus Sp. Richmondi**** | √ | | | | | | | NE |
| **09. Family Gobiidae** | | | | | | | | |
| ***Sicyopterus halei*** | | | | | √ | | | CR |
| ***Sicyopus jonklaasi*** | | | √ | √ | √ | | | EN |

NB: ** not evaluated

### 7.7 Endemic Fishes Restricted to Hill Streams

**Pulli Ahirawa** (Jonklaasi's Loach or Spotted Loach)
*Lepidocephalichthys jonklaasi* (Deraniyagala, 1956)
Family: Cobitidae
IUCN Status: CR



First reported from Nilwala River basin, near Akuressa, but also inhabits slow-flowing shady small headwater streams in Gin and Kalu River basins, biology is unknown, reported as critically endangered rare species

**Rath Gadaya** (Red Finned Labeo)
*Labeo lankae* (Deraniyagala, 1952)
Family: Cyprinidae
IUCN Status: CR

*Labeo lankae*, a medium size carp with oblong body have a small pair of barbels. Its dorsally olive green body has silver color in the belly and there is a dark elongated blotch on its caudal peduncle. NARA found a refuge population of *L. lankae* in Knuckles mountain range (Dumbara valley) in 2008.

**Asoka Pethiya** (Asoka Barb)
*Systomus asoka* (Kottelat & Pethiyagoda, 1989)
**Family:** Cyprinidae
IUCN Status: CR

The type habitats of Asoka Barb (fast flowing streams with sandy and gravel beds) are reported from Sithawaka Ganga near Kithulgal in the Kelani River basin. Streamline body of this cyprinid indicates its ability of fast swimming.

**Dumbara Pethiya** (Martenstyn's Barb)
*Systomus martenstyni* (Kottelat & Pethiyagoda, 1991)
**Family:** Cyprinidae
IUCN Status: CR

This small cyprinid that shows more or less similar features of Asoka Barb was described in 1991 and restricted only to Knuckles biogeographic region. Although described several years back, habitat, life history and biology of the species unknown.

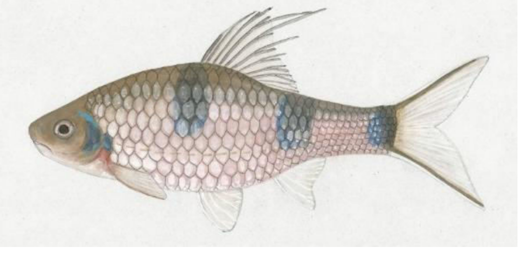
**Hal Mal Dandiya** (Blacklined Fire Rasbora)
*Rasboroides nigromarginatus* (Meinken, 1957)
**Family:** Cyprinidae
IUCN Status: CR

*Rasboroides nigromarginatus* was first described by a German scientist H. Meinken in 1957 as a new species base on a single specimen collected from the 'Ceylon' without knowing exact locality. Later, this endemic cyprinid was reported from Kalu Ganga basin at several instances. It is an important freshwater fish in the aquarium trade and the species was misidentifies as *Rasboroides vaterfloris*.

**Bandula pethiya** (Sri Lanka Bandula Barb)
*Pethia(Puntius) bandula* (Kottelat & Pethiyagoda, 1991)
**Family:** Cyprinidae
IUCN Status: CR

Bandula Barb (Pethia bandula) is one of the rarest and critically endangered freshwater fish in Sri Lanka described recently although it was in the aquarium trade for a long time. It can only be found in a stretch of a small stream in Galapitamada area in Kegalle district.

**Dankuda Pethiya** (Sri Lanka Blotched Filamented Barb)
*Dawkinsia (Puntius) srilankensis* (Senanayake, 1985)
**Family:** Cyprinidae
IUCN Status: EN



This species was collected from Knuckles and described in 1985. Adults of *Puntius srilankensis* are distinguished from *P. filamentosus* and *P. singhala* by possessing prominent black markings on body anterior to the caudal fin. Captive breeding of this species under laboratory conditions is successful according to aquarium traders.

**Pathirana Salaya** (Pathirana Salaya)
*Devario pathirana* (Kottelat & Pethiyagoda, 1990)
Family: Cyprinidae
IUCN Status: CR

Reported only from Nilwala River basin near Opatha village in large numbers. No studies have been conducted so far on its biology and geographic distribution. Since this species has a big demand in ornamental fish trade, illicit collection from wild is not uncommon.

**Varuna Thatu Dandia** (Waruna Blue Laubuca)
*Laubuca varuna* (Pethiyagoda, Kottelat, Silva, Maduwage &Meegaskumbura, 2008)
Family: Cyprinidae
IUCN Status: CR

This species is restricted to the headwater streams of Kelani and Kalu Rivers draining the southwest wet zone. Considering the genus *Chela* is a synonym of genus *Laubuca* the latter was further divided into *L. insularis, L. ruhuna*, and *L . varuna* in 2008.

**Dumbara Thatu Dandia** (Knuckles Blue Laubuca)
*Laubuca insularis* (Pethiyagoda, Kottelat, Silva, Maduwage &Meegaskumbura, 2008)
(Family: Cyprinidae)
IUCN Status: CR

Found in headwater streams of Kalu Ganga, a tributary of Amban Ganga draining the northeast foothills of the Knuckles Range. Co-exists with other cyprinids such as *Puntius srilankensis*, *Puntius martenstyn,* and *Labeo fisheri* according to available information.

**Belihuloya Dandiya** (Sri Lanka Naggsi Rasbora)
*Rasbora naggsi* (Silva, Maduwage & Pethiyagoda 2010)
Family: Cyprinidae
IUCN Status: NE

*Rasbora naggsi* is a minnow endemic to Sri Lanka. The fish was discovered from a stream running across the Sabaragamuwa Campus in Belihul-Oya, Sri Lanka. This species is named after the famous malacologist Fred Naggs

**Rakwana Dandiya** (Sri Lanka Armitagi Rasbora)
*Rasbora armitagei* (Silva, Maduwage & Pethiyagoda, 2010)
Family: Cyprinidae
IUCN Status: CR

*Rasbora armitagei* is a minnow endemic to Sri Lanka. The fish was discovered from a small tributary of Kalu Ganga at Rakwana, South-Western Wet zone, Sri Lanka and described in 2010. This species is named after naturalist David Armitage.

**Malpulutta** (Ornate Paddle Fish)
*Malpulutta kretseri* (Deraniyagala 1937)
Family: Cyprinidae
IUCN Status: CR

The ornate paradisefish or spotted gourami is a species of gourami endemic to Sri Lanka. It inhabits shallow, slow-flowing streams in forested areas shaded with plentiful vegetation near the edges and a substrate covered by leaf litter.

**Rath Penda Weligouwa** (Red-tailed Goby)
*Sicyopterus halei* (Day, 1888)
Family: Gobiidae
IUCN Status: CR

Reported only from Nilwala Ganga. The adults inhabit fast-flowing sections of clear rainforest streams over rocky bottoms. Nevertheless, the endemism of this species to Sri Lanka is questionable. Some have reported this species as a migratory, hatching and larval stage occur at sea, postlarval stage to adult in freshwater.

### 7.8 Movements of Riverine Fish

In general, many riverine fishes are potamodromous, move downstream and upstream but the range of their movement circuits in the river depends on their size. The trek of the large fishes is longer compared to the small species. Nonetheless, they require lotic habitats to complete their life cycle. Although some species have colonized manmade reservoirs or lentic habitats in Sri Lanka no evidence is available for breeding and spawning within reservoirs. Spawning movement of indigenous riverine species inhabiting lowland reservoirs in the dry zone has been observed and reported. Nine riverine species have been recorded attempting to jump over a small anicut at Diyabeduma, where Elahera-Minneriya Yoda Ela is bifurcated to convey water to Minneriya and Giritale reservoirs. All those species that were attempting to jump over the anicut and the Stone Sucker (*Garra ceylonensis*) who crept over the concrete slab during the late night were found sexually matured (Table 7.3). Similar fish jump attempts were also observed at Angamedila anicut on Amban Ganga and Neela

Bemma on Kala Oya. According to the peasants in the vicinity of irrigation anicuts and the anicut operators of the Irrigation Department, fish jumps are common at diversion weirs especially with the onset of monsoon rains.

Spawning grounds of Mahseer (*Tor khudree*), a relatively large cyprinid are confined to fast flowing upstream. Even some exotic cyprinids introduced to Sri Lanka (viz., *Cyprinus carpio* and *Catla catla*) move upstream rivers when they are sexually matured. Active movements of marsh-dwelling Striped Snakehead (*Channa striata*) and riverine Common Labeo (*Labeo dussumeiri)* can observe during floods in the lowland dry zone and people catch them in larger numbers. The Stone Sucker, the most common and widely distributed endemic cyprinid in Sri Lanka is morphologically adapted to thrive in rapids and also capable of creeping on rock surfaces as it was found creeping along the concrete slopes. Glass eels or elvers of Level-finned Eel (*Anguilla bengalensis*) was also found creeping along the slopes of the Victoria dam with the onset of northeast monsoonal rains.

It has been observed that Green Labeo (*Labeo fisheri*) attempting to jump over the Minipe anicut whereas *Anguilla bengalensis* were swimming against the flow at the same place. None of those attempts were successful at the Minipe Anicut, which is 270 m long and 5 m high as reported. Avoidance of impoundment is possible for downstream migrants under floods and with reservoir spills, especially during the peak northeast monsoon but it is very unlikely to cross over high dams or barrages for upstream migrants. In the Mahaweli River, fish can move upstream 189 km up to Minipe anicut without any obstacle. The alternative route via Amban Ganga will end at Angamedila after 15.4 km journey from Manampitiya entrance since no facilities are available at Angamedila to bypass the anicut, which has been repaired and restored by local engineers. In the Walawe River, fish will be terminated at the British built Liyangasthota anicut located 16.6 km upstream of Amabalanthota, whereas the river discharges into the sea. In the case of Kala Oya, the fish can swim upstream up to Neela Bemma (38.8 km) if they are successful at Eluwankulama causeway, which is located 8.8 km upstream of Dutch Bay of the Puttalam Lagoon. Along the Yan Oya still fish can move 112 km up to Hurulu Wewa dam. This facility will be limited only for about 40 km in the near future until the proposed Yan Oya reservoir dam erects across the river.

This evidence suggests that a majority of freshwater fishes in Sri Lanka either endemic or native, exotic or indigenous are evolutionarily adapted to migrate in riverine circuits during some period of their life-history. Although some native species have successfully colonized manmade reservoirs, they are not physiologically adapted to complete their life cycle within lentic habitats and require to move into streams or irrigation canals when they are sexually matured but irrigation canal with sudden changes in water availability are not suitable for fish breeding.

**Table 7.4:** Riverine fish species showing migratory or moving behavior in Sri Lankan waters (modified from Silva and Davies 1986) A1 (Diyabeduma anicut), A2 (Minipe anicut), E (Endemic)

| Species | Family | A1 | A2 | Remarks |
|---|---|---|---|---|
| *Garra ceylonensis*[E] | Cyprinidae | √ | √ | Creeping over concrete slab |
| *Labeo dussumieri* | | - | √ | Active mover in floodwater |
| *Labeo fisheri*[E] | | √ | √ | |
| *Puntius chola* | | √ | √ | |
| *Puntius dorsalis* | | √ | √ | |
| *Puntius filamentosus* | | √ | √ | |
| *Puntius sarana* | | √ | √ | |
| *Ompok bimaculatus* | Siluridae | √ | √ | |
| *Wallago attu* | | √ | - | |
| *Anguilla bicolor* | Anguillidae | | | Elvers creeping Victoria dam |
| *Anguilla nebulosa* | | | √ | Creeper does not jump |
| *Channa striata* | Channidae | - | - | Active mover in floodwater |
| *Catla* | Cyprinidae (exotic) | - | - | Moves upstream of Walawe Ganga |
| *Cyprinus carpio* | | - | - | Moves upstream of Hulu Ganga |

### 7.7 Threats to Hill Stream Fishes

Freshwater fishes in Asian rivers and associated wetlands are susceptible to the following anthropogenic threats;

- Deforestation
- Infrastructure development in the drainage basin
- Alteration of riverine and riparian habitats
- Streamflow regulation (diversions, dams, extraction etc.)
- Diffuse and point-source pollution
- Over-harvesting of fishes

The situation in Sri Lanka is also similar with several exceptions as reported in many studies.

Exceptions in Sri Lanka;

- Urbanization
- Gem mining
- Overuse of pesticides
- Ornamental fish trade
- Use of destructive fishing methods (phytotoxins and dynamiting)
- Introduction of exotic fish

Most of these factors are interrelated with each other but habitat degradation and impairment of water quality are among the main decisive factors attributable to population decline. With respect to hill stream fish fauna, none has highlighted the impact of tea plantation and vegetable cultivation on native fish fauna. Nevertheless, fish fauna in agricultural watersheds is eco-physiologically substandard compared with their counterparts inhabiting forested watersheds. Although negative effects of large dams on riverine fish fauna have discussed in detailed in many instances, the effects of small hydro on hill stream fishes have never been addressed correctly in developing countries, assuming the effects are insignificant.

Many freshwater fish species of Sri Lanka including endemic species namely *Danio* (=*Devario*) *pathirana*, *Garra phillipsi* and *Rasbora* (=*Rasboroides*) *vaterifloris* prefer un-silted stream habitats with clear water. Siltation resulting from erosion and gem mining is considered as a man-induced threat for the survival of *Belontia signata*, *Puntius nigrofasciatus*, *Sicyopterus halei*. *P. srilankensis*, *Labeo fisheri*, *R. vaterifloris*, and *Malpulutta kretseri*. Fishes and other organisms inhabiting stream habitats are adapted to the flood pulses in the rivers of tropical Asia. Nevertheless, it has been reported that due to the construction five major dams across the mainstream of the Mahaweli River and subsequent alteration of hydrological network, *Labeo fisheri*, and *Labeo dussumieri*, were severely affected and the populations have been markedly declined.

## Chapter 8

# Environmental, Ecological, and Social Impacts

### 8.1 Introduction

Small Hydropower is considered as a clean renewable source of energy having high conversion efficiency with spectacular flexibility and operational and economic superiority over other modes of electricity generation. Although large and medium hydroelectric projects have been identified for their certain social complexities and harmful ecological and environmental consequences, Sri Lanka has tapped most of the potential sites for large hydropower generation. Consequently, the country paid more attention to the generation of electricity by tapping the potential energy of small mountain streams, which can generate less than 10 MW. This was one of the top priorities of the Ministry of Power and Energy of the country, which highlighted its environmentally friendly nature of these schemes primarily attributing to the slogan of zero emission of greenhouse gasses. The gravity of social and environmental impacts of hydropower generation, either small or large depends primarily on the locality of the project, in other words, it is a site-specific consequence.

Indeed, major hydropower projects invariably cause larger negative social and environmental impacts inundating and subsequent displacement of human settlements, loss of large areas of productive land, creation of ecological fragmentations, misbalancing hydrological network including surface and groundwater equilibrium of the area. Such impacts due to small hydro projects are normally assumed to be insignificant and SHP projects are therefore considered as environmentally friendly options when compared to larger hydropower schemes. Nevertheless, SHP schemes also influence the microclimate and hydrological network, as well as spatial distribution of macroinvertebrate and fish population of stream habitats of the project site and livelihood of riparian communities living in along the stream banks.

Environmental impacts of SHP schemes are highly site-specific and technology-bound. It is very unlikely to have similar impacts at both temperate and tropical sites. A high mountain diversion scheme situated in a highly sensitive area is more likely to generate an impact than an integral low-head scheme in a valley under any climatic condition. Similarly, low-head schemes established on irrigational channels and outflows of existing reservoirs have no significant impacts on aquatic life. Two examples are small hydropower schemes established on Maduru Oya Left Bank (LB) canal at Drop 9 and Drop 10. In general, mountain diversion projects in Sri Lanka that use the large change in elevation of a river, the water is diverted from the main river and re-enters again at the tailwater below the power plant. In this case, entire areas of the main river may be bypassed by a large volume of water leaving a long stretch of exposed stream when the plant is in operation, as most small hydropower projects in Sri Lanka do note release environmental flow.

### 8.2 Pioneer Studies

Environmental impacts of construction and operation of mini-hydropower projects in Sri Lanka was first discussed by two students of the Royal College, Colombo at the International Conference on Small Hydropower - Hydro Sri Lanka, held in October 2007 in Kandy. They highlighted the problems at different stages of the approval process of EIA and also suggested solutions for the identified problems at different steps analyzing three EIA reports on small hydropower projects namely Bambarabotuwa, Atabage and Magal Ganga mini-hydropower schemes. At the same international conference, three academics from the University of Moratuwa highlighted the social and environmental problems of mini-hydropower projects established on Ma Oya basin in Sri Lanka. The paper described the application of a framework, which develops and educates trade-offs between different resource users in a river basin, to identify and quantify the social and environmental impacts of electricity generation through mini-hydropower schemes. Nevertheless, considering major hydropower development in Sri Lanka under Accelerated Mahaweli River Program, it has been shown that turbines, dams, and tunnels have negative impacts on riverine fish populations. In 1986, it was reported that many riverine fish species colonized downstream for feeding migrate upstream for spawning when they are sexually matured.

**8.3 Sudu Ganga Cascade**

In 2012, a request was made to Water Resources Science and Technology (WRST) by Mahaweli Authority of Sri Lanka (MASL) to examine the fish fauna of Mahaweli areas (i.e., Mahaweli, Kala Oya, Walawe, Maduru Oya and Yan Oya basins) with special emphasis on negative effects of mini-hydropower plants. The WRST examined the riverine fish fauna and the mini-hydropower schemes of designated Mahaweli areas under the sponsorship of the International Water Management Institute (IWMI) and submitted a comprehensive report on the findings to both the project proponent and the sponsor.

The detailed observations made during this study on a cascade of mini-hydropower plants (in operation, under construction and proposed) on Sudu Ganga, a major tributary of the Amban Ganga concluded the potential negatives impacts of construction and operation of small hydropower plants on indigenous and endemic riverine fishes in Sri Lanka. WRST also showed the weaknesses and incompatibility of EIA reports submitted to the Project Approving Agencies, for example to the Central Environmental Authority. On Sudu Ganga, three small hydropower plants were in operation (viz., Branford, Ross Estate, and Rajjammana) whereas Owala MHP project was under construction by the end of 2014. In addition, licenses have granted for three more MHP plants (viz., Kiula, Diggala, and Ankenda) to construct and operate (Figure 3.1). Accordingly seven small hydropower plants will be operated soon on Sudu Ganga within 21 km long stream stretch from Kiula village (342 m amsl) to Rajjammana village (276 m amsl). Details of the seven small hydropower plants are given in Table 8.1.

Completion of a cascade of seven mini-hydropower plants may impose severe environmental threats to both riverine and riparian habitats as evidence are already there. Fish fauna reported from this stream stretch during feasibility studies was unbelievably low and incompatible compared to available information. A little consideration has been paid to environmental flow in most cases and fish ladders designed for some dams seems technically unsound as they may not synchronize with the water release from the weir and the behavior of migratory fish. Apparently, there is an underestimate of native or endemic fish diversity and the potential impacts of such a cascade of mini-hydropower plants on riverine and riparian ecosystems of Sudu Ganga.

**Table 8.1:** Geographic positions, topographic features, generation capacities and status of seven mini hydropower projects in operation and to be constructed on Sudu Ganga on Mahaweli River basin

| Project | Elevation (m amsl) | Capacity (MW) | Distance (km) | Status |
|---|---|---|---|---|
| Kiula | 342 | 2.8 | 0.00 | Approved |
| Branford | 336 | 2.5 | 0.95 | Commissioned |
| Owala | 309 | 2.8 | 2.66 | In progress |
| Ross Estate | 305 | 4.5 | 11.93 | Commissioned |
| Diggala | 298 | 4.4 | 13.94 | approved |
| Ankenda | 297 | 6.5 | 18.34 | approved |
| Rajjammana | 276 | 6.0 | 23.34 | Commissioned |

### 8.4 Wee Oya Cascade

The most recent study conducted by WRST in collaboration with the Uva Wellassa University on the impact of cascade mini-hydropower plants on some eco-hydrological and environmental aspects of Wee Oya in the Kelani River basin demonstrated the impacts of the construction and operation of four small hydropower plants on native fish fauna and riparian community There are four mini-hydropower plants (viz., Wee Oya, Punugala, Amanawela and Monara Ela) on the Wee Oya between Yatiyantota and See Forth along 24 km river stretch. In addition, the fifth small hydropower plant registered as Berannawa mini-hydropower plant is under construction on Kandal Oya, a left bank tributary of the Wee Oya. Geographical coordinates and some other basic features of five mini-hydropower plants on Wee Oya are given in Table 8.2. This study has clearly demonstrated the environmental impacts resulting from different structures and operational activities of the power plant and the magnitude that could occur in similar stream ecosystems in the country are shown in (Table 8.3). Most of these negative effects will cause significant impacts on aquatic flora and fauna including stream fishes, native and endemic to the country. Some are directly affected on the livelihood of riparian communities who have an inherent association with some services provided by stream ecosystems for their day to day life for generations. In addition, riparian communities are susceptible to health risks resulting from alteration in stream bed between the weir and the powerhouse.

**Table 8.2:** Geographic positions, topographic features, generation capacities and status of five mini-hydropower projects in operation and under construction on Wee Oya in Kelani River basin (*Under construction; YOC, Year of Commissioned; ASS, Affected Stream Stretch

| MHPP | YOC | Elevation (m amsl) | Capacity (MW) | Distance (km) | ASS (km) |
|---|---|---|---|---|---|
| Monara Ela | 2014 | 342 | 1.80 | 0.00 | 2.605 |
| Amanawala | 2009 | 336 | 2.50 | 0.95 | 0.787 |
| Punugala | 2012 | 309 | 1.00 | 2.66 | 1.824 |
| Wee Oya | 2005 | 305 | 6.00 | 11.93 | 1.594 |
| Berannawa* | - | 298 | 0.50 | 13.94 | 0.376 |

**Table 8.3:** Potential impacts due to different structures or devices of mini-hydropower plant (source: ESHA, 2004)

| Structure or Device | Person or thing affected | Impact | Magnitude of Impact |
|---|---|---|---|
| **Intake weir** | Stream habitat, sediment flow, fish movement | Habitat alteration Fish population | moderate |
| **Headrace channel** | Hydrological network/forest | Water balance fragmentation | moderate |
| **Forebay** | wildlife | Drowning | minor |
| **Penstock (over earth surface)** | Hydrological network/forest | Water balance /fragmentation | moderate |
| **Penstock (underground)** | Deep-rooted plants | No growth | medium |
| **Powerhouse** | Wildlife/riparian community | noise | moderate |
| **Tailrace channel** | Aquatic biota | Wash-off due to flash flow | high |
| **Stream stretch between weir and powerhouse** | Aquatic life. Riparian community, Atmosphere | Fish movements, bank vegetation, human health Ecosystem services, GHGs | high |
| **Due to operation** | **Person or thing affected** | **Impact** | **Magnitude of Impact** |
| **Tailrace release** | Aquatic biota | Wash-off due to flash flow | high |
| **Power generation** | Wildlife/riparian community | noise | moderate |
| **No e-flow under dry weather** | Aquatic life. Riparian community, Atmosphere | Fish movements, bank vegetation, health risks ecosystem services, GHGs | high |
| **River bed exposure between weir and powerhouse** | Bathing pools, habitats Mosquito breeding Pathogenic protozoa | Riparian population/ Livelihood | High |
| **Ripraps** | Aquatic ecosystem, Riparian community | Habitat alteration/visual intrusion | Low |
| **Levees** | Aquatic ecosystem/ Riparian community | Habitat alteration/visual intrusion | Low |

Ecological risk of cascade operation of small hydropower plants established on the trunk stream poses adverse impacts, as it leads to almost drying up of the natural river channel during the dry season. Small hydropower plants are affecting not only fish but also other species inhabiting in stream ecosystems, in terms of mortality, migration, and change in the conditions and quality of their habitats. In some cases, abrupt changes in flow velocity can destroy fish eggs and other larval forms. It has been reported that cascade planning for mini-hydropower generation should be contemplated with due consideration of the environment. Certainly, many economic benefits can provide to human society from maintaining healthy aquatic and riparian ecosystems, compared to the high cost involved and difficulty of restoring degraded ecosystems. The present knowledge and findings have fuelled that principles of ecosystem science need to be more fully integrated into water resources planning and management. Unfortunately, these aspects have been totally ignored by project approving agencies in the Asia-Pacific region when permissions are granted to establish and operate small hydropower plants on hill streams that are highly rich in endemism. If small hydropower plants are designed, monitored and managed in a sustainable way, can have a reduced impact on the ecosystems and currently there are some eco-friendly examples in western countries. Nevertheless, small hydropower plants still have a negative impacts on the environment, which are not addressed rightly and sufficiently in this region.

### 8.4 Negative Impacts

The potential impacts of construction and operation of small hydropower plants can be categorized into three major groups namely, ecological, environmental and social (Figure 8.1). The difference between ecological and environmental to be correctly distinguished and treat separately to avoid confusions as ecological effects are more associated with aquatic flora and fauna and processes related to aquatic life whereas environmental effects emerge as a result of anthropogenic activities and directly or indirectly alter the composition and processes of natural cycles. In other words, environmental effects may have direct effects on human beings while the ecological changes may affect the biodiversity. Nevertheless, most EIA/IEE reports highlight terrestrial flora and fauna that have no relevance whatsoever but ignore the important aspects of ecological effects.

It is assumed that run-of-river SHP scheme has little or no reservoir impoundment, which is not correct in most cases. Although engineers claim always that SHP has less ecological problems but technological advances made are not properly harmonized with an environmental protection. Environment Impact Assessment (EIA) has been formally introduced in many countries including in Sri Lanka during the recent past and relied on an institutional framework with a strong support of legislative, administrative and procedural set up. Most of the engineering biased bulky EIA reports conclude that there are negligible impacts of the projects on surrounding environment and, therefore, the project are environmentally safe.

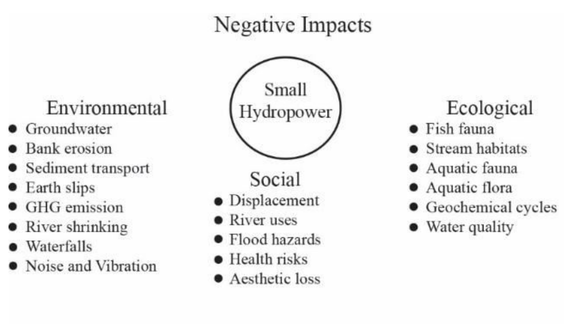



**Figure 8.1:** Environmental, ecological and social impacts of small hydropower projects

### 8.4.1 Ecological impacts

**Aquatic habitats:** A habitat is a place where an organism normally lives and it provides the necessary living conditions for feeding, breeding, protection etc. Some species such as fish may change their habitat for different life-history functions while others stay in the same habitat throughout their lifetime. In aquatic habitats, the availability of water is the most important factor because the aquatic organisms cannot perform their activities without water. Further, in stream habitats, aquatic organisms are there where water is available. In the case of small hydropower schemes, the water flow is reduced by more 75 % by constructing a weir across the river. In simple, it means an elimination of 75 % of aquatic life which represents an enormous diversity. The habitat alteration or elimination increases with increasing stream stretch between the weir and the powerhouse. Besides, most of the semi-aquatic animals (e.g., amphibians) inhabit stream banks and semi-aquatic plants thrive on land-water interface.

**Benthic life:** When the water flow is arrested by the weir, hardly any water flows along the banks except under flood conditions. On the other hand, stream habitats are badly affected at the outfall of the tailrace channel due to high-pressure water release. Most of the aquatic organisms will be eliminated at this point and high water pressure affects the stream habitat to a certain distance along the downstream. In the long run, both banks along the stream between the weir and the powerhouse will dry off and semi-aquatic plants and animals on the same stream stretch will be disappeared. Further, this will cease the lateral input of organic matter into the stream with an enhancement of bank erosion and instability.

**The pond behind the weir:** The stream stretch behind the weir will be converted into a small pond or pseudo-lacustrine ecosystems (neither standing water nor running water). The bottom of this area will be covered by a sediment layer over the time due to sedimentation under low flow conditions eliminating all microhabitats of the stream bed. Subsequently, more lacustrine organisms including planktonic organisms will colonize the pond. The banks of the pond will flourish with semi-aquatic plants and animals.

**Fish fauna**: Fishes are the most dynamics aquatic organisms in stream ecosystems. They move upstream and downstream, feed at different habitats having different feeding guilds but mostly spawn at a particular place where they look after offsprings. Therefore, fishes are more vulnerable to habitat alteration resulting from the establishment of small hydropower plants. In Sri Lanka, hill streams are the type habitats of many species endemic to the island. Further, two species of eels migrate upstream of most of the Sri Lankan rivers and they have been reported at higher elevations of major river basins before they were dammed. Some riverine species such as Mahseer (*Tor khudree*) is reported to be spawned at upstream tributaries of major rivers. Besides, freshwater Gar Fish (*Xenentodon cancila*), which grows up to 30 cm swim upstream of most of the west zone rivers.

**Water quality:** As small hydropower schemes deal with streams and rivers, it is assumed that stream water quality of the project area could be a major issue and incorporated with mitigation plans. Of course, sediment loading and subsequent increase in turbidity or suspended solids and smothering of benthic organisms are major issues to be considered but confined only to the construction phase. The quality of the pond water behind the weir may change to some extent depending on the depth of the pond and flushing rate or retention time. But, water retention in the pond is very short and stratification of the pond water column is very unlikely. There may be a significant increase in temperature of the water released by the powerhouse compared with the natural stream water. The high temperature dissipates along the downstream and became to an equilibrium at a certain distance depending on the discharge of stream at the point of tailrace water release. This situation could be considerable if there are no lateral input between the weir and powerhouse.

**Biogeochemical cycles:** This aspect should be treated as a holistic ecological issue of the entire river basin. In essence, biogeochemical cycling is a land-ocean phenomenon but the entire river basin plays an important role with respect to material loading into the river, which eventually reach the coastal seas after undergoing several physical, chemical and biological transformations. It is certainly insignificant when one particular small hydropower scheme is considered. Nevertheless, when all small hydropower schemes are taken into account, the cumulative impact is highly significant. For an example, at present, the sub-watersheds of the Mahaweli River have been blocked by about 57 weirs in addition to six major trunk stream dams, whereas the other major dams are under construction on Kalu Ganga, Amban Ganga, and the Mahaweli Ganga at Moragolla. The situation in the Kelani River is also shocking since there are about 32 small hydropower plants on the sub-watershed in addition to four major dams on two main tributaries, Kehelgumuwa Oya, and Maskeliya Oya. Another dam is under construction at Broadland estate, on the Kelani River proper. The number of weirs on the Kalu Ganga is about 28 in addition to the high dam on Kukule Ganga, which has a sediment flushing facility.

### 8.4.2 Environmental impacts

**Groundwater equilibrium:** In small hydropower schemes, stream water will be diverted at the weir intake and convey through the headrace channel and penstocks (optional) to the turbines in the powerhouse. The water released from the powerhouse will be directed to the tailrace channel, which eventually release the water back to the stream. The entire convey passage of water between the weir intake and tailrace outfall has no linkage with the ground preventing seepage and recharge. This may happen for several river kilometers as in Badulu Oya mini hydropower plant or in contrast, only for several meters as in low head mini hydropower plants embedded to large reservoirs, for an example Rajjammana mini hydropower plant on Sudu Ganga in Matale District. Nevertheless, surface and groundwater equilibrium will dramaturgically change as a result of construction and operation of small hydropower schemes, which lead to other environmental consequences such as bank erosion, earth slips flooding etc., depending the site.

**Bank erosion and earth slips:** The river bank erosion due to surface run-off is inevitable due to the elimination riparian vegetation along the stream bank from the weir to the powerhouse resulting from reduced stream flow and surface and groundwater disequilibrium. The surface soils of vegetation-free river banks are susceptible to continuous erosion by surface runoff and intermittent flood events. The restoration of river banks with riparian vegetation is a difficult task and very expensive process for the project developers but in most cases, they describe trivial methods for river bank restoration under mitigation plans. The most likely events of earth slips within the project area are directly associated with the landscape topography, changes in the hydrological network, surface and groundwater equilibrium and rainfall events. This may have direct bearings on climate change associated intensive rainfall events as predicted to occur in the highland of the wet zone of the country. This issue has not been addressed yet by the experts working on climate change issues in Sri Lanka.

**Sediment transport**: The productivity of the running water ecosystems are regulated by nutrients (nitrogen and phosphorous) regenerated from the bottom sediments and loaded by lateral inputs. Water currents in streams and rivers displace nutrients downstream as those nutrients move from one compartment of the nutrient cycle to another as described by nutrient spiraling. This movement of cycling nutrients which is called a nutrient spiral is an important ecological process that leads to sustain running water ecosystems alive. Estuaries and coastal waters are also productive as a result of nutrients transported via sediments and hence indispensable components in marine production. Besides, the inorganic part of the bed load sediments formed by physical and mechanical kinetics is required for beach formation and sand nourishment. Therefore, disruption of sediment transport via streams and rivers as a result of the construction of dams and weirs without having effective sediment flushing facilities will lead to profound effects on river ecosystems and coastal water as well. A small weir with poor sediment flushing facilities has been proposed to construct downstream of a major hydropower plant facilitated with effective sediment flushing gates (e.g., Kukule Ganga hydropower plant and proposed Bogahahena mini-hydropower project).

**GHG emission:** It is assumed that the emission of greenhouse gasses (e.g., carbon dioxides, methane, and nitrogen oxides) in small hydropower projects is insignificant and, therefore, it is not incorporated into carbon trade calculation in most cases. Nevertheless, any water body emit GHGs to some extent due to decomposition of organic matter while fixing carbon dioxide by photosynthesis but methane is emitted to the atmosphere. Organic matter rich surface water bodies emit more carbon dioxide during the night due to respiration and decomposition. Therefore, GHG emission from the pond behind the weir cannot be ignored although emission is very small compared to fuel fossil burning. In addition, GHGs are emitted by stagnant pools are significant and the amount depends on the length of the affected stream stretch and the slope of the streambed.

**River shrinking:** This aspect has been addressed in 1990 with respect to the construction of trunk stream hydropower schemes on the Mahaweli River in cascade without facilitating environmental flow. River flow is not there at immediate downstream of the high dams for several kilometers when there are no lateral perennial tributaries in between the dam and the power station. An exception can be seen at Randenigala hydropower project where the powerhouse is located underground at the beneath of the dam. Nevertheless, the outflow of the powerhouse is conveyed to the Rantambe reservoir about 2 km long concrete canal. Accordingly the trunk stream of the Mahaweli River has been discontinued at five places and subsequently shortened or shrunk by 20 km, which is 6.0 % of the total length of the mainstream of the Mahaweli River. If it is calculated for the entire river basin of the Mahaweli River considering the total loss of stream stretch due to 60 mini hydropower schemes, it would be over 100 kilometers. The affected stream stretch or stream loss for Kelani River has been calculated as 88.00 km.

**Waterfalls:** For a small island nation, Sri Lanka has a recorded number of nearly 400 waterfalls. Where there are hills and rivers, there are waterfalls. Most of them are popular destinations for local and foreign tourists. Beautiful waterfalls cascading down the mountain slopes enhance the aesthetic beauty of the hilly landscape of the country. The geographical formation of the Island with the central highland sloping down to the coastal plains has resulted in several rivers and streams starting from the central region flowing down the hilly slopes in a radial pattern, creating beautiful waterfalls in several places in the hill country. The largest number of waterfalls are found in the Mahaweli River basin Kau Ganga basin followed by Kelani River and Kalu Ganga basins. We also have pathetic examples of waterfalls being tapped for the generation of hydropower to produce electricity. The

Laxapana fall on Maskeliya Oya was arrested for the first hydropower project in Sri Lanka when the Canyon pond was constructed. Victoria fall (11 m ) on Hulu Ganga disappeared because, the construction of Victoria dam across the Mahaweli River. Likewise now we cannot see Walawe Ganga fall (30 m),

### 8.4.3 Social impacts

Although it is assumed that negative impacts on riparian communities are insignificant due to mini-hydro projects, the occurrence of several negative impacts during construction and operational phases are inevitable. The argument on insignificant negative social impact is not correct when potential social impacts are analyzed in detail giving due consideration to livelihood strategies of remote riparian communities those who depend on a variety of services provided by the adjacent running water resource. Indeed, major hydropower projects invariably cause larger negative social impacts including displacement of human settlements, loss of large areas of productive land, ecological imbalances of the area, emission of GHGs, etc. whereas such options are minimum in small hydropower schemes when compared with the larger hydropower projects.

The small hydropower plants operated in large tea estates during British period were mostly confined only to the isolated parts of the estates and people new virtually nothing about social and environmental impacts of those power generation projects. Over one hundred schemes of off-grid community-based micro hydropower plants (2 to 10 kW) are in operation at present and they are operated and managed by village level societies. The social and environment impacts of such micro-hydropower plants were mostly limited to the village concerned and the stakeholders (beneficiaries and the affected communities) are usually empowered to resolve the impacts through the village level committees. A major difference of grid-connected mini-hydropower projects when compared to the off-grid estate owned and village electrification plants is that grid- connected projects use public resources, both water, and the crown land, for certain parts of the project whereas the latter used all the resources within their private ownership. This situation resulted in the local population being subjected to both positive and negative impacts associated with grid-connected small power generation projects.

Most of these issues were largely ignored or not given solutions at the project formation and construction could, therefore, cause considerable social and environmental impacts in the operational phase.

- Displacement
- Nuisance and noise pollution
- Flood hazards
- River uses
- Earth slips and landslides
- Health
- Aesthetic loss

The significant global advantages of small hydropower must not prevent the identification of burdens and impacts at the local level and the taking of necessary mitigation actions. Large thermal plants, because of their economic relevance and scale, are authorized at very high administrative levels and in some cases, their impacts cannot be mitigated at present. A small hydropower scheme producing impacts that usually can be mitigated if considered at lower administrative levels, where the influence of pressure groups – angling associations, ecologists, etc. is greater in developed countries. The situation is quite different in developing countries because remote riparian communities are ignorant, stream ecologists are lacking and decision makers are politically biased.

Since the knowledge on ecological structure, processes and functions of nature is adequately understood and social requirements and livelihood strategies of remote communities are well recognized it is not difficult to identify the negative impacts of small hydropower operations. But to decide which mitigation measures should be implemented is not simple because these are usually dictated by subjective arguments. It is therefore extremely important to establish a productive dialogue with the environmental authorities at the initial stage in the design phase considering the riparian community as an important stakeholder group. Even if this negotiation must be considered on a project-by-project basis, it would be convenient to provide a few guidelines that will help the project designer to propose mitigating measures that can easily be agreed with the licensing authorities.

**Displacement:** In general, each preselected dam site may have its own unique set of ecological, environmental and social challenges since the design requirements are different for dams of different size, purpose and hazard potential classification. As mentioned earlier, more than 600 locations in Sri Lanka have been identified as potential sites and many of them are already tapped for power generation. Besides, most of the potential sites are sparsely populated and users of the land and water in the area for their livelihood. Further, there are cases that project area falls within small townships as in Padiyapelella mini hydropower scheme on Belihul Oya and Waltrim mini hydropower scheme on Agra Oya. Although electricity generation in small hydro plants does not produce GHGs carbon or liquid pollutants in significant amounts, their location in sensitive areas, especially with human settlements may result in the displacement of people. People will have to be displaced when their houses are located within or in the vicinity of proposed tailrace canal, power transmission lines, and powerhouse. In most cases, prior negotiation will be done with the landlords or house during the planning phase. On their consent, project developers make necessary arrangements together with government authorities for re-settlement depending on the ownership or the land. If the household owned the property, cash compensation will be the most likely solution. There are instances that the developers have offered job opportunities in the power project to a member of the affected family.

**Nuisance and noise pollution:** Drilling, excavation, heavy vehicle transportation and rock blasting during the construction phase and vibration related noise pollution of turbines during the operation cannot be avoided in hydropower development.

**Aesthetic loss:** The quality of visual aspects is important to the public, who is increasingly reluctant to accept changes taking place in their visual environment. The problem is particularly acute in the high mountain hydropower schemes or in schemes located in an urban area. This concern is frequently manifested in the form of public comments and even of legal challenges to those developers seeking to change a well-loved landscape by developing a hydropower facility.

Each of the components that comprise a hydro scheme - powerhouse, weir, spillway, penstock, intake, tailrace, substation and transmission lines - has potential to create a change in the visual impacts of the site by introducing contrasting forms, lines, color or textures. The design, location, and appearance of any one feature may well determine the level of public acceptance for the entire scheme.

Above ground transmission lines and transmission line corridors can have a negative impact on the landscape. In sensitive mountain areas, where schemes are developed, transmission lines can dominate the landscape and therefore influence the beauty of the scenario

**Health risks:** Clean freshwater is essential to human health. Its importance for domestic consumption (drinking, cooking, washing etc.,) cannot be over emphasized. A significant portion of life-threatening and health-threatening infections are transmitted through contaminated water. Fecal contamination of drinking/domestic water supplies is the main reason for the high and sustained incidence of amoebic dysentery in this country. Bacillary dysentery is on the rise during the drought and after floods. Helminth infections continue among our population due to the use of contaminated water; fecal pollution of water also results in typhoid and hepatitis, which are very common occurrence in Sri Lanka. Most of the riparian communities in the upland draw water from streams and rivers for domestic uses. Mosquitoes that breed in stagnant water are vectors of human diseases, which reach epidemic proportions. Dengue is considered one of the most important arbovirus disease of man and is transmitted by *Aedes aegypti* and *Aedes albopictus* mosquitoes, which breed in drains and ditches etc., with the human fatalities caused by this virus, Sri Lanka is no longer considered dengue safe area.

Leptospirosis ("Mee Una"), is present at low levels in areas associated with polluted water. The pathogenic organism is present in the urine of rats (breeding in garbage dumps), which contaminate these waters. In the recent past too such epidemics were reported from different parts of the country. Mini hydropower schemes create excellent habitats for mosquito breeding and bacteria and algal growth between the weir and the powerhouse due to the formation of stagnant pools. Ironically, riparian communities living along the stream n banks of mini hydropower schemes are venerable for infectious diseases. This aspect is hardly addressed in IEE/EIA studies, although affected stream stretch is more than 5 km in some run-of-river schemes (e.g, Badulu Oya mini hydropower scheme). In addition to the visual intrusion, some people may dislike walking under transmission lines because of the perceived risks of health effects from electromagnetic fields.

# Chapter 9

## Mitigation and Monitoring

### 9.1 Introduction

In small hydropower, it is much easier to meet environmental demands than in the development of major hydropower schemes where technical concerns are rather less flexible and an enormous area with different land use including human settlements is involved. Nevertheless, the establishment of small hydropower is not in principle free of environmental problems as described in the previous chapter. Therefore, a wide range of effective mitigating measures offers many worthwhile approaches for the responsible, open-minded, and experienced designer. Construction and operation of small hydropower projects while protecting the environment simultaneously are not a contradiction but an extraordinarily interesting and exciting challenge. The impacts of hydropower schemes are highly localized and technology-specific. But certain impacts are usual and common to all small hydropower projects. In developed countries, appropriate mitigation measures are amalgamated with respective impacts to avoid or minimize potentially adverse effects on the environment, human health and safety and social aspects of the proposed project. According to the existing law, it is mandatory to monitor the impacts and whether mitigation measures are correctly implemented or not. Therefore, there is a mutual agreement between the Developer and the Project Approving Agency to implement mitigation measures along with the constructions as well as conduct a monitoring program during the operation.

**9.2 Mitigation During Construction**

The impacts generated during the construction of a small hydro dam do not differ from those induced by any large-scale dam construction but different in magnitude. The effects generated during the dam building and mitigation measures to be implemented are well known. The most common impacts produced are;

- Noise affecting the man and the wildlife
- Bank erosion due to the loss of vegetation cover
- Increase in turbidity and suspended matter due to erosion
- Sediment deposition in ripples and pools
- Impairment of water quality
- Loss of microhabitats or habitat alteration
- Smothering of aquatic organisms

To mitigate such impacts, it is strongly recommended that the excavation work should be undertaken during the dry season and the disturbed ground to be restored as soon as possible. Nevertheless, these impacts are always transitory and do not constitute a serious obstacle to the administrative authorization procedure but ecologically extremely important as far as the stream ecosystem processes and functions are concerned.

In view of its protective role against stream bank erosion, it is wise to restore and reinforce the riverbank vegetation that may have been damaged during construction of the hydraulic structures and excavation for headrace channel. It has been recommended that the ground is re-colonized with indigenous species best adapted to the local conditions rather than fast-growing tree species.

During the process of Initial Environmental Examination or Environmental Impact Assessment, it should be highlighted not to disperse excavated material in the stream bed and to avoid the unfavorable consequences of construction workers living in a usually uninhabited area during the construction period. Although it is illegal and prohibited some contractors do additional rock blasting and sand mining from stream bed for construction work in remote sites.

**Plate 9.1:** Illicit rock blasting and sand mining

This impact, which may be negative if the scheme is located in a natural park or a reservation, would be positive in a non-sensitive area by increasing the level of its activity. Vehicle emissions, excavation dust, the high noise level and other minor burdens contribute to damaging the environment when the scheme is located in sensitive areas. To mitigate the above impacts, the traffic operation must be carefully planned to eliminate unnecessary movements and to keep all traffic to a minimum. The developers always willing to hire local manpower and small local subcontractors during the construction phase as a measure of mitigating minor burdens affecting the local communities.

There are instances that penstocks and headrace channels are buried to eliminate visual intrusion and to facilitate wildlife movements, especially elephant corridors are blocked by water conveying systems in the areas where dense populations of wild animal inhabit. This is not suitable because both headrace channel paths and penstock buried tracks restrain the colonization of deep-rooted tree species. It is reported that sometimes animals may fall into an open canal without any chance to get out due to a rectangular cross section. Certain ladder constructions may serve effectively at rather a low cost.

**9.3 Mitigation During Operation**

Although a majority of the small hydropower schemes are run-of-rivers systems there are low head reservoir systems (e.g., Branford and Rajjammana mini-hydropower plants) that are designed to generate electricity during the periods of maximum electrical demand. Such operation is referred to as "peaking" or "peak-lopping." In integral low head schemes, peaking can result in unsatisfactory conditions for downstream fish movement because the flow decreases when the generation is reduced.

The lower flow can result in stranding newly deposited fish eggs in spawning sites. The eggs apparently can survive periods of de-watering greater than those occurring in normal peaking operation but small fish can be stranded particularly if the level fall is rapid. Further, the reduction in flow in the streambed between the point of diversion and the tailrace downstream of the powerhouse may affect spawning, incubation, rearing, and the passage of fish and of living space for adult fish. Most of the mini-hydropower plants in Sri Lanka never release required environmental flow downstream to sustain the aquatic biodiversity and the pertinent authorities have attempted yet to find solutions to overcome this situation.

**Plate 9.2:** A large reservoir

**Plate 9.3:** Unsatisfactory environmental flow

On the other hand, there are difficulties in calculating correct environmental flow but a number of methods are available in the literature. Nevertheless, no one has derived a good universally acceptable solution for environmental flow. People also consider base flow or dry weather flow as the environmental flow or reversed flow. 10 % of the average flow at a given cross section of the stream is also widely used as environmental flow. Several other values consider as environmental flow are given below;

- l/s/km$^2$ of catchment area
- Values based on velocity and depth of water
- Values calculated based on both ecological and economic objectives

### 9.3.1 Fish passes (upstream)

A great variety of fish pass designs is available, depending on the species of fish involved. Otherwise, freshwater fish seem to have restricted movements, upstream and downstream. Upstream passage technologies are considered well-developed and understood for Salmon like anadromous species but there is no single solution for designing upstream fish passageways. Effective fish passage design for a specific site requires a good understanding between engineers and biologists, and thorough understanding of site characteristics. Upstream passage failure tends to result from a lack of adequate attention to operation and maintenance of power generation facilities. The types of upstream passages are;

- Fish ladders
- Fish lifts (elevators or locks)
- Fish pumps
- Fish translocation

Nevertheless, in the case of small hydropower schemes, site and species-specific criteria and economics would determine the most suitable solution.

**Translocation of Gadaya to Kelani River**

Construction of hydropower dam on the trunk stream of the Mahaweli River, 22 km upstream of Kandy city near Ulapane at Moragolla with about 30 MW installed capacity is in progress. The project reports show that *Labeo fisheri*, a vulnerable fish endemic to Sri Lanka is at risk from the reductions in water quality and also from pressure waves caused by bedrock blasting, and from poaching by site workers during the construction phase. The potential impacts on fish fauna will be mitigated by reducing the incidence of water pollution, utilizing non-explosive methods of rock blasting on the river bed and educating workers on the environmental value of rare species and prohibiting all fishing on site according to the EIA report. The EIA consultants have also proposed two further activities, which include; a catch-and-haul program to capture *Labeo fisheri* and other large species and translocate them upstream or to the nearby Kelani River and cutting channels in the river bed below the Moragolla dam site to improve connectivity between pools in the area during low flow conditions when the project is in operation.

These proposals show the dearth of knowledge of EIA consultants on ecology endemic fish and their native stream habitats. It may be difficult to find a suitable site in the Mahaweli to translocate the Mountain Labeo because this rare species is evolutionary established in its peculiar trophic and spawning guilds. That is why one cannot find Mountain Labeo in the Kelani River. Translocation of fish species to favorable habitat beyond their native range to protect them from human-induced threats, such as climate change and other development interventions is widely discussed subject by conservation ecologists. Fish ecologists argue that conservation biologists have not developed yet a sufficient understanding of the impacts of introduced species to make decisions regarding species translocations.

**Plate 9.4:** Plate Closed environmental flow

**Plate 9.5:** Plate; Former fish breeding ground

**Plate 9.6:** Plate Diversion and pond behind the weir

**Plate 9.7:** Present mosquito breeding site

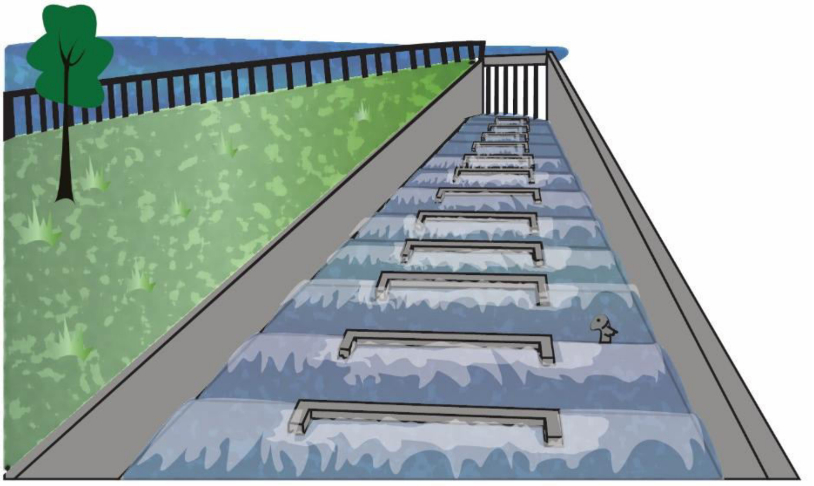


**Figure 9.1:** A common upstream fish pass

### 9.3.2 Fish passes (downstream)

In the past downstream migrating fish passed through the turbine. The fish kill associated with this method varies from a few percent to more than 40% depending on the turbine design and more specifically on the peripheral speed of the runner. In a Francis turbine increasing the peripheral runner speed from 12 m/s to 30 m/s increases the percentage mortality from 5% to 35%. Francis turbines, due to their inherent construction features cause greater mortality than Kaplan turbines. Bulb turbines reduce mortality to less than 5%.Recently an innovative self-cleaning static intake screen that does not need power has been used for fish protection

### 9.3.3 Noise mitigation

The noise comes mainly from the turbines and when used from the speed increasers. Nowadays noise inside the powerhouse can be reduced if necessary to the level in the order of 70 dBA, almost imperceptible when outside.

The maximum allowed external sound level, at night, was set at 40 dBA in the surroundings of some houses located about 100 meters away. Noise generators, turbines, speed increasers and asynchronous generators can be covered with sound insulating blankets. Water cooling instead of air cooling of the generator is also possible. As well as the usual thermal insulation, the building can be provided with acoustic insulation. Consequently, the level of noise may regulate between permissible or desirable level. The external noise level reduction can be obtained by using vibration insulation of the powerhouse walls and roof.

The principle for the vibration reduction system is to let the base slab, concrete waterways, and pillars for the overhead crane be excited by vibration from the turbine units. The other parts of the building such as supporting concrete roof beams and pre-cast concrete elements in the walls are supported by special rubber elements designed with spring constants giving maximum noise reduction.

For the roof beams, special composite spring-rubber supporting bearings (Trelleborg Novimbra SA W300) can be selected. A similar solution can be chosen for the precast wall components. Once built, the sound emission from the powerhouse could not be detected from the other noise sources as traffic, sound from the water in the stream, etc. at the closest domestic building. Sound and vibration generating from the powerhouse can further reduce by;

- Insulation of the machine hall, constructing double walls
- Applying soundproofing doors
- Floors floating on thick glass wool carpets
- False ceiling with noise deadening characteristics
- Heavy trapdoors to the ground floor
- Vibration damping joints between fans and ventilation ducts
- Low air velocity ducts
- Silencers at the top and rear of the ventilation plant
- Inlet and outlet stacks equipped with noise traps
- Air ducts built with a material in sandwich
- Turbine rotating components dynamic balanced
- Water-cooled brushless synchronous generator
- Precision manufactured gears in the speed increaser
- Stiffened turbine and speed increaser casings
- Anchoring of the turbine by special anti-shrinking concrete

### 9.3.4 Visual aspects

Most of these components, even the largest, may be screened from view using landscaping and vegetation. Painted in non-contrasting colors and textures to obtain non-reflecting surfaces a component will blend with or complement the characteristic landscape. Creative effort, usually with a small effect on the total budget, can often result in a project acceptable to all parties concerned: local communities, national and regional agencies, ecologists etc.

The penstock is usually the main cause of "nuisance". Its layout must be carefully studied using every natural feature - rocks, ground, vegetation - to blanket it and if there is no other solution, painting it so as to minimize contrast with the background. If the penstock can be interred, this is usually the best solution, although the operator has to meet some disadvantages in terms of maintenance and control. Expansion joints and concrete anchor blocks can then be reduced or eliminated; the ground is returned to its original state and the pipe does not form a barrier to the passage of wildlife.

The powerhouse, with the intake, the penstock tailrace, and transmission lines must be skillfully inserted into the landscape. Any mitigation strategies should be incorporated in the project, usually without too much extra cost to facilitate permit approval.

## 9.4 Monitoring Program

Under the Environmental Clearance and Environmental and Social Action Plan, Monitoring Program is a requirement in the National Environmental Act. Therefore, a Monitoring Plan should be included in the IEE/EIA report. Nevertheless, In Sri Lanka Small Hydro Projects are not operated in compliance with the European Union Environmental and Social standards. Monitoring Plan shall also be made available to the contractors who will be expected to comply with relevant requirements and implement of mitigation during the construction.

The Project Developer in collaboration with the members of the CEA shall monitor the mitigation and report to the Project Approving Agency. These reports are not publicly available in Sri Lanka. This monitoring of compliance must include an auditing/verification element, a reporting element and a tracking mechanism to ensure that all identified non-compliances are remedied. Monthly reports during the construction and quarterly monitoring reports during operation is the common practice in small hydro projects. The Developer shall nominate a community liaison officer to the Monitoring Team to deal with the community, answer questions, and make sure that people are aware of the commitments of the developer.

In addition, the Developer shall mandate a Construction Supervisor, who is responsible for the supervision of the environmental, social and as well as health and safety related activities. Besides, there is Action Item Table in the EIA report, which describes;

Potential impact/issue

- Responsibility/Implementation
- Monitoring/Key performance indicator
- Timeline/Milestone
- Cost/budget (Optional)

Under the monitoring program, the Developer must maintain or perform;

- Monitoring and Audit Reports
- Implementation of a Management System ( based on International Standards, ISO)
- Manuals highlighting Environmental Process
- Waste Management Plans
- Pollution Prevention Plans
- Quality Assurance Plans
- Minutes of stakeholder meetings
- Training Matrix
- Training Records
- Visual Inspections and Photographs of Affected Sites
- Monthly Reports on Implementations
- Visual Inspections on the Dust Sources
- Environmental and Social Impact Assessment report for Transmission line (optional)

In addition, it is necessary to monitor and audit topsoil stripping, soil storage, soil use, stockpile, and soil compaction on a regular basis. After construction, the following aspects should be monitored on a quarterly basis.

- Auditing on soil erosion and measures against erosion (e.g., vegetation rehabilitation, filling holes, and leveling surfaces),
- Periodic visual inspections on aquatic habitats and thermal springs,
- inspection of streambed by an experience aquatic biologists
- Inspection of fish movements
- Vegetation growth on the river banks from the weir to the tailrace outflow
- Observations on ecological flow

### 9.4.1 Template for Hydrological Monitoring Program

| Parameter | Frequency | Site | Method | Recording | Remarks |
|---|---|---|---|---|---|
| Turbidity | Daily | D | Visual | Photograph | Note if any |
| Conductivity | Weekly | A,B,C,D, E | EC meter | Data | Note if any |
| Temperature | Weekly | A,B,C,D, E | Thermometer | Data | Note if any |
| pH | Weekly | A,B,C,D, E | pH meter | Data | Note if any |
| Discharge | Weekly | A,B,C,D, E | Flow meter | Data | Note if any |
| Isotopic | Bi-annual | A, D | Laboratory | Data | Note if any |

**Sites; A, Intake point;** B. Weir; C. Environmental flow; D, Tailrace outflow; E, 50 m downstream of powerhouse,

### 9.4.2 Documentation and reporting

- Recording in field notebooks
- Recording in data sheet
- Compilation of XL sheets
- Interpretation and graphical representation in trends
- Graphics for flow pattern (e-flow)
- Reporting to the Developer and PAA on a regular basis

**Note:** Monitoring frequency can reduce after one year if monitoring parameters are consistent with no major deviation from baseline data. It is also important to avoid monitoring irrelevant parameters such as COD, BOD, micronutrients, which cannot be produced from project activities. Intermittent measurement of isotopic activity is important as the power generation involves many different metal machinery and structures,

# Chapter 10

## Conclusions and Recommendations

Water resources development and management in Sri Lanka since ancient time to date have benefited people in many ways fulfilling their basic requirements and providing a variety of services. Besides, in the process of evolution of water resources development, watershed-based ecosystems approach, the basic concept of ancient hydraulic civilization in Sri Lanka has gradually disappeared or purposely ignored to a greater extent. Water resources development during the Dutch and British periods were not alert to achieve the basic requirements of the nation. Most of the development projects implemented since independence were very ruthless and undermined the basic principles and concepts inherited in ancient systems as well as essential environmental regulations leading to the nation's aquatic environment into an agony.

Indeed, it is irrelevant to compare the sustainability of the ancient systems over the modern schemes since the reasons for the fall down of ancient systems still remains unsolved, difficult to understand, and the river basin had not changed then to the extent what we have done at present. The negative impacts of water resources development in a small island like Sri Lanka are largely restricted to local settings and poor decision making. The existing negative impacts in the present context can be minimized by understanding the holistic approach of scientific-based resource management in the development process for the well-being of the nation. The famous saying of King Parakrama Bahu denotes interest and it also reflects the genius knowledge on irrigation. No suspicion that watershed-based ecosystem approach was embedded in the ancient practice.

Apparently, all the stream flow regulation schemes launched for the water resources development, and energy production in Sri Lanka since the ex-colonial period to date have assumed river ecosystems as lifeless hydraulic flows. Of course, they are hydraulic but systems are fluvial that also transport materials including essential nutrients to the coastal seas. Their biological integrity associated with ecosystem diversity from headwaters to downstream have totally ignored prioritizing engineering supremacy. Evidently ancient systems were more environment-friendly than modern restoration and construction as written Arumugam in 1969 witnessing the present status of Hattota Amuna, an ancient anicut on Kalu Ganga, a major tributary of the Ambang Ganga.

Small hydropower potential in Sri Lanka has been almost tapped within a short period of time from 2000 to 2015 constructing about 143 mini-hydropower plants mainly on major river basins (viz., Mahaweli, Kelani, Kalu, Gin, Nilwala, and Walawe) generating hydroelectricity ranging from 0.1 MW to 10.00 MW.

Two types of mini-hydropower plants, namely low head reservoir type and so-called run-of-river system are in operation in addition to a few irrigation drop plants. Nevertheless, the type of the run-of-river system is operated in Sri Lanka assuming that the run-of- river means diverting river flow leaving only an insignificant discharge as an environmental flow and releasing diverted water back to the river through a tailrace canal emerged from a power generating turbines.

Approvals for mini-hydropower plants have been granted by project approving agencies primarily considering the generation of electricity by mini-hydropower plants as environment-friendly sources of alternative energy with insignificant environmental impacts comparing GHG emission during the generation of the similar amount of electricity by fossil fuel burning or calculation of carbon trade.

Although it is compulsory to comprise the composition of EIA team for a mini-hydropower projects, a hydrologist/drainage engineer, a stream ecologist, a fish ecologist and other subject specialists (an agronomist/pesticide expert, a soil conservation expert, a biological/environmental scientist, an economist, a social scientist and a health scientist, preferably an epidemiologist) as stipulated by the Central Environmental Authority, IEE/EIA teams hardly maintain stipulated composition.

Most of the IEE/EIA reports hardly addressed the direct and indirect ecological issues on the long run but contain a fair amount of irrelevant information, perhaps due to irrelevant composition and poor competence of IEE/EIA teams

The Developers have attempted various methodologies to convince different values of stream discharge as the correct environmental flow as the authorities have not defined yet the site-specific environmental flow on the basis of ecological requirements of downstream aquatic life.

Public consultations are misleading in most cases, the remote riparian communities are hardly benefited by mini-hydropower projects and the developers can satisfy them offering sundry benefits when agitations occur against the projects, normally persuaded by hidden parties.

The grave ecological problem of construction and operation of mini-hydropower plants is the cumulative loss of stream habitats within the entire river watershed as a result of creating almost dead stream stretches between the weir and the powerhouse in the case of run-of-the-river systems. This impact is extremely high for tributary streams when a cascade of mini-hydropower plants is in operation as in the Sudu Ganga and Hatton Oya, major tributaries of the Mahaweli River.

The weirs of cascade mini-hydropower plants that receive release water from major hydropower plants are more susceptible to wash off when coincided with flash floods creating major environmental hazards and social consequences.

The relevant operational activities of mini hydropower plants (e.g., release of downstream flow) and their potential effects on the environment (e.g., stream bank vegetation and erosion, flooding, earth slips, infectious diseases) and riparian communities (e.g. water availability for irrigation and other domestic purposes) are not adequately monitored due to lack of staff in respective government organizations, however generation of electricity is well maintained as each plant is connected to the national grid according to the power purchasing agreement with the Ceylon Electricity Board.

The entire hydrological network of each river basin in the island has been compartmentalized into hydrological cells of different magnitude by artificial structures apprehending fluvial movements and sediment transport. As a result, the fish fauna, the most dynamic and wandering aquatic organisms in running water ecosystems have been distinctly affected. For example, migratory species between seawater and freshwater or catadromous eel populations have disappeared or declined from regulated river basins throughout the world. Of the eels only the juveniles (elvers or glass eels) of genus Anguilla enters the freshwater to feed and grow up to maturity and make epic journeys to deep seas return to spawn in the sea where they assumed die just after spawning. They leave rivers and brackish habitats, swimming hundreds of miles into the open ocean region that is warmer, saltier, bluer and clearer than the surrounding waters. This trek had remained a mystery to science since no eggs nor had adult eels ever been caught in the deep ocean. They are the only major group of catadromous fish, that is spawning in the sea but spending part of their lives, usually the adult feeding phase, in freshwater.

The upstream migrating glass eels or elvers have been reported from Sri Lankan rivers. They creep upstream along moist concrete dams, of which the purpose a complex behavioral adaptation. Two species of eels namely *Anguilla bicolor* (Long Level-finned Eel) and *Angulilla bengalensis* (Mottled Eel) are found in Sri Lankan freshwaters of which *A. bengalensis* show distinct upstream migration. This species that is identified as a commercially important freshwater fish in Sri Lanka has been disappeared from Mahaweli. Kala Oya and Walawe basins to a greater extent. The adult individuals migrating back to sea for spawning are the most difficult phase of their life as they are vulnerable to fishing. The migratory routes cease to exist due to multiple impoundments or flow regulatory features in small streams and rivers. But, some get independence through spills or flood water. Therefore, this is the high time to revisit water resources based development projects to give a verdict on environmental justice.

Small hydroelectric projects certainly would cause a variety of ecological, environmental and socio-economic problems, even though they are free from greenhouse gas emission. Arresting stream flow by building dams across running water systems may permanently alter riverine ecosystems and aquatic life due to changes in Ecohydrology and habitat alteration. Exposed river beds between the weir and the powerhouse discontinue the ecological integrity along the longitudinal axis of the river system resulting in cease of material transport, nutrient spiraling, and drift of macro-invertebrates. Leaf litter decomposition will be reduced due to both elimination of riparian vegetation and poor colonization of benthic aquatic organisms. The reduced lateral transport of water between the river bank and the trunk stream (Ecotone) may affect the growth of riparian vegetation including aquatic and semi-aquatic plants. Fishes and other river fauna may no longer be able to swim upstream as shown by Silva and Davies (1986). Also, there is no doubt that hydropower projects have made an important contribution to the quality of life human beings but such developments had significant negative impacts on local livelihood and the environment. Extinction of riverine fishes may occur in the long run, perhaps some of them may be endemic to Sri Lanka.

Flooding of stream stretches with lesser gradients between major hydro and mini-hydropower plants is unavoidable during rainy seasons. A good example is the stream stretch between the outflow of Kukule hydropower plant and the weir of the proposed Bogahahena mini hydropower plant on the Kukule Ganga.

The effects clusters of mini-hydropower plants on major river basins on sediment transport, the most important biogeochemical process between the land and ocean have not been correctly understood as a fundamental process in evolutionarily established biogeochemical cycles.

The project approving agencies that are responsible for granting permission for the establishment of mini-hydropower plants on mountain streams do not have expertise qualified in aquatic science and aquatic resources management which has led to incorrect approval of EIA teams.

The site-species local issues must be taken into consideration rather than global scenarios with respect to GHG emission. The policies should be framed by an accurate examination of local sites so that the proportionate balance between the biotic and its components of the environment can be maintained and the potential capacity of rivers can be utilized properly.

**Recommendations**

- Before sanctioning any other mini-hydropower project in Sri Lanka, the recommendation of the World Commission on Dams, which has stressed on five fundamental values regarding the dam building viz., equity, efficiency, participatory decision-making, sustainability and accountability must be taken into consideration.
- The non-governmental organizations should come forward with full-time participation to protect the environment and by taking appropriate strategies and to make the riparian communities aware about their rights and environmental services.
- It is also recommended that a state level interdisciplinary committee or expert panel on mini-hydropower be constituted with eminent experts with proven track records, like river basin planner, botanist specialized in aquatic and semi-aquatic plants, hydrogeologist, environmentalist, aquatic ecologist specialized on stream

ecology with ichthyology background and socio-economic expert with rural resources management background. These experts should have at least three publications in citation index journals on the respective subject area.

- It is high time Sri Lanka to follow international guidelines stipulated with respect to economic development programs associated with stream flow regulation. Central environmental Authority has to play a stringent and impartial role in IEE and EIA processes, especially when approving EIA teams or else EIA teams should be approved by an expert panel.
- All stream flow regulatory structures must be facilitated with environmental flows and biodiversity protection devices such as fish ladders if appropriate or other types fish by-passes etc.
- EIA reports should include a comprehensive checklist of aquatic macroinvertebrates and fish fauna (sampled using electrofishing gear).
- All critically affected stream/river sites must be revisited and appropriate strategies or mitigation measures should be implemented as far as possible to rehabilitate riverine ecosystems. The weirs should be inspected and recommended on a regular intervals by the Dam Safety Project of the Mahaweli Authority of Sri Lanka.
- Monitoring programs conducted by the officials of the Central Environmental Agency or Project Approving Agencies accompanied by subject specialists as the need arises. For examples, stream ecologist (not a plant ecologist) with experience in fish communities must the best candidate for examination of mini-hydropower plants.
- MASL and the Department of Irrigation, dominated by engineers should create cadre positions for aquatic ecologists/limnologists and provide facilities for them to obtain post-graduate degrees in the relevant fields with foreign exposure. At the same time, foreign exposure to engineers must also be facilitated.
- It is necessary to convince the engineering faculties of the local universities to include theoretical and applied ecology with special emphasis on water resource ecology in the civil engineering curriculum.
- Mahaweli Authority of Sri Lanka must be much more concerned about further approval of establishing mini-hydropower plants in the upper Mahaweli watershed and request the owners of the plants that are already connected to the national grid to abide by the environmental regulations.
- Utilization of upland streams for the establishment of mini-hydropower plants must be carried out through environment-friendly best management practices within the framework of already available environmental regulations while considering not only human benefits and welfare but also direct and indirect impacts on aquatic life.

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## GLOSSARY

**Abney level:** Is an instrument used in surveying which consists of a fixed sighting tube, a movable spirit level that is connected to a pointing arm, and a protractor scale.

**Alternating current (AC):** Electric current that reverses its polarity periodically (in contrast to direct current).

**Anadromous fish**: Fish (e.g. salmon), which ascend rivers from the sea at certain seasons to spawn.

**Anicut:** A dam made in a stream for maintaining and regulating water for irrigation, term used in India and Sri Lanka

**Asphalt:** Asphalt, also known as bitumen, is a sticky, black and highly viscous liquid or semi-solid form of petroleum

**Average Daily Flow**: The average daily quantity of water passing a specified gauging station.

**Base flow**: That part of the discharge of a river contributed by groundwater flowing slowly through the soil and emerging into the river through the banks and bed.

**Borehole**: A deep, narrow hole made in the ground, especially to locate water or oil.

**Cascade:** A series of shallow or step-like waterfalls, either natural or artificial

**Catadromous fish**: Fish that live in freshwater but migrate to sea for breeding

**Catchment Area**: The whole of the land and water surface area contributing to the discharge at a particular point on a watercourse.

**Cichlids:** A group of African fish introduced to Sri Lanka for commercial purpose

**Clinometer:** Is an instrument for measuring angles of slope or tilt), elevation or depression of an object with respect to gravity.

**Cyprinid:** Carp-like fish common in Sri Lanka

**Debris:** Scattered fragments, typically of something wrecked or destroyed.

**Demand (Electric):** The instantaneous requirement for power on an electric system (kW or MW). Demand Charge that portion of the charge for electric supply based on the customer's demand characteristics.

**Dendro:** Real wood, also used to generate electricity

**Direct Current (DC)**: Electricity that flows continuously in one direction sd contrasted with alternating current.

**El Niño: P**rolonged warming in the Pacific Ocean sea surface temperatures when compared with the average value.

**Elvers:** Juveniles of eels

**Embankment:** A wall or bank of earth or stone built to prevent a river flooding an area.

**Endemic:** A plant or animal, native or restricted to a certain country or area.

**Energy:** Work, measured in Newton-meters or Joules. The electrical energy term generally used is

**Epilithic:** Growing on stones or rocks

**Evapotranspiration**: The combined effect of evaporation and transpiration.

**Exotic:** A plant or animal introduced from another country

**Feeding guilds:** Is any group of species that exploit the same food resources, often in a related manner.

**Feed-in-tariff:** Advanced renewable **t**ariff or renewable energy payments is a policy mechanism designed to accelerate investment in renewable energy technologies.

**Fish Ladder**: A structure consisting of a series of overflow weirs facilitating migrant fish to travel upstream pass a dam or weir.

**Flashboards:** A board used for increasing the depth of water behind a dam.

**Flashboards:** One or more tier of boards supported by vertical pins embedded in sockets in the spillway crest.

**Flow duration curve (FDC):** Is a graph that shows the percentage of time that flow in a stream is likely to equal or exceed some specified value of interest.

**Forebay**: A pond or basin of enlarged water from where a penstock leads to a powerhouse.

**Freeboard**: In a canal, the height of the bank above the water level.

**Gabions:** Large, usually rectangular, boxes of metal mesh filled with stones or broken rock.
**Gate Valve**: A vertical gate type water control valve in the weir
**Geomorphology:**
**Geotextiles**: Synthetic materials (e.g. polypropylene, nylon) woven into rolls or mats which are laid as permanent but permeable foundation blankets under stone, rock or other revetment materials.
**Gross Head:** The difference in level between the water surfaces at intake and tailrace of a hydroelectric system
**Hertz (Hz):** Cycles per second, as applied to AC generation.
**Home range:** That part of an animal's familiar area within which it moves
**Hydraulic Gradient**: The hydraulic pressure profile along a pipe or conduit, which is flowing full.
**Indigenous:** A plant, animal or person that is native or original to an area.
**Infiltration**: The process whereby rainfall penetrates through the land surface to form soil moisture or groundwater.
**Installed Capacity**: The total maximum capacity of the generating units in a hydropower plant.
**Kilowatt-hours (kWh):** Represents power (kilowatts) operating for some period of time (hours)1 kWh = 3.6x103 Joules.
**Lacustrine**: Plants or animal inhabiting lakes
**Larvivorous:** Feed on larvae
**Legislation:** Laws considered collectively
**Lentic**: Standing or still water
**Load (Electrical):** The power capacity supplied by a particular plant on an electric system.
**Load factor:** Is defined as the ratio annual energy output kWh/max power output x 8760 hours
**Lotic:** Running or flowing water
**Low-head:** Dams with relatively low height
**Macro-invertebrates:** Small interrelate aquatic animals
**Migration:** Movement from one place to another
**Moraine:** A mass of rocks and sediment carried down and deposited by a glacier,
**Net Head**: The head available for power generation at the turbine, incorporating all head losses in screens, intakes, pipes, valves, draft tube and tailrace.
**Non-conventional:** Not used in the past in conventional grid power generation
**Nutrient spiraling:** Mechanism of nutrient transportation along a river
**Oceania**: Mainly Australia and New Zealand
**Orographic:** Of or relating to mountains, especially with regard to their position and form.
**Output:** The amount of power (or energy, depending on definition) delivered by a piece of equipment, station or system.
**Peak Load**: The electric load at the time of maximum demand.
**Peaking Plant**: A power plant, which generates principally during the maximum demand periods of an electrical supply network.
**Pedology:** Is the study of soils in their natural environment.
**Penstock:** A pipe (usually of steel, concrete or cast iron and occasionally plastic) that conveys water under pressure from the forebay to the turbine.
**Percolation**: The movement of water downwards through the soil particles to the phreatic surface (surface of saturation within the soil; also called the groundwater level).
**Plunge pool:** A deep basin excavated at the foot of a waterfall by the action of the falling water
**Potamodromous fish:** Migrating within freshwater
**Power factor**: The ratio of the amount of power, measured in kilowatts (kW) to the apparent power measured in kilovolt-amperes (kVA).
**Power**: The capacity to perform work. Measured in joules/sec or watts (1MW = 1 j/s).
**Riparian:** Relating to, or situated on the banks of a river
**Rip-rap**: Stone, broken rock or concrete block revetment materials placed randomly in layers as protection from erosion.
**Riverine: R**elating to, or situated on a river or river bank

**Runoff:** The rainfall, which actually does enter the stream as either surface or subsurface flow.
**Run-of-river scheme**: Plants where water is used at a rate no greater than that with which it "runs" down the river.
**Spillway:** is a structure used to provide the controlled release of flows from a dam or levee into a downstream area,
**Stereoscopy: I**s a technique for creating or enhancing the illusion of depth in an image by means of stereopsis for binocular vision.
**Stilling basin:** Is a hydraulic structure located between the outlet works of a dam and the tailwater, to where should return excess flows safely
**Supercritical flow**: Rapid flow who is unaffected by conditions downstream
**Synchronous speed**: The rotational speed of the generator such that the frequency of the alternating current is precisely the same as that of the system being supplied.
**Synergistic:** Together with or united
**Tailrace**: The discharge channel from a turbine before joining the main river channel.
**Theodolite:** A surveying instrument with a rotating telescope for measuring horizontal and vertical angles
**Trade-off**: A balance achieved between two desirable but incompatible features; a compromise.
**Trashrack:** A structure made up of one or more panels, each generally fabricated of a series of evenly spaced parallel metal bars.
**Weir:** A low dam, which is designed to provide sufficient upstream depth for, a water intake while allowing water to pass over its crest.