RETROSPECTIVE REVIEW OF ESMAP TECHNICAL ASSISTANCE TO SUPPORT DEVELOPMENT OF MINI-HYDRO FACILITIES ON IRRIGATION DAMS AND CANAL DROPS IN INDIA

KNOWLEDGE EXCHANGE REPORT

ESMAP/ World Bank
1818 H Street, Washington DC

DECEMBER 2010

DEVELOPED BY
SIVAGURU ENERGY CONSULTANTS &
SOFTWARE DEVELOPERS PVT LTD.

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ACRONYMS

Adanki BC ABC	Adanki Branch Canal
AP	Andhra Pradesh State
APC	Atria Power Corporation
APTRANSCo	Andhra Pradesh Power Transmission Company
BC	Branch Canal
BPC	Bhoruka Power Corporation
CDM	Clean Development Mechanism
CER	Certified Emission Reductions
CESCOM	Chamundeshwari Electric Supply Company
CO_2	Carbon Dioxide
CUMI	Carborundum Universal Murugappa
DANIDA	Danish International Development Agency
DCR	Dhanalaxmi Cotton and Rice Mills
DNES	Department of Non Conventional Energy Sources
DPR	Detailed Project Report
DSI	Detailed Survey and Investigation
EDCL	Energy Development Company Limited
EPC	Engineering Procurement and Construction
ESCOM	Electric Supply Company
ESMAP	Energy Sector Management Assistance Program
FDC	Flow Duration Curve
FSL	Full Supply Level
GEF	Global Environment Facility
GHG	Greenhouse Gases
GOI	Government of India
GOK	Government of Karnataka State
Guntur BC GBC	Guntur Branch Canal
IDA	International Development Association
IBRD	International Bank for Reconstruction and Development
ICR	Implementation Completion Report (for a World Bank project)
IDBI	Industrial Development Bank of India
IFCI	Industrial Finance Corporation of India
IPP	Independent Power Producer
IREDA	Indian Renewable Energy Development Authority
KA	Karnataka State
KCP	KCP Industries Limited
KE	Kerala State
KNNL	Kaveri Neeravari Nigam Limited
KPCL	Karnataka Power Corporation Limited
KPTCL	Karnataka Power Transmission Company Limited
KREDL	Karnataka Renewable Energy Development Limited
KSEB	Kerala State Electricity Board
KSPCB	Karnataka State Pollution Control Board
MNES	Ministry of Non-Conventional Energy Sources
MNRE	Ministry of New and Renewable Energy
MOE&F	Ministry of Environment and Forests
MPG	Master Power Group
NEDCAP	Non Conventional Energy Development Corporation of Andhra Pradesh

NBFC	Non-Banking Financial Company
NHPC	National Hydro Power Corporation
PFC	Power Finance Corporation
PPA	Power Purchase Agreement
RBI	Reserve Bank of India
REC	Rural Electrification Corporation
SBC	Shahapur Branch Canal
SBICap	State Bank of India
SDC	Swiss Development Cooperation
SCL	Sagar Cements Limited
SEB	State Electricity Board
SECSD	Sivaguru Energy Consultants and Software Developers
SERC	State Electricity Regulatory Commission
SNA	State Nodal Agency
SPL	Sagar Power Limited
TN	Tamilnadu State
TWL	Tail Water Level
TNEB	Tamilnadu Electricity Board
UK	United Kingdom
UNDP	United Nations Development Program
USBR	United States Bureau of Reclamation
YIL	Yuken India Limited

MEASURES

cumecs	cubic meters per second
ha	hectares
km	kilometer
kV	kiloVolt
kVA	kilo Volt Ampere
kW	kilowatt
m	meters
mm	millimeter
msl	meters above sea level
MU	million units
MVA	mega Volt Ampere
MW	megawatt
PLF	Plant Load Factor
rpm	revolutions per minute
t	ton
W	Watt
yr	year

EQUIPMENT

BUL	Bulb Type Turbine
CPH	Canal Power House
CSP	Concentrated Solar Power
DSE	Downstream Elbow Turbine
E&M	Electro-Mechanical Equipment
EOT	Electric Operated Overhead Travelling Crane
FRA	Francis Turbine
H&M	Hydro-Mechanical Equipment
HOT	Hand Operated Overhead Travelling Crane
IG	Induction Generator
OFK	Open Flume Kaplan Turbine
OFV	Open Flume Vertical Kaplan Turbine
PH	Power House
PIT	Pit Type Turbine
RBPH	River Bed Power House
RCC	Reinforced Cement Concrete
S Type	Downstream Elbow Type Turbine
SHP	Small Hydro Project
SUB	Submersible Type Turbine
SY	Synchronous Generator
SYP	Siphon (Syphon) Type Turbine
T&D	Transmission and Distribution
UEB	Upstream Elbow Turbine
VSK	Vertical Shaft Kaplan Turbine
VSS	Vertical Shaft Saxo Turbine

FINANCIAL

B/C	Benefit-Cost Ratio
BOOT	Build Own Operate Transfer
Cap	Capital Cost
CC	Capital Cost
CkW	Cost per kilowatt
CRR	Capital Recovery Factor
Dep	Depreciation
E	Energy
FIRR	Financial Internal Rate of Return
Gen	Generation
IDC	Interest During Construction
INC	Incremental
INR	Indian Rupee
IRR	Internal Rate of Return
LCB	Life Cycle Benefits
LCC	Life Cycle Costs
M	Million
M.Rs	Million Rupees
NPV	Net Present Value
O&M	Operation and Maintenance costs
PWF	Present Worth Factor
ROR	Rate of Return
Rs.	Rupees
TA	Technical Assistance
USD	United States Dollar

EXCHANGE RATES (annual averages)
1US$ =

YEAR	INDIAN RUPEES Rs.
1990	17.90
1991	22.72
1992	25.90
1993	30.50
1994	31.40
1995	32.40
1996	35.40
1997	36.30
1998	41.30
1999	43.10
2000	44.90
2001	47.20
2002	48.83
2003	47.53
2004	43.40
2005	43.62
2006	44.48
2007	43.10
2008	40.02
2009	50.64
2010	44.89

Section 1 Executive Summary

Part 1 .1 Background

In 1991, the Energy Sector Management Assistance Program (ESMAP) assisted the Government of India in the development of mini-hydro power plants at existing irrigation dams and canal drops. At that time, attracting private sector investment in renewable energy was widely debated, and some Indian states started awarding concessions to industries. However, with respect to irrigation-based mini-hydro schemes, the perception in India was that such schemes were uneconomic due to high capital costs incurred by a few pilot projects.

The ESMAP assistance included a pre-investment study to review the design and economics of a series of irrigation-based mini-hydro schemes in the States of Andhra Pradesh, Karnataka, Kerala, and Tamilnadu in the southern region, and Punjab in the northern region. Fifty-two prospective schemes proposed by the State Electricity Boards (SEBs) in the mentioned states were reviewed for cost effectiveness, and appropriate techno-economic concepts were applied to improve the designs, minimize investment cost requirements and to enhance the economic merits of the schemes.

The pre-investment study concluded that all the basic prerequisites for economically viable mini-hydropower generation existed at sites in India that were associated with irrigation water storage and distribution infrastructure. An important enabling factor was that, compared to river-based schemes, the cost of developing irrigation-based mini-hydro schemes was assessed to be considerably lower because most of the civil works have already been constructed.

The pre-investment report covered eight projects in Andhra Pradesh, eighteen in Karnataka, seven each in Kerala and Tamilnadu and twelve in Punjab. During the period of 1994-2006, many of the projects covered in the study were implemented by industries and IPPs, which reduced the energy demand supply gap, provided voltage support to the rural grids, and reduced extent of standby diesel auto generation by industries. Specifically, all eight projects in Andhra Pradesh, fifteen in Karnataka, two in Kerala, six in Tamilnadu and ten in Punjab have been implemented. The projects Deverebelekere and Mudhol of Karnataka are under construction. Thus, forty-three schemes have been implemented with a total of 53 power stations including the projects in Punjab. The implementation status of the projects is shown in the table below.

Table 1-1 Pre-Investment Projects Implemented and Reviewed

	Pre-Investment Study Sites (PI)	No of Pre-Investment schemes Implemented/ Under construction	Extra Projects Implemented at Pre-Investment sites (EX)	Total Projects Implemented at Pre-Investment Sites	Reviewed Schemes (PI+EX=TOTAL)
Karnataka	18	15 + 2 = 17	5	22	11+5=16
Kerala	7	2	0	2	2+0 = 2
Tamilnadu	7	6	1	7	5+1=6
Andhra Pradesh	8	8	4	12	8+4=12
Punjab	12	10	0	10	0
Total	52	43	10	53	26+10=36

The 1991 technical assistance from ESMAP was documented in a three-volume report entitled "Mini-Hydro Development on Irrigation Dams and Canal Drops Pre-Investment Study" which was approved by the GOI. The ESMAP reports 139A, 139B and 139C introduced, for the first time in India, concepts such as standardized parameters for turbine flow, rated head, and unit capacity with varied types of turbines suitable for mini-hydro power stations so that electro-mechanical equipment manufacturers get multiple orders for at least a few years and the costs are reduced.

The ESMAP study had a significant leveraging effect for small hydro investments financed by both public and private funds – particularly in the southern states where the policy environment was the most favorable. Indeed, the pre-investment study of 1991 established the rationale for the Renewable Resources Development Project (RRDP) by the World Bank, followed by another similar operation justified by the success of the investments implemented under RRDP. Both operations have devoted great efforts and resources to establishing the government-sponsored lending facility called IREDA (Indian Renewable Energy Development Agency) which was instrumental to attracting private investments into small hydropower by offering both technical assistance and loans to developers on reasonable terms such as interest rate of 12.5% p.a. with 10 years maturity for projects upto 25MW. Many of the projects under review have been implemented under the BOOT method of private sector participation with a thirty-year concession.

Part 1 .2 Purpose of Review

While the results of the two World Bank projects are covered in detail in their respective performance assessment reports and ICRs published in 2003 and 2008, the purpose of the present review is to assess the design and performance of a representative set of projects from those originally proposed by the SEBs and analyzed in the 1991 pre-investment study.

The review covers the following aspects of projects performance:

- Economic and financial results, with implications for viability of irrigation-based mini-hydro schemes in India and elsewhere
- Technical aspects including the optimality of engineering solutions such as the types and layouts of the hydropower schemes
- Implementation aspects including the risks involved and key drivers of success or failure
- Institutional framework and its effectiveness in attracting private investment to the projects.

The major focus of the report is on the technical aspects, where the authors have considerable in-depth knowledge and experience. It is hoped that this analysis, based on two decades of practical implementation of irrigation-based mini-hydro projects, will be of use to practitioners both in India and in other countries with extensive surface irrigation infrastructure wishing to utilize this non-conventional source of energy generation.

This review covers twenty-six implemented projects of the pre-investment report. The twenty-six projects have a total of thirty-six power stations. This is because the pre-investment report mainly envisaged power stations to utilize water released into the canals at irrigation dams, canal drops and at dam toe in a few cases. However, at most of the dam locations, to maximize water utilization for power generation, an additional power station has been proposed by the IPPs consultant, approved by the SEB and stakeholders, and built to utilize the flows released from river sluices to the river course for downstream use. Also in some of the canals, power stations have been constructed at each drop instead of diverting the flows into bypass canals to utilize the head from three to four successive drops in a single power station (Guntur BC and Adanki BC).

The schemes covered in the review are dam- and canal-based schemes constructed with different electro-mechanical equipment types, with a head range from 4m to 30m and plant sizes from 350kW to 12000kW. These characteristics are typical for irrigation-based mini-hydro developments.

Part 1 .3 Structure of the Report

The report is organized in the following sections.

	Title of Section	Purpose
Section 1	Executive Summary	Overall summary of the report with the main findings.
Section 2	Introduction	Provides an overview of irrigation based hydropower projects with a description of various components.
Section 3	Strategic Context	Discusses the purpose for which the concessions were taken up by the IPPs, institutional framework, key contractual agreements and stakeholders.
Section 4	Assessment of the Projects	This section contains the performance assessment of the reviewed projects in terms of a number of criteria, starting from the flow duration curve and actual energy production. The extremities in quantity of energy produced and plant load factors (Table 4-2), time period for implementation (Table 4-5), unit implementation cost (Table 4-6), rates of return (Table 4-11), benefit-cost ratios (Table 4-12),) are presented state by state. The projects are ranked in merit order through financial and energy production criteria and a combined merit is computed. An estimate of greenhouse gas reduction (Table 4-18) attained through the projects with estimated additional revenue per unit energy through sale of CER credits is computed. The section concludes with an overview of some institutional aspects.
Section 5	Key Drivers of Success/Failures, Lessons Learned and Recommendations	Discusses issues affecting project viability, barriers to project success, important lessons learned and recommendations for future projects.
Section 6	Good Practice Projects	Selection of ten projects from the review, which best illustrate good practice in irrigation based mini-hydro are given in Table 6-1.
Section 7	Turbine Efficiency and Flow Duration Curve	Typical efficiency curves for low head turbines and flow duration curves for three projects with methodology for optimizing number of units to maximize energy production is explained in Figures 7-2, 7-3 and 7-4.
Section 8	Electro-Mechanical Equipment Types	An overview of the various types of electro-mechanical equipment especially suitable for low head mini-hydro projects is shown in Figures 8-1 to 8-15.
Section 9	Layout Selection Case Studies	A case study of five projects, which illustrate layouts as implemented with suggested alternatives, which would have resulted in considerable cost savings. The projects are Maddur, Harangi, Guntur, Deverebelekere and Brindavan and shown in Figures 9-1 to 9-5.
Section 10	Optimization Analysis	Outlines the principles of optimizing the installed capacity based on incremental cost-benefit analysis Tables 10-3 and 10-4.
Section 11	Economic and Financial Analysis	Illustrates the methods of calculating economic and financial results of the projects (used for Section 4 and elsewhere) based on the example of five IPP projects on the Guntur branch canal. The results of economic analysis are shown in Table 11-2, with sensitivity cases in Table 11-3 and Figure 11-4. The financial analysis includes sensitivity cases for various parameters listed in Table 11-5. The results are shown in Figures 11-5 and 11-6, and Table 11-6.
Section 12	Annex and References	Project design parameters recommended in the pre-investment report and as implemented by IPPs with the financial results of the projects reviewed in Table 12-3. The current terms and conditions of IREDA loans are also included.

The following sections provide a brief summary of the results of the retrospective review. A total of thirty-six dam based and canal based power stations were reviewed in the study to cover the various types of electro-mechanical equipment types and layouts. The range of installed capacity was from 350kW to 12000kW. Twenty-nine of these projects have been implemented by IPPs and the rest by the SEBs. Separate detailed review reports were developed for each of the projects in this review, covering hydrological aspects, energy production, technical features, and financial analyses. Those separate reports form the reference material for this report.

Part 1 .4 Performance of Implemented Projects by State

Many of the projects have been running successfully for over ten years, with loans fully repaid. Amongst the most successful canal-based projects are the series of projects on the Guntur branch and Adanki branch canals in Andhra Pradesh, whereas for dam-based schemes they are lower Bhavani canal powerhouse in Tamilnadu and Maniyar in Kerala, which was incidentally the first to be implemented in 1994.

The comparison between the envisaged addition to installed capacity in the ESMAP-financed pre-investment report at these locations and that actually achieved in each state is shown in Table 1-2. At some of the dam-based locations, two independent power stations have been implemented, one at the canal sluices and the other at the river bed sluices for more effective utilization of the potential. Such projects are Brindavan, Nugu, Kabini and Harangi.

Table 1-2 Comparison Between Planned and Implemented Capacity and Energy

STATE	DESIGN RECOMMENDATION			AS IMPLEMENTED		
	INSTALLED CAPACITY (MW)	ENERGY (GWh)	LOAD FACTOR (%)	INSTALLED CAPACITY (MW)	ENERGY (GWh)	LOAD FACTOR (%)
KARNATAKA	28.5	130.25	50.15	66.7	193.17	34.28
ANDHRA PRADESH	21.1	96.6	50.35	27.9	94.5	36.93
TAMILNADU	20.5	75.4	43.64	30.75	79.76	28.66
KERALA	19.5	84.2	61.54	17.25	51.9	35.70
TOTAL	89.6	386.4	51.42 (MEAN)	142.6	419.33	33.89 (MEAN)

The installed capacity as implemented has exceeded the capacity estimated in the pre-investment report by a considerable margin. On the other hand, the plant load factors fell short of the envisaged values. This is partly due to the fact that some power plants were built with installed capacity larger than justified by the available water flows.

Following the implementation of the initial mini-hydro projects covered in the pre-investment report, other similar projects were taken up and a total of fourteen projects in Tamilnadu, sixteen in Kerala, seventy in Karnataka, fifty-eight in Andhra Pradesh, and fifty-five in Punjab have been implemented to-date, including those of the pre-investment report. The total installed capacity contributed by these projects is 932MW.

Part 1 .5 Design Approach

The approach to the plant layout and design of the projects has not been the most economic in the majority of the projects. Significant improvements could have been made in the layout and design to reduce costs and implementation period. This report gives a number of recommendations for more cost-effective design of mini-hydro projects. There are many opportunities to reduce costs by appropriately tailoring the design to the project at hand. At the same time, the availability of standardized designs is also beneficial, so a balance always needs to be found between standard and tailor-made solutions.

Examination of some of the tenders under review has revealed that they were very elaborate and overloaded with detailed specifications. At the same time, they were often repetitive from project to project and not necessarily taking account of the factors most important for mini-hydro plant efficiency, such as the maximum utilization of available flows from the irrigation system.

Even more important than the level of detail is the appropriateness of the design approach. For example, mini-hydro projects should not be designed as scaled down versions of large hydro plants as this approach introduces many costly redundancies that unfortunately have been found in many cases. Many opportunities for reducing costs through optimal design have been overlooked by a few IPPs, consultants to the IPPs, and associated organizations such as SEBs and Renewable Energy Departments at State and Central level. Typically, this was because the IPP project consultant has not analyzed energy production potential from the perspective of the available flow, and has instead accepted the recommendation of the manufacturer.

A total of five projects with drawings to illustrate approaches that would have resulted in marked reduction in costs are given in Section 9. These drawings illustrate the use of vertical shaft turbines to reduce powerhouse size for Maddur 2, submersible units for Deverebelekere to reduce water conductor, use of existing sluices for Brindavan to eliminate rock excavation, individual power stations on Guntur branch canal to illustrate how the IPP avoided bypass canals, and the use of a tunnel in the embankment at Harangi by which the IPP reduced rock excavation – though it could have been avoided if the existing sluices had been utilized.

Part 1 .6 Implementation of Construction

The projects were implemented largely by the private sector, often under the BOOT method, with the exception of the projects in Tamilnadu, which have been exclusively implemented by the TNEB. Periods of implementation by the private sector ranged from three to twenty years with an average of five years. Plant layout with appropriate installed capacity and carefully selected electro-mechanical equipment could have reduced the construction period.

Part 1 .7 Energy Production

Irrigation-based projects depend on the releases from the dams into the canals. Their power output is dependent on the pattern of releases, which varies considerably amongst the projects. Flows are available from nine to ten months in certain cases to only four months in others. On average, a plant load factor of 35% was attained, which is higher than the normative plant load factor value of 30% for hydropower plants in the southern grid but lower than the pre-investment report target. Values of 50% were achieved in Guntur canal projects.

Part 1 .8 Cost of Production

Most of the projects, particularly those with nine to ten months flow, have successfully repaid the loan and are profit-making ventures for the private sector. The main advantage for the developers is the negligible running costs, which enables production of low-cost electric energy in the post debt stage.

Schemes that have underperformed could have been successful if prudence had been given to the design and layout. The error was found to be always on the part of the planning and engineering consultants. For example, in the case of the Attehalla scheme, in spite of availability of good potential, improper hydraulic design resulted in very low energy output (maximum power recorded at 100kW against unit capacity of 350kW).

Part 1 .9 Benefits

Irrigation-based mini-hydro projects rely on infrastructure that already exists and can result in very low unit investment on capacity. Typical range was found to be between Rs.17,500 per kW for Maniyar project of 12,000kW capacity completed in 1994 and Rs.69,000 per kW for Brindavan scheme 2 of capacity 4,000kW completed in 2009[1]. Through proper selection of E&M equipment, cost can be contained between Rs.30,000 to 35,000 per kW.

The grid interconnection at 11kV and 33kV in most cases provides voltage and energy support in the rural grids and lowers transmission losses for the SEB due to reduced power flows in the main transmission lines feeding the substation due to localized distributed generation from these mini-hydro plants directly supplying the substation.

Some of the project companies have registered the project as a Clean Development Mechanism activity. This additional revenue, along with the fact that CER revenues are in hard currency, helps the promoter to achieve enhanced overall return on investment. Normal values of baseline

[1] These costs when converted to 1991 prices as per the Consumer Price Index translate to Rs.12,957 per kW to Rs.18,000 per kW respectively. Exchange rates in 1994 were Rs.31.4 per US$ and in 2009 Rs.50.64 per US$. This translates to $557 per kW for Maniyar (in 1994 dollars) and US$1362 per kW for Brindavan (in 2009 dollars).

emission for the southern region grid are 798 t CO_2/GWh. If registered under the CDM activity, the reviewed projects can provide 334,625 CER credits. This translates to an additional revenue of Rs.0.33 per kWh, which can be shown in the benefit stream in the financial analysis. Each MW of installed capacity has the potential to earn 2346 CER credits.

Part 1 .10 Implementation Challenges

The review has revealed a number of challenges that have affected the success of the projects, including: changes in hydrological conditions (e.g., Lock-in-Sula scheme), cost overruns (e.g., Sathanur scheme), risk of undue delays in implementation (e.g., Maddur 2 scheme), non-availability of sound technical advisors to the IPPs (e.g., Attehalla scheme), and accidents due to improper design (e.g., Attehalla and Brindavan schemes).

Attehala is an example of how engineering flaws may severely affect project performance. Specifically, the low energy production in Attehala is due to non-utilization of available discharge in the powerhouse resulting from a number of incorrect design features such as construction of an additional low-crested weir immediately downstream of the main weir, which caused spill over the downstream weir and flooding of the powerhouse. Secondly, the use of a single-unit fixed-blade turbine of 350kW with 9 cumecs rated flow resulted in non-utilization of flows below 2 cumecs. Thirdly, during periods when 9 cumecs was available, flows entered the power canal but resulted in spill from the forebay sides due to insufficient area of the bell mouth intake at the forebay. The details are illustrated with text and drawings in the review report for Attehala, along with suggestions given for rectification of the mistakes together with methods for augmenting the head and flow. The IPP has accepted these alternatives and is interested in modifying the scheme to restore the annual energy generation to the anticipated values.

Part 1 .11 Institutional Framework

Under the current institutional framework, SEBs are obligated to purchase energy produced by small hydro generators at preferential prices set by SERCs. Concessional loans from IREDA are still available, and MNRE continues to provide limited capital subsidies upon completion of such projects, in addition to a three-year interest moratorium and an income tax exemption for ten years and customs duty exemption for schemes implemented with World Bank funds. Additionally, the SNAs (state nodal agencies), also known as energy development agencies, are responsible for promoting renewable energy, in tandem with the MNES, in their respective states.

Overall, the current framework for implementation of small hydro projects is quite supportive and especially well suited to projects in the 2MW to 20MW range.

Projects with capacities of 2MW and more have earned enough revenue to repay the loans and operate profitably. In the review, twenty-one schemes were of capacity more than 2000kW, eighteen below 2000kW including two below 1000kW. It is noticed that some of the smaller schemes have lower load factors (typically 20% to 30%) and hence are likely to have lower returns. Rural agencies such as cooperatives need to be encouraged to develop schemes of 500kW or less. With youth in rural areas now being technically educated, promotion of projects of 100kW to 500kW by them could be encouraged. Hence special incentives such as reduced rates of interest, longer loan terms and higher tariffs would promote many schemes of capacity below 1000kW and promote rural development – especially under Integrated Rural Development at block (county) level with components including roads, water supply, minor irrigation and electricity.

Frequent changes in the contractual agreements such as price paid for energy, levies and limits on the plant load factor by the electricity regulatory commissions in Andhra Pradesh discourages some of the aspiring IPPs.

Part 1 .12 Good Practice Projects

A set of ten representative projects with desired features in layout have been selected as illustrative examples and described in Section 6. The projects are Adanki BC 1, Guntur BC 3, Malligere, Harangi, Lower Bhavani Canal PH, Maniyar, Kabini Canal PH, Nugu, Thirumurthy, and Amaravathy. The main reasons for success in these projects can be attributed to the layout being selected properly and the projects being executed without delays, thus avoiding cost overruns.

Part 1 .13 Conclusions and Recommendations

1.13.1 *Conclusions*

In countries with existing irrigation infrastructure, the addition of hydropower facilities at the dams and canal drops can significantly contribute to meeting the energy requirements in rural grids[2]. Such projects are suitable for providing power to agro-based industries in the vicinity through the local grid and for coordinated operation with existing wind farms or biomass plants. Mini-hydro projects ranging in capacity from 250kW to 12000kW are also well suited for introducing private sector investments in power generation with moderate capital investment.

Despite the prevailing perception of the early 1990s that irrigation-based mini-hydro projects are uneconomic, the experience of practical implementation of such projects in India points to the contrary. Even though the unit investment costs of the projects under this review have not been as low as they were assumed to be in the pre-investment study of 1991, the construction and operation of private hydropower facilities at state-owned infrastructure has proved to be largely successful. Out of thirty-six projects reviewed in this report, twenty-nine were able to find private financiers and seven were implemented by the SEBs. All of the reviewed projects in Karnataka, Andhra Pradesh, and one in Kerala were implemented by the private sector whereas in Tamilnadu they were implemented by the TNEB.

Ex-post assessment of financial returns on the thirty-six projects has shown that they have produced FIRRs in the range of –3.0% to 37.04%[3]. In 25 projects out of 36, the FIRR is above 11%, which is considered satisfactory by the participating investors. Higher rates of return could have been achieved if the layout and design recommendations of the pre-investment study were followed more closely.

The review clearly demonstrates that the lowest rate of return, or longest payback period, is found in those projects where the engineering solution was deficient which, in its turn, often contributes to implementation delays and cost overruns. The case studies analyzed in the report demonstrate how selection of correct electro-mechanical equipment types can markedly reduce the complexity of the hydropower project and reduce costs.

Mini and small hydropower plants should be planned so that the implementation period does not exceed 18 months. Exceeding this period results in mounting interest during construction and other costs.

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[2] All projects studied have been interconnected to the state grid at 11kV, 33kV, 66kV or 110kV substations as per the installed capacity. None of the schemes are supplying power to isolated grids, but serve rural parts of state grid and thereby reduce power flow from distant power stations to the substation and reduce transmission losses.

[3] The revenue streams in the financial analyses are based on the yearly actual energy production and tariff variations till date. Hence they are what the IPPs have realized. Questionnaires were issued to the IPPs in which actual cash flows were also requested. None provided the actual cash flows except the IPP for Nugu schemes 1 and 2. The outflows for debt service, O&M, are based on the factors enumerated in the Section 11 on financial analysis.

In those projects where the rates of return have been disappointing, the IPPs have become aware of the mistakes in design and are interested in rehabilitation of the schemes. For example, in Attehalla the IPP is keen on adopting the recommendations provided in the detailed review report developed as part of this study for restoring the energy production to envisaged values. Similarly, the IPP for Lock-in-Sula, despite the setback due to change in hydrological conditions, has constructed two other schemes which are performing well.

A couple of the originally envisaged projects, such as Shahapur 6 scheme in Karnataka and Pechiparai of Tamilnadu, have not been implemented. Both schemes are below 2000kW and were probably found uneconomic and thus never found financiers. The two schemes could be implemented through careful review by SECSD to improve the design to make them cost-effective.

The general conclusion on economic/financial viability of irrigation-based mini-hydro power projects in India is twofold. First, it must be acknowledged that such projects are highly location-specific, varying significantly in costs and feasibility depending upon topography, hydrology, geology, and accessibility related factors. The investment costs per kW and the realizable plant load factor are the most powerful determinants of economic/financial viability of such projects, with the plant load factor highly dependent both on the natural hydrology of the location and the agreements reached with the irrigation department.

Secondly, where preexisting infrastructure available from the irrigation sector (such as dams and canals) substantially reduces the need for similar construction costs for mini-hydro, and where both natural conditions and institutional arrangements are favorable, such projects are not only viable but in fact represent attractive investments for the private sector, provided that the following enabling factors are in place:

a) Local manufacturing capacity of sufficient scale, and availability of standardized layouts and designs (as well as specifications, tender documents, construction, operation and maintenance procedures) to allow mini-hydro power installations of sufficient quality to be built at competitive costs.

b) Local expertise and capacity to identify the most promising project locations, and develop and implement cost-effective technical solutions for layout and design of mini-hydro schemes, and select appropriate equipment.

c) Assured purchase by the SEB of the energy priced at a level sufficient to create the cash flow required for an attractive return on equity, and timely disbursement of payments to the IPP.

d) Ready access to finance from commercial banks and/or government-sponsored lending facilities on reasonable terms for the greater part of the project investment cost.

e) Arrangements with the state grid for wheeling energy from the mini-hydro generation plant to the point of use at a reasonable cost to the generator.

f) Arrangements with the state grid for banking of energy, which provides for drawing energy by the promoting industry equal to that generated by mini-hydro during periods when the mini-hydro is shut down. This promotes investment in these projects by industries.

g) Some projects will require additional incentives from the government to be viable, such as income tax exemption for several years (up to ten years as per regulations in India) from the date of project implementation and/or capital subsidy (as per the formula Rs.15 x Capacity in MW)$^{0.646}$ million in India which is Rs.15,000 per kW for 1MW to Rs.4,800 per kW for 25MW schemes) given to project developers on successful completion of the project.

Most of the project schemes analyzed in this study have benefited from the availability of at least some of these enabling factors.

There has been good coordination between the irrigation department, which decides the daily allotment of water releases, and the IPP which operates the turbines in the powerhouse to match the required flow pattern.

1.13.2 *Recommendations*

- Concession policies aimed at attracting private sector to renewable energy projects such as small hydro should be introduced more broadly. E.g., the introduction of the BOOT method of private sector participation with a thirty-year concession should be considered in those states (such as Tamilnadu and the northern states) where it is not yet in place. This would provide a boost to renewable energy generation in those states while also promoting small business.
- Measures should be taken to reduce the perception of risk for private investors entering PPAs with the SEBs. Standardized price escalation clauses should be introduced in the PPAs to protect the investors from the inflation risk. Innovative financial instruments to protect small hydro investors from hydrological risks should also be considered.
- A single-window clearance scheme should be introduced at the state nodal agencies, in which the state nodal agency obtains the various permits including land transfer for project development from other government departments. This would enable IPPs to obtain clearances with ease and to save time and effort.
- Ideally, the state nodal agencies should also be strengthened technically to be in a position to comprehensively evaluate project design, viability, and offer advice.
- There should also be a greater interaction by the nodal agencies with the IPPs, whose knowledge and experience, if documented and disseminated, would be useful in avoiding mistakes in the future. E.g., a knowledge bank maintaining the technical records of design and construction similar to USBR reports for the projects would play a major role in knowledge transfer.

At the level of operational policy framework, several additional improvements may be suggested:

- Steps should be taken to reduce delays in land acquisitions/transfer for the project components as well as in the signing of the PPA and approval of the tariff.
- The tendering process for small hydro projects should be streamlined by simplifying or completely omitting some of the steps of the current procedure comprising tender preparation, sale of tenders, pre-bid meeting, bid submission, bid opening and evaluation, etc. For small projects, such an elaborate procedure is not necessary.
- Payment for actual energy produced by the IPP instead of energy delivered at substation should be considered (in conjunction with technical measures to improve the condition of low-voltage transmission networks).
- Access for small entrepreneurs to affordable loans could be further facilitated. In particular, the interest rate of 10.75 to 12.5% available under the current IREDA program could be reduced for mini-hydro projects of less than 1000kW.

For methodology of project appraisals, the following recommendations are made:

- It is very important to conduct an appropriate analysis of hydrologic flow patterns before deciding on the parameters of the power plant. Analysis utilizing the flow duration curve is recommended.

- In financial appraisal of small and mini-hydro projects, cash flows during the loan period need to be carefully evaluated. The use of a ten-year annual energy generation series computed from the observed flow should be used instead of the constant average value of the ten-year long-term annual energy, which will not bring out the magnitudes of deficit in cash inflow patterns.

Recommendations for more cost-effective design include the following:

- The approach to detailed engineering should be commensurate to the scale of the project. At the same time, electro-mechanical equipment should be carefully selected through evaluation of overall cost of installation for several alternatives.
- In irrigation projects being planned or under construction, provision of sluice liners, embedded penstocks in dams, wider drop structures at canal drops suitable for incorporating siphon turbines over the structure will result in reduced implementation periods of the hydropower projects by the private sector.
- Simplification of powerhouse structures by eliminating crane columns and overhead cranes for successive canal drop schemes and adopting the use of mobile cranes.
- Reducing other redundancies in powerhouse design applicable to large hydro projects such as large service bays, butterfly valves in low head projects, adopting induction generators, and simplifying control room instrumentation.
- Selection of multiple semi-Kaplan units based on flow duration curve analyses instead of large capacity Kaplan units.
- Recruiting experienced in-house engineering staff by the IPPs for preliminary designs and layout to be followed by the engineering consultants.

Section 2 Introduction

Part 2 .1 General

India has an estimated small hydropower potential of about 15,000 MW with perennial rivers, streams and a large number of irrigation dams with canal networks. Of this potential, 5,403 sites with an aggregate capacity of 14,293 MW have been identified by MNRE.

The growth of small hydropower is encouraging with the capacity addition of about 100 MW every year over the last few years, and the total capacity addition during the period 2002-2007 was about 537 MW. The target for capacity addition of small hydropower projects for eleventh plan period (2007 - 2012) has been fixed at about 1,400 MW.

Hydropower is the second main source of power generation in India; the installed capacity of hydropower is about 33,711 MW out of the total installed capacity of about 134,942 MW. Of this, the contribution from small hydropower projects below 25 MW capacity is about 2014 MW (i.e. about 1.5% of total installed capacity and 6.0% of hydropower).

In the last 50 years, a large number of irrigation dams have been constructed in India with associated reservoirs, canals and control structures. These projects provide much needed water to many dry areas transforming the barren land into productive fields. The implementation of these projects also created a potential for production of hydropower at these structures, mainly because:

- The irrigation dams are about 10m to 30m in height; hence the created hydraulic head between the water level in the reservoir and the level at the beginning of the canal or the toe of the dam provides scope for power production utilizing water discharged from the river and canal sluices located in the dams.

- Water is conveyed by canals with gentle gradients to limit the flow velocity over vast tracts of undulating terrain. Numerous drop structures are constructed along the course of the canal to negotiate the topography. Such drops are normally 2 to 4 meters in height and suitable for low-head hydropower projects.

- The irrigation season in the country extends from July to March. Therefore, for about nine months each year, a fairly continuous though not uniform supply of irrigation water is available for power generation.

- The investment required to generate power at these structures is minimal since the cost of the main structures have been allocated to irrigation. Hence investment is only required for the power generating equipment and modifications to the irrigation structures.

- Irrigation projects normally require electricity for pumping water onto higher lands than that of the canal course. This is called lift irrigation. Generation of power at the irrigation structures provides this electricity from within the irrigation project thereby reducing demand on the grid.

This report highlights the findings of a retrospective review study of ESMAP's technical assistance in 1991 to aid mini-hydro development at existing irrigation dams and canal drops in India. The technical assistance covered a total of 52 potential mini hydropower projects in the four South Indian States of Andhra Pradesh, Karnataka, Tamilnadu, Kerala and the north Indian state of Punjab.

The technical assistance resulted in a pre-investment report with the objective that private sector participation would be used to implement the projects. Techno-economic criteria were applied and cost-effective layouts were suggested – mainly through adoption of standardized unit capacities to reduce E&M equipment costs to make the projects competitive for private sector implementation.

The following guidelines were presented along with several case studies illustrating methods for reducing civil works:

- Use existing irrigation sluices at dams for the powerhouse flow, instead of constructing new intakes and canals in the flanks.
- Realign water conveyance structures and split single development into stages to shorten water conductor system.
- Eliminate bypass channels in canal drop schemes to reduce civil works.
- Use closed conduits for bypass channels to minimize land acquisition.

Now, almost all the proposed schemes have been implemented, and it is worthwhile to document the experience of the SEBs, private sector and consultants for use in other parts of the world.

This retrospective review examines thirty-six projects. The selection of the projects from the fifty-two schemes was such that the full range of standardized design parameters and various types of electro-mechanical equipment installed is covered. For each of the thirty-six projects, the review included:

Visits to the various nodal agencies in each state to collect information on the project as implemented from the feasibility reports prepared by the IPPs (technical record of design and construction).

Visits to the hydropower projects[4] to collect information on project performance, take photographs and identify the departures from the pre-investment report approach in the layout of the project, design, construction, operation and maintenance.

A set of review reports for the power stations reviewed and assessed was developed and forms an annexure to this report. Each review report gives an in-depth analysis of the project with layout, design parameters, energy generation, photographs of various components, technical particulars of the equipment, cost and financial analysis, etc. The appropriate reports are referred to in the present report. A drawing showing the locations of the projects with illustrative layouts is given at the end of this section.

Projects that have not been implemented were examined to establish whether the reasons are technical and, if so, to provide alternative layouts so that they could be implemented.

Part 2 .2 Types of Hydropower Projects

Hydropower is the only renewable energy technology that is presently commercially viable on a large scale. It has four major advantages: it is renewable, it produces negligible amounts of greenhouse gases, it is the least costly way of storing large amounts of electricity, and it can easily adjust the amount of electricity produced to the amount demanded by consumers. Hydropower accounts for about 17 % of global generating capacity, and about 20 % of the energy produced each year.

[4] For thirty-two of the projects, site visits were completed. Four schemes could not be visited due to time constraints, hence detailed review reports could not be produced. However, the basic information for these four projects such as cost and energy production figures was obtained.

Hydropower projects are classified in India as follows.

Table 2-1 Classification of Hydropower Projects

Classification as per size (as per NHPC)	
Pico-hydro	Capacity less that 5kW
Micro-hydro	Capacity from 5kW to 100kW
Mini-hydro	Capacity from 100kW to 2000kW
Small-hydro	Capacity above 2000 kW and up to 25000kW
Large-hydro	Capacity 25000kW and above
Classification as per Water Regulation	
Storage based	Projects constructed at reservoirs and dams.
Run-of-river	Projects that do not depend on a reservoir for power generation but rather use the flow as available.
Classification as per head	
High head	More than 50m
Medium head	10 to 50m
Low head	2 to 10m
Classification as per Development	
New developments	Projects intended and designed to incorporate hydropower as part of overall development.
At existing hydraulic structures	Projects planned and constructed at a later stage to utilize head created by construction of other infrastructure such as irrigation dams, canals, weirs, drop structures etc.

Part 2 .3 Components of Hydro Projects

Regardless of the type of project, the following main components are required in a hydropower scheme. Section 8 on electro-mechanical equipment provides a more elaborate description of the components.

2.3.1 *Infrastructure*

The basic facilities that must be created for the project to be implemented include development of access roads to the site, acquisition of land for the project components, establishing the site office and material storage yard, providing area for accommodation of workforce, and creating basic amenities at the site.

2.3.2 *Civil Works*

Depending on the type of the project, this includes structures for diverting the water from the sluices / canals to the turbines, powerhouse for accommodating the electro-mechanical equipment and structures for conveying water after generation back to the irrigation canal or river course.

2.3.3 *Electro-Mechanical Equipment*

This includes equipment required to convert the hydraulic energy of water into electric energy and consists of the turbine, gearbox, generator and associated control, protection and monitoring equipment.

2.3.4 *Hydro-Mechanical Equipment*

This includes equipment required to control the flow of water into the powerhouse and consists of various types of gates fabricated out of steel like radial and slide gates and valves such as a butterfly valve.

2.3.5 *Switchyard and Transmission*

The switchyard normally contains a power transformer, which steps up the voltage of the generator to a higher value for economically transmitting the power over a distance to an existing high voltage substation forming part of the grid. Voltages normally adopted are 11, 22, 33, 66 or 110kV.

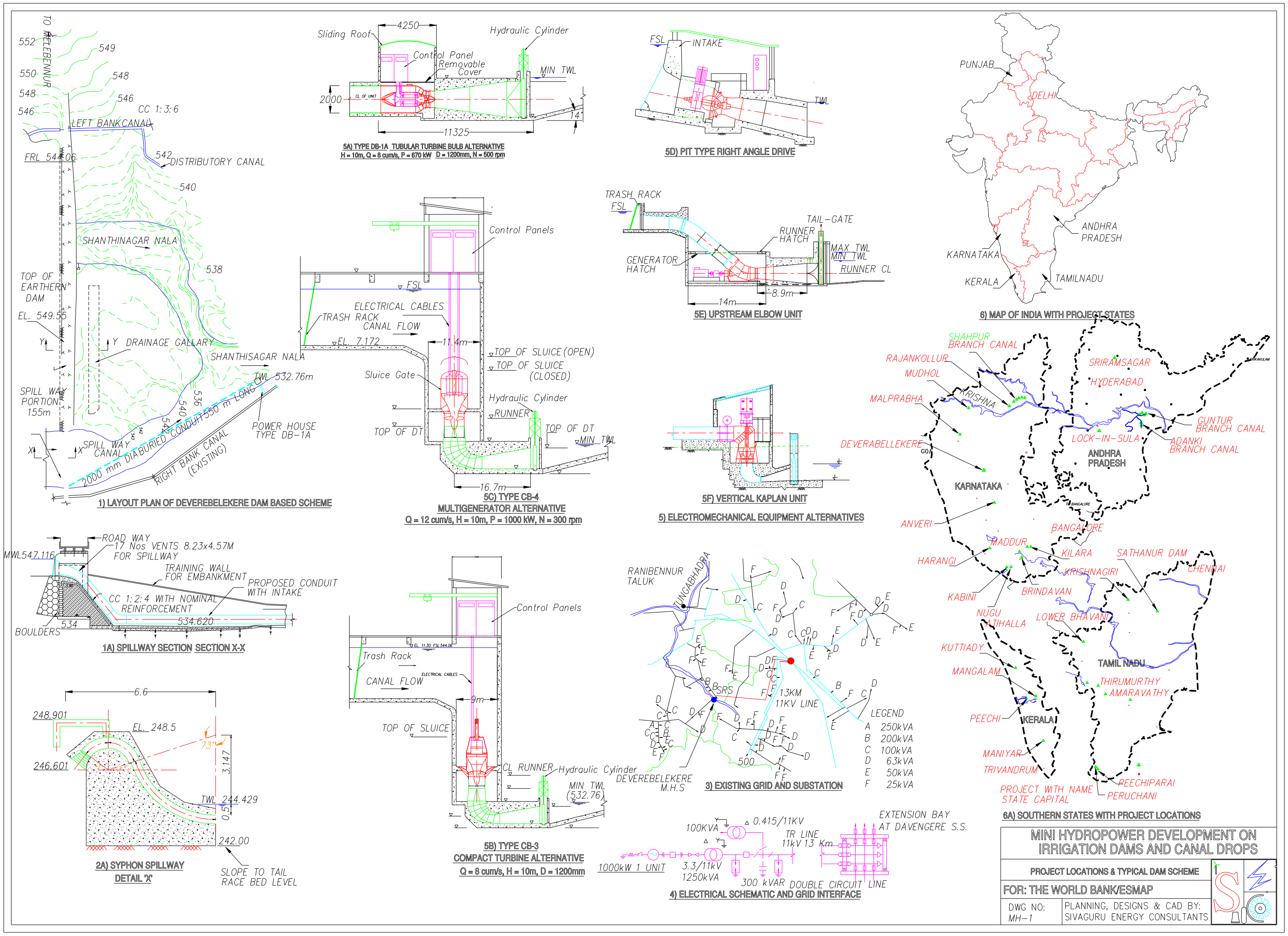


Figure 2-1 Locations of Mini-Hydro Plants with Typical Layouts

Section 3 Strategic Context

This section discusses the types of IPPs which took up concessions, their aims, the institutional framework, key contractual arrangements and stakeholders.

Part 3 .1 Reasons for taking Concessions

During the period 1980 to 1990, grid power supply for industrial consumers was curtailed due to a mounting gap between demand and supply. Following the liberalization in 1990, which allowed the private sector to establish power plants, a number of industries which had either shut down or were operating at part capacity began to explore the prospect of establishing mini and small hydropower projects as an alternative, reliable, and more economical source of electricity.

Most of the initial concessions awarded were hence taken up by industries that also had significant retained earnings for implementing the hydropower projects. The following table gives examples of industries which were awarded concessions.

Table 3-1 Concessions Taken by Industries

Type of Industry	State	Name of Industry/IPP	No of Projects	Aggregate Capacity (MW)
Agro Processing	Andhra Pradesh	Dhanalaxmi Cotton and Rice Mills	3	6.25
Cement Plants	Andhra Pradesh	KCP Cements	5	8.25
		Deccan Cements	1	3.75
		Sagar Cements	2	8.30
Steel Re-rolling	Karnataka	Bhoruka Steel	6	11.2
Hydraulic Engineering	Karnataka	Yuken India	1	0.35
Brewery	Karnataka	Khodays	3	4.0
Heavy Engineering	Karnataka	Tungabhadra Steel Products	1	2.0
Abrasives	Kerala	Carborundum Universal	1	12.0
			23	56.0

Seeing the success of these projects, and introduction of power purchase from private sector by the SEBs, non-industrial companies followed and took up concessions to develop projects – even though their requirement of electricity was not significant. Amongst such companies were new startup ventures for which the primary goal was to invest in hydropower as a self-supporting business venture. Details are given in the table below.

Table 3-2 Concessions Taken as IPPs for Energy Sale to SEBs

Type of Business	State	Name of IPP	No of Projects	Aggregate Capacity (MW)
Hotel	Karnataka	Maruthi Hotels	1	2.0
Hotel	Karnataka	Atria Hotel	2	16.0
IPP		Venika Green Power	1	0.75
IPP	Karnataka	Energy Development Company	2	15.0
IPP	Karnataka	Master Power	2	3.0
Total			8	36.75

Part 3 .2 Issues addressed by the IPPs

The key issues that each type of project developer wanted to address are given below.

Table 3-3: Issues Addressed by the IPPs

Project Developer Type	Key Issues
Existing Industry	A significant part of the energy demand of the existing industry should be met from the mini-hydro plant. Electricity should be wheeled to the industry at nominal charge using the existing grid. Differences between power demand by the industry and supply by the mini-hydro plant is taken care of by a banking arrangement where energy produced by the mini-hydro is drawn by the industry from the grid at a different period. The cost of energy produced by the mini-hydro should be competitive compared to grid power. Power from mini-hydro should be more reliable than that from the grid.
Self-standing IPP	The percentage of equity investment required for the mini-hydro must be low. Financing should be readily available for the debt portion on reasonable terms. The energy generation from the project should be reliable and as far as possible uniform from year to year to ensure debt servicing. Concessions should be available during the tenure when the principal is being returned. Regulatory framework should ensure consistent policy with respect to duties and levies. SEBs should guarantee purchase of power produced. Sale of energy produced to third parties should be possible through use of the existing grid.

Part 3 .3 Project Types and Parameters

The projects covered in the review range from a plant of 350kW up to a plant of 12MW. The following table gives the categories of plant, which are either dam-based or canal-based with the exception of Attehalla and Kutiyadi schemes, which are run-of-river.

Table 3-4 State-wise Distribution of Projects

Type of Project	State with number of schemes
Dam Based	Andhra Pradesh (0) Karnataka (10) Tamilnadu (6), Kerala (1)
Canal Based	Andhra Pradesh (11), Karnataka (7)
Run of River	Karnataka (1) , Kerala (1)

The design parameters of the projects as envisaged in the pre-investment report is given in Table 12-1 and as implemented by the IPPs/ State Government in Table 12-2 for comparison, along with main technical parameters of the electro-mechanical equipment in Table 12-5. Results of the economic and financial analyses are given in Table 12-3 and merits of the projects in Table 12-4.

Part 3 .4 Institutional Framework

The Department of Non-Conventional Energy Sources (DNES) was created in 1982, with the mandate to develop renewable energy projects including small hydro. Later on, with the objective to develop the available small hydropower potential in the country, electricity generation from small hydro projects with capacity up to 3 MW was transferred from the Ministry of Power to DNES. In 1989, the installed capacity of small hydropower projects up to 3 MW was just 76 MW.

Initially, DNES supported demonstration projects throughout the country for various types of small hydropower projects and extended a subsidy of up to 50% of the total project cost under state sectors[5], in addition to the financial support for Detailed Survey Investigations and Detailed Project Report preparation.

The Energy Sector Management Assistance Program (ESMAP), jointly supported by UNDP and the World Bank, assisted GOI to prepare an investment program to develop irrigation / canal based hydropower schemes.

The DNES was later on converted into a full-fledged Ministry of New and Renewable Energy (MNRE) in 1992. Subsequently, the Ministry announced its scheme to support private sector small hydropower projects by providing interest subsidy and other fiscal and financial support for both private and state sector projects.

Subsequently, under the Renewable Resources Development Project (RRDP), the World Bank provided a credit of US$ 115 million from IDA and a US$26 million grant from the GEF for renewable energy to IREDA in 1992. This was supplemented by US$ 50 million from DANIDA and US$ 4 million from SDC. Of this, US$70 million[6] was to be utilized to support small hydropower projects on irrigation dams and canals for a target capacity of 100 MW. The operation moved successfully, and IREDA disbursed the first line of credit to 47 projects with an aggregate capacity of 145.16 MW, exceeding the target by 45%.

The next World Bank project supporting renewable energy in India, approved in 2000, was financed by US$80 million from IBRD, US$ 50 million from IDA, and US$ 5 million from GEF. The target was to develop 200MW of small hydropower projects which was later reduced to 153MW due to cancellation of US$ 26 million of IBRD proceeds at project closure.

The Government of India announced the Electricity Act in 2003, which mainly deals with the laws relating to generation, transmission, distribution, trading and use of electricity. The Act has specific provisions for the promotion of renewable energy, including hydropower and cogeneration. It has been made mandatory that every state would specify a percentage of electricity to be purchased from renewable energy by a distribution licensee.

The National Electricity Policy announced in 2005 aims to provide access to electricity by all households and achieve a per capita availability of electricity of 1000 kWh by 2012. The policy underlines that renewable energy potential needs to be exploited and private sector would be encouraged through suitable promotional measures. The Government has announced a tariff policy in 2006 wherein the State Electricity Regulatory Commissions (SERCs) are required to fix tariffs in their respective states and also decide about the renewable energy purchase obligation. Small hydropower projects are now governed by these policies and the tariff is decided by the SERCs as per the tariff policy. Presently nineteen states – namely, Andhra Pradesh, Assam, Bihar, Haryana, Himachal Pradesh, Jammu and Kashmir, Jharkand, Karnataka, Kerala, Madhya Pradesh, Maharashtra, Mizoram, Orissa, Punjab, Rajasthan, Tamil Nadu, Uttarakhand, Uttar Pradesh, and West Bengal have announced policies for setting up commercial small hydropower projects through private sector participation.

[5] Projects by the state sector are those implemented by the state Government agencies such as SEBs, TRANSCo, ESCOs, etc.
[6] IREDA News Volume 4, No. 3 July – September 2007 page 30.

The MNRE continued to provide financial incentives to the small hydropower developers by way of capital subsidy for commercial projects, which has given impetus to the growth of the sector.

Part 3 .5 Institutional Assessment

The fiscal incentives for small hydropower developers offered by MNRE are detailed below:

- Schemes involving capital up to Rs 1000 million need no environmental clearance from the Ministry of Environment & Forests (MoE&F).
- Ten years tax holiday on grid connected power generation projects.
- Loans from IREDA for schemes with installed capacity up to 25 MW[7].
- Customs duty exemption for electro-mechanical equipment under World Bank source of funding.
- Excise duty exemption for electro-mechanical equipment under World Bank source of funding.
- Promotional incentive scheme to carry out a Detailed Survey & Investigation and preparation of a Detailed Project Report.
- Interest subsidy scheme for setting up of commercial small hydropower projects especially in the private sector.
- Capital subsidy scheme for setting up of small hydropower projects in the State sector.

Some of the improvements that could be made in the institutional framework are:

- The state nodal agencies should be strengthened, especially in the technical aspects to assist developers.

- Steps should be taken to reduce delays in land acquisitions/transfer for the project components, as well as in signing the PPA and approval of the tariff.

- Assistance should be rendered by state nodal agencies to the IPP in getting clearances/approval from the Government agencies.

- Payment for actual energy produced by the IPP instead of energy delivered at substation by the transmission line should be considered (in conjunction with technical measures to improve low-voltage transmission network to enable the use of induction generators).

- Access for small entrepreneurs to affordable loans could be further facilitated. In particular, the interest rate of 10.75 to 12.5% available under the current IREDA program could be reduced for mini-hydro projects of less than 1000kW.

Part 3 .6 Concession Award and Project Development

An institutional framework has been in place in some of the South Indian states to facilitate development of mini-hydro projects under a BOOT scheme. However, Tamilnadu State does not have a private sector participation policy for hydropower with the result that none of the projects have been implemented by the private sector there. In Kerala, only one scheme has so far been developed by the private sector in hydropower.

Karnataka and Andhra Pradesh have however made significant progress and permit hydropower projects of up to 25MW capacity to be implemented on BOOT basis. The tariff for energy from small hydropower is the highest in Karnataka and licensing procedure is not very stringent.

[7] IREDA terms and conditions for the loan are given in Part 3.7.4 and in more detail in Part 12.2 of the Annex.

3.6.1 *Allotment*

A project developer initiates the process of obtaining a concession to develop a project by submission of an application to the state nodal agency for renewable energy (KREDL in Karnataka) and (NEDCAP in Andhra Pradesh).

The nodal agency NEDCAP in Andhra Pradesh periodically issues a request for proposals with brief technical particulars in newspapers for prospective mini-hydro sites on irrigation canal drops which have been identified by the power and irrigation departments.

Prospective IPPs respond to the request by NEDCAP. The applications are reviewed by an allotment committee comprising members from the state nodal agency together with senior personnel of irrigation department, State Electricity Board, forest and pollution control departments. The committee recommends to the Department of Energy the projects for allotment to qualifying IPPs. The Department of Energy then prepares the Government order, which is subsequently published in the state gazette.

3.6.2 *Agreement*

A period of three months is given to the Independent Power Producer to sign a formal agreement with the State Government for the project implementation after approval of the allotment. The time frame given for commissioning the project is normally three years. In Karnataka, if the time frame, which is normally three years for implementation, elapses, the license can be extended in blocks of one year through payment of a fee to the government.

3.6.3 *Purchase of Electricity*

It is now mandatory for State Electricity Boards to purchase electricity produced by renewable sources. Various states have set the tariff, which will be paid for a particular period. The tariffs are set by the state electricity regulatory commission with specific escalation rates.

3.6.4 *Tax*

As one of the financial incentives, income tax on income from the projects is exempted for a period of ten years.

3.6.5 *Duties and Taxes*

Value added tax on electro-mechanical equipment is reimbursable. After project execution, the same can be claimed back. Reduced import duty is applicable to imported electro-mechanical equipment for hydropower projects. For projects under World Bank finance, import and excise duty on electro-mechanical equipment is waived.

3.6.6 *Incentives and Subsides*

Promotional incentives are available to project developers in the form of reimbursement of expenses on field investigations and development of a Detailed Project Report. For project developers who successfully complete the projects, financial incentive in the form of capital subsidy is available in which a part of the capital cost is returned as per the formula 15 x (Capacity in MW)^0.646 Million Rupees.

Part 3 .7 . Contractual Arrangements

3.7.1 *Allotment and Agreements*

The key contractual agreement executed between the IPP and the state government stipulates that the rights to construct and operate the project with specified installed capacity is bestowed on the Company for a period of 30 years, and in case the use of the water resource allotted to the project company is found to interfere at a later date with any planned project by the Government, the IPP shall surrender the concession and will have no rights to claim any compensation.

3.7.2 *Water Rights*

The rights to use water for various purposes are vested with the irrigation department. Right to use water is conveyed to the project company under the condition that at any time the rights can be withdrawn or altered as mentioned above. The quantity of water released daily through the irrigation sluices at the dam will be decided by the irrigation department and communicated to the IPP, which will operate the turbines in the powerhouse at the stipulated flows. In case of a breakdown or maintenance being carried out on the machines, the flows should bypass the powerhouse so that irrigation water is not curtailed. In the event of maintenance work on the canals, the government may order the powerhouses at the irrigation dams to shut down, and IPP is not entitled to any claims.

3.7.3 *Power Purchase Agreement*

The IPP initially applies for an evacuation clearance indicating its choice of the substation for grid interconnection. Proposals are reviewed by the SEB and accorded clearance. The IPP executes a power purchase agreement with the State Electricity Board, which is witnessed by the regulatory commission specifying the purchase price of electricity together with the escalation rate and the time period for which it is applicable. Electricity purchase can be stopped at any time by the SEB in case of surplus power availability in the grid. The agreements generally have a validity period of ten years, after which they are renewed. A network augmentation fee of Rs.300,000 per MW is to be paid towards the construction of a receiving bay at the substation for projects in Karnataka state.

3.7.4 *Loan Terms and Agreement*

The projects are usually constructed by the private sector through borrowing from banks or from IREDA. Loans provided by IREDA can cover up to seventy percent of the estimated cost of the project.

Loans for the debt portion of capital cost were initially available to IPPs from IREDA which disbursed credit received from World Bank, Asian Development Bank, KFW, DANIDA, GEF, etc. In recent years, a number of banks such as SBICap in the country have also been providing loans for mini and small hydropower projects, The loan terms are set by the market conditions and a number of IPPs – especially industries with existing good credit records – have preferred to obtain finance from the commercial banking sector.

IREDA provides loans to:

- Public, private limited companies, NBFCs, and registered societies.
- Individuals, proprietary and partnership firms (with applicable conditions)
- SEBs which are restructured or in the process of restructuring and eligible to borrow loans from REC/PFC.

The general eligibility criteria for obtaining loans from IREDA and the terms and conditions are given in Part 12.2 of the Annex.

The basic interest rate for IREDA loans is currently 10.75% per annum with a maximum loan repayment period of ten years.

3.7.5 *Implementation Contract*

The projects are executed either by a single EPC contract taken up usually by the equipment supplier or through separate contracts issued by the project developer. The usual practice is to develop separate tender documents by the IPPs engineering consultant for civil works, E&M, H&M, and transmission works. The tenders have penalty clauses for delays, shortfall in performance of the equipment, and quality of the civil works.

Part 3 .8 Stakeholders

No specific public consultation / participation requirements are included in Indian statutes for setting up mini-hydro projects. However, there are certain procedural requirements that every project investor needs to follow before implementing the project.

Before implementing the project, investors / developers need to identify the stakeholders, prepare necessary documents, approach the identified stakeholders directly and obtain required clearances / approvals. The stakeholders, after review of documents and investment profile, will accord approvals / licenses or send comments in writing to project investors for further clarifications / corrections. In case they are not satisfied with the project design or have the opinion that the project impacts any of the local environmental / social / economic conditions, they will not issue clearances / approvals and stop the implementation of the project.

The following table gives the representative stakeholders for a project in Karnataka State.

Table 3-5 Typical Stakeholders and their Functions

Stakeholder	Function	Action
KREDL KARNATAKA RENEWABLE ENERGY DEVELOPMENT LIMITED	Policy implementation body in respect of renewable energy projects in Karnataka. KREDL reviews the project documentation and accords clearance for utilizing renewable energy sources in the state.	Issues clearance for setting up the project in Karnataka utilizing hydropower potential available at the proposed site.
KPTCL KARNATAKA POWER TRANSMISSION CORPORATION LIMITED	The state owned electricity utility company that manages the electricity transmission and distribution in Karnataka state. Any electricity generation project proposed in Karnataka shall approach KPTCL for power evacuation arrangements. Both KPTCL and the project proponent shall sign a Power Purchase Agreement, before implementing the project.	Purchases power from the project proponent by executing Power Purchase Agreement to determine the tariff and other terms.
CESCO CHAMUNDESHWARI ELECTRIC SUPPLY COMPANY	A Govt. of Karnataka regional undertaking, which deals with purchase, supply and distribution of electricity in the Karnataka state. Similar ESCOs are responsible for different geographical parts of the state.	Purchases power from the project proponent as per terms of Power Purchase Agreement executed between KPTCL and the IPP.
KSPCB KARNATAKA STATE POLLUTION CONTROL BOARD	A statutory local body that oversees the pollution control aspects in the state. Any project activity shall obtain clearance from the KSPCB before implementation.	Issues clearance for setting up of the project.
REVENUE DEPARTMENT	Is part of Government and monitors utilization of land.	Gives consent to establish the project and registers the project in revenue records of the Karnataka state. Converts land records to enable use by the project.
KAVERI NEERAVARI NIGAM LIMITED KNNL	One of the Government of Karnataka undertakings which takes care of irrigation and hydropower projects in Cauvery basin. Similar organizations are responsible for other river basins.	Provides permission for utilizing the irrigation canal water in Cauvery basin, or in the basin where the project is situated.
FOREST DEPARTMENT	Government organization responsible for overseeing utilization of forestland if any.	Provides permission for utilizing forestland for construction of the project.
LOCAL VILLAGE PANCHAYAT	Elected statutory body of the local populace.	Accords permission for setting up of the project under the jurisdiction of the village. The elected general Body of the Gram panchayat discusses the proponent's proposal for setting up the project in the village limits and gives or refuses consent to establish the project.

The process of obtaining stakeholder comments is either through public announcements or directly approaching the stakeholders as required.

The discussions with the local village panchayat are mainly focused on:

- Significant impact in the region due to the project.
- Are there any possible impacts in the long run?
- To understand stakeholder perceptions.
- Stakeholder awareness of project related issues.

Part 3 .9 Environmental Assessment

The project feasibility report should address comprehensively the following aspects, which will be reviewed by the Environment and Pollution Control Board if required.

- Predominant existing land use pattern in the project area.
- Classification of areas submerged – e.g., forest, fallow, wetlands, etc.
- Nature of forest in surrounding areas
- Duration of project construction with estimated peak strength of workforce and classification, and percentage recruited from local population
- Villages likely to be displaced with proposed resettlement plans.
- Rates of siltation
- Wind flow pattern, climatic conditions
- Ground water levels and quality with pattern of use.
- Surface water use pattern.
- Known sources of pollution and likely industrial developments in the area
- Details of economically viable aquatic life, wildlife, flora and fauna.
- Existing and potential tourist developments
- Existing monuments, religious, archeological sites
- Endemic health problems
- Measures taken to enhance aesthetic aspects
- Changes in water salinity, waterlogging.

Section 4 Assessment of the Projects

This section contains the performance assessment of the reviewed projects in terms of a number of criteria, starting from the flow duration curve and energy production. The actual amounts of annual energy produced, unit implementation cost, time period for implementation, benefit-cost ratio, and rates of return are presented state by state. The projects are ranked in merit order through financial and energy production criteria, and a combined merit is computed. An estimate of GHG reduction attained through the projects with estimated additional revenue per unit energy through sale of CER credits is also computed.

To carry out the assessment, the following tables were developed and are given at the end of this report in the annex:

TABLE	DESCRIPTION
12-1	Names of projects and design parameters as per pre-investment report.
12-2	Names of projects and design Parameters as constructed by IPPs / State Electricity Boards.
12-3	Results of the financial analysis of the projects.
12-4	Rank and merit order computation of the projects.
12-5	Main technical parameters of the electro-mechanical equipment.

Part 4 .1 Technical Assessment

4.1.1 *Hydrological Assessment with Flow Duration Curves*

The hydrologic flow pattern in the canals varies from month to month. A flow duration curve prepared on the basis of historic observed data for each year graphically depicts the water availability in the canal. The pre-investment report analyzed daily flow data for the potential schemes, and an annual flow duration curve was prepared for each project. Based on the shape of the flow duration curve, optimal unit flow and number of units were decided and marked on the flow duration curve so that minimum wastage of available flows resulted, taking into account that turbines have constraints on the minimum flow which can be used for a given rated flow.

In some of the power plants, the number of units and size have not been selected in accordance with the flow pattern requirements indicated by the respective flow duration curves. Such plants are Sathanur, Brindavan, Guntur 2, Shahapur branch canal schemes, and Harangi. The units selected are large capacity units with the result that lower flows cannot be utilized for power generation. This is due to the electro-mechanical equipment manufacturer determining the plant configuration from the manufacturing cost point of view and not from the point of view of maximizing water utilization for power generation. It is more cost-effective to manufacture a large sized turbine than to manufacture a series of smaller capacity units. The IPP’s project consultant has hence not analyzed energy production potential from the aspect of plant operation and has instead accepted the recommendation of the manufacturer. Other advantages of using a larger number of smaller units are: reduction in crane size, more units are available as standby thus improving plant availability, and less wastage of low flows resulting in increased energy generation. This aspect has been illustrated with typical duration curves of Shahapur I, Maddur I and Attehala projects in Figures 7-2, 7-3 and 7-4 of Section 7.

A few findings on outcome of adopting recommendations of pre-investment report on unit capacity are given in the table below.

Table 4-1 Adoption of Pre-Investment Report Recommendations on Unit Capacity

State	Followed pre-investment report	Did not follow pre-investment report	Remarks
Andhra Pradesh	Guntur BC 2 Adanki BC 1,2		The plant flow fixed in the pre-investment report has been followed to within 15% in all the projects.
Karnataka	1	Shahapur 1 to 5	In Shahapur projects 1 to 5, the pre-investment report recommendation to install three units in each powerhouse was not adopted. Instead a single large unit of 1300kW has been installed in all 5 power stations. In Harangi, Brindavan and Kabini, the proposal to have 3 units has been reduced to 2 larger machines.
Tamilnadu	5	1	The State Electricity Board has followed the pre-investment recommendation in all projects except at Sathanur where a single large unit of 7.5MW has been installed.
Kerala	2	0	Followed pre-investment report recommendations.

4.1.2 *Energy Generation*

An analysis of energy generation at the plants gave plant load factor variation from 2.94% to 53.2%. In the table below, the extreme and average project PLF values are compared with the normative PLF of other hydropower projects functioning in each state, and the number of projects achieving better than normative plant load factors is given.

Table 4-2 Plant Load Factor Variation

STATE WITH NORMATIVE PLF	MIN (%)	MAX (%)	AVERAGE (%)	No OF PROJECTS WITH PLF > NORMATIVE
Andhra Pradesh 35%	15.29 Lock in Sula	54.13 Guntur BC 3	33.18 Guntur BC 4	6 out of 12
Karnataka 30%	2.94 Attehala	53.20 Maddur PH 1	34.17 Nugu PH 2	8 out of 16
Tamilnadu 30%	15.05 Sathanur	50.51 Lower Bhavani Dam PH	26.51 Lower Bhavani Canal PH	2 out of 6
Kerala 30%		52.05 Kutiyadi	29.97 Maniyar	1 out of 2

The low value of plant load factor at Attehala is a result of non-utilization of available flows due to incorrect hydraulic design.

As part of the review study, the stream flow for twelve years (1998 to 2010) was analyzed and is presented as duration curves in Figure 7-4 which shows available flow quantum for power generation. The low energy production is due to non-utilization of available discharge in the powerhouse due to a number of incorrect design features such as construction of an additional low-crested weir immediately downstream of the main weir for creating a small pool from which water could be diverted to the power canal. This however caused spill over the downstream weir and also submergence of the upstream weir banks leading to flooding of the power house. Secondly, the use of a single-unit fixed-blade turbine of 350kW with 9 cumecs rated flow resulted in non-utilization of flows below 2 cumecs. Thirdly, during periods when 9 cumecs was available, flows entered the power canal but resulted in spill from the forebay sides due to insufficient area of the bell mouth intake at the forebay. The maximum power output recorded was about 100kW against unit capacity of 350kW. The details are illustrated with text and drawings in the review report for Attehala.

The energy productivity[8] of a plant giving the kWh generated per annum per Rs.100 invested is given in the following table computed with costs adjusted to 1991 levels.

Table 4-3 Variation in Energy Productivity in 1991 Prices (kWh/kW/Rs.100)

STATE	MIN	MAX	AVERAGE	MEAN FOR THE PROJECTS REVIEWED	Average Cost/kW In 1991 prices
Andhra Pradesh	5.71 Lock in Sula	21.09 Guntur BC 3	13.45 Adanki BC PH 1	12.88	20,840
Karnataka	0.81 Attehala	34.85 Maddur PH 2	15.24 Harangi PH 2	14.92	26,482
Tamilnadu	5.47 Sathanur	15.79 Lower Bhavani Dam PH	10.30 Amaravathy	10.14	24,554
Kerala		43.96 Kutiyadi	20.26 Maniyar	27.07	11,665

The average cost per kW in 1991 terms for the reviewed projects was Rs.20,885. Comparing this with the value of Rs.15,908 determined in the pre-investment report, the implemented values are higher by about 31%. This is mainly attributed to changes in layout, adoption of different electro-mechanical equipment requiring more civil works compared to the recommendations in the pre-investment report and not adopting suggested standardization in electro-mechanical equipment parameters.

The present values of maximum tolerable investment per kilowatt for an economic value of Rs.4.55 per kWh for the energy generated and seven year loan term comes to Rs.46,418 per kW in economic terms and Rs.58,023 per kW in financial terms. The minimum annual energy productivity comes to 5.66 kWh p.a./100 Rs invested in economic terms and 4.52 kWh p.a /100 Rs. invested in financial terms. The mean for the reviewed schemes in 2009 price levels was Rs.4.63 kWh p.a/100 Rs.

4.1.3 *Optimization Analyses*

To arrive at the most cost-effective and practical layout, it is necessary to evaluate a series of plant layouts and, for each layout, compute the optimal installed capacity. This procedure is outlined in Section 10 for a representative project.

4.1.4 *Layout*

The use of a downstream elbow turbine is common for mini-hydro plants. Some disadvantages of this are excessive volume of powerhouse due to the width and height from turbine floor to the roof of the machine hall when compared to vertical shaft installation. The space within the powerhouse above the machines is not utilized. This is illustrated in Figure 9-1 which shows the reduction in size of the powerhouse for vertical shaft turbine. Measurements conducted at Maddur scheme 2 powerhouse showed the dimensions to be 18.5m(W) x 19m (L) x 19m (H), which gives a volume of 6680 cubic meters. Against this a powerhouse of 7.8m x 16m x 16m, which is about 2000 cubic meters, is required for a vertical shaft turbine, representing a 70% reduction in volume, giving substantial savings in excavation and concrete and reducing time required for implementation.

[8] The pre-investment report evaluated the energy productivity for the schemes which varied from 20.4 to 117.5 kWh pa/100 Rs. for dam based schemes and from 21.3 to 56.0 kWh pa / 100 Rs. for canal based schemes. In economic terms, maximum tolerable investment per kW was computed as Rs.12,726 and Rs.15,908 per kW in financial terms. The minimum annual energy productivity was 20.6 kWh p.a/100 Rs. invested in economic terms and 16.5 kWh p.a/100 Rs. invested in financial terms. The computation used a CRR of 0.127 and O&M cost factor of 0.02, a plant load factor of 30% and an economic value of Rs.0.80 per kWh for the energy produced.

Some of the powerhouses experience vibratory problems when the machine is loaded to more than 75% of the rating[9].

The table below gives the various types of electro-mechanical equipment used in thirty-three power stations. It is seen that over half the stations are equipped with the downstream elbow type turbine. Discussions with the IPPs brought to light the fact that the careful selection of electro-mechanical equipment was dependent on the knowledge and experience of the IPP or its in-house engineer. For example, in the case of the Guntur branch canal projects by KCP, it is important to note that the Managing Director had spent time visiting a number of plants with similar design parameters in other countries before selecting the Tubular Kaplan with right angle drive type turbine which has many merits.

Table 4-4 Types of Electro-Mechanical Equipment Utilized

	KARNATAKA	ANDHRA PRADESH	TAMILNADU	KERALA	TOTAL
DSE	12	3	3	1	19
VSK	1	0	3	0	4
PIT	1	0	0	0	1
BULB / RAD	0	3	0	0	3
OFK	1	3	0	0	4
FRA	1	0	0	1	2
TOTAL	16	9	6	2	33

4.1.5 *Construction*

Construction period for the projects varied widely. The first concession was awarded in Kerala State to Carborundum Universal for the Maniyar Project, which was the earliest to be completed in 1994. In over thirty of the projects concessions were awarded during 1990-95 with most of the projects commissioned by 2000. A few projects could not be completed due to technical delays.

Amongst the pre-investment report findings of 1991 was the fact that the cost of pilot mini-hydro schemes was high because they were being executed as scaled down versions of large hydropower projects with a number of redundancies and inapt layouts[10]. The construction period was hence extended leading to cost overrun and increase in IDC. The period can be reduced by adoption of suitable construction techniques listed below for reduction in the implementation period of mini-hydro schemes.

[9] Vibration in some of the power houses for instance at turbine floor (draft tube top of downstream elbow turbine) is due to incorrect foundation design. The ratio of forcing frequency (synchronous or runaway speed of generator) to natural frequency of draft tube opening (including concrete over the draft tube) should not be in the range 0.75 to 1.25. For example it is noticeable in Brindavan scheme 2 and Nugu scheme 2 where the equipment is by the same supplier.

[10] The present review confirmed this since most of the powerhouses are large with overhead cranes.

Table 4-5 Variation in Implementation Period[11]

	MINIMUM	MAXIMUM	AVERAGE
ANDHRA PRADESH	2 (Lower Manair)	5 (Guntur BC 3)	3.6 (Guntur BC 4,5)
KARNATAKA	3 (Maddur at Malligere)	20 (Maddur at Hulivana)	7.2 (Harangi Scheme 1)
TAMILNADU	3 (Lower Bhawani Dam PH)	12 (Perunchani)	7.8 (Thirumurthy)
KERALA	3 (Maniyar)	21 (Kutiyadi)	11.5
AVERAGE	3.25	14.5	8.4

Most of the projects have been constructed with little mechanization in the construction activities. Adoption of prefabricated members for RCC works could further reduce construction period.

The powerhouse superstructure construction period can be reduced significantly by adopting a steel structure as has been done in the Malligere powerhouse on the Maddur Branch Canal.

The use of prefabricated buried conduits for water conductor system instead of open canals minimizes land acquisition and reduces the cross-sectional area required (applicable to Maddur at Hulivana project).

Specifying the use of a mobile crane instead of using an overhead crane for equipment erection can eliminate the need for erecting crane columns and result in a simpler powerhouse.

Part 4 .2 Economic and Financial Assessment

The projects were constructed during the period of 1992 to 2010; hence there is a variation in the cost range as given below. For each of the projects a financial analysis as given in Section 11 was carried out. The main results of the analysis are given in Table 12-3. Key values of the parameters from the analysis are given in the following tables.

The ESMAP-financed pre-investment study of 1991 estimated the investment costs of dam-based mini-hydro to be between Rs. 5,204 and 14,140 per kWh. For projects based on canal drops and weirs, the estimated costs were between Rs. 9,807 and 22,560 per kWh. Subsequently, IREDA has found that the average cost of mini and small hydropower plants varied from Rs.58,200 to Rs.67,600 per kW during 2009. This would correspond to about Rs.15,200 – 17,600 in 1991 prices, which is the year when the pre-investment study was done.

The investment costs actually incurred by the IPPs at the sites of the pre-investment study proved to be substantially higher on average than both the original ESMAP and IREDA estimates (except for the two projects in Kerala). In the table below, the figures in parenthesis are expressed in constant Rupees for base year 1991 by converting costs as per the Consumer Price Index curve given in the annex.

[11] Figures in the table are the period in years taken to implement the project

Table 4-6 Variation in Cost per kW

	Period	Min Cost/kW	Max Cost / kW	Average Cost /kW
Andhra Pradesh	1997-1999	40,486 (23,719) (Adanki PH 3) 1997	62,972 (36,893) (Adanki PH 2) 1997	50,667 (25,628) (Guntur BC 1) 1999
Karnataka	1997-2007	25,783 (6,726) (Harangi Scheme 2) 2011	69,000 (18,000) (Brindavan Scheme 2) 2009	49,444 (25,010) (Harangi Scheme1) 1999
Tamilnadu	1990-2006	25,938 (28,032) (Lower Bhawani Dam PH) 1990	65,231 (23,354) (Perunchani) 2006	50,538 (27,916) (Lower Bhavani Canal PH) 1998
Kerala	1994-2010	17,500 (12,957) (Maniyar) 1994	39,760 (10,372) (Kutiyadi) 2010	

In terms of 1991 prices, the projects with minimum and maximum investments per kilowatt are shown in the following table.

Table 4-7 Variation in Cost per kW at constant 1991 prices

	Period	Min Cost/kW	Max Cost / kW	Average Cost /kW
Andhra Pradesh	1997-1999	21,036 (Lower Manair) 2001	36,893 (Adanki PH 2) 1997	26,977 (Guntur BC 6) 1999
Karnataka	1997-2007	6,726 (Harangi Scheme 2) 2011	31,565 (Attehala) 1998	20,861 (Maddur Scheme1) 1999
Tamilnadu	1990-2006	20,103 (Amaravathy) 2006	28,032 (Lower Bhavani Dam PH) 1990	24,110 (Sathanur) 1999
Kerala	1994-2010	10,372 (Kutiyadi) 2010	12,957 (Maniyar) 1994	

Table 4-8 Variation in Cost per kWh at constant 1991 prices

	Period	Min Cost/kWh	Max Cost / kWh	Average Cost /kWh
Andhra Pradesh	1997-1999	0.76 (Guntur BC 3) 1999	2.80 (Lock-in-Sula) 1998	1.28 (Lower Manair) 2001
Karnataka	1997-2007	0.46 (Maddur Scheme 2) 2011	19.64 (Attehala) 1998	1.16 (Shahapur Scheme1) 1997
Tamilnadu	1990-2006	1.01 (Lower Bhawani Dam PH) 1990	2.93 (Sathanur) 1999	1.55 (Amaravathi) 2006
Kerala	1994-2010	0.36 (Kutiyadi) 2009	0.79 (Maniyar) 1994	

The average cost of generation from the projects was Rs.1.52 per kWh in 1991 constant prices. This is much higher than the Rs. 0.424 per kWh estimate (average for the states of Andhra Pradesh, Kerala, Karnataka, Tamilnadu, and Punjab) in the original pre-investment report. The substantial upward revision of the generation costs is due both to the higher investment costs incurred and, in some cases, lower than expected annual plant load factors. However, the difference would not have been as dramatic if not for a few outliers like Attehala.

If the cost is arranged as per the types of electro-mechanical equipment adopted, irrespective of the state, the following results are obtained with the cost in 1991 constant prices indicated in parenthesis.

Table 4-9 Cost per kW as per Electro-Mechanical Equipment

	KA	AP	TN	KE
DSE	36,714 to 50,250 (21,509 to 17,991)	41,488 to 50,667 (24,306 to 25,628)	50,538 to 65,231 (27,916 to 23,354)	17,500 (12,957)
VSK	53,000 (22,168)	-	47,667 to 56,150 (24,110 to 20,103)	-
PIT	43,667 (18,264)			
BULB	-	44,440 to 53,333 (22,481 to 29,460)	-	-
OFK	58,093 (19,628)	40,486 to 62,972 (23,719 to 36,893)	-	-
FRA	42,900 (18,659)	-	-	39,760 (10,372)

An analysis of the average cost per kWh evaluated during the loan term for the various projects gave a variation of Rs.0.75 to 37.64 per kWh during the loan period is given in the table below.

Table 4-10 Variation of Cost of Energy in Loan Period

	Period	Min Cost/kWh	Max Cost / kWh	Average Cost /kWh
Andhra Pradesh	1997-1999	2.10 (Lower Manair)	5.96 (Guntur BC 5)	4.32 (Adanki PH 1)
Karnataka	1997-2007	1.22 (Maddur Scheme 2)	25.16 (Attehala)	3.39 (Kabini Dam PH)
Tamilnadu	1990-2006	0.75 (Lower Bhavani Dam PH)	37.64 (Sathanur)	9.97 (Lower Bhavani Canal PH)
Kerala	1994-2010	0.85 (Maniyar)	1.42 (Kutiyadi)	1.42 (Kutiyadi)

With the exception of a few outliers such as Sathanur which introduce an upward bias into the average cost estimates, it must be noted that most projects had cost of generation comparable to the selling price, thus avoiding significant negative cash flows during loan period.

The financial rate of return for the projects (FIRR) was computed and the following table gives the variation. The rates of return varied from –3.00% to 37.04%.

Table 4-11 Variation in Financial Rate of Return

	Tariff	Min FIRR (%)	Max FIRR (%)	Average FIRR (%)	Number of Projects in which FIRR > 10.6%
Andhra Pradesh	2.25	0.1 Lock-In-Sula	37.04 Guntur BC 3	18.38 Adanki PH 1	9 out of 12
Karnataka	2.80	-3.00 Attehala	29.48 Brindavan Scheme 1	15.89 Shahapur 4	14 out of 16
Tamilnadu	2.80	0.1 Sathanur	36.05 Lower Bhavani Canal PH	12.65 Perunchani	3 out of 6
Kerala	2.80		35.90 Maniyar	33.51 Kutiyadi PH	2 out 2

Comparing the above rates of return on the investment with the weighted average costs of capital of 10.6%[12], most of the projects are profitable ventures – despite the setbacks noted above, such as the higher than expected investment costs and lower load factors in some cases. The average payback period for the thirty-five projects excluding Attehala is about 7 years, or 9 years if Attehala is included. Payback periods for all thirty-six projects are included in Table 12-4.

Projects with the lowest rate of return or longest payback period are those in which the engineering solution was deficient. E.g., in the projects Lock-in-Sula and Sathanur, the installed capacity provided is more than that justified by the flow duration curve analysis. In the case of Attehala, the hydraulic design of the project was incorrect.

The evaluated benefit-cost ratios from the economic analysis are as follows. Almost all the projects have benefit-cost ratios significantly more than one.

Table 4-12 Variation in Benefit-Cost Ratios

	Min BC	Max BC	Average BC	No of Projects with BC > 1
Andhra Pradesh	0.773 Lock in Sula	2.893 Guntur BC 3	1.894 Adanki BC PH 1	11 out of 12
Karnataka	0.143 Attehala	3.527 Brindavan Scheme 2	2.128 Nugu Scheme 2	15 out of 16
Tamilnadu	0.823 Sathanur	4.226 Lower Bhavani Canal PH	2.102 Perunchani	5 out of 6
Kerala		4.173 Kutiyadi	Maniyar 2.987	2 out of 2

The variation in benefit-cost ratio is from 0.14 to 4.22. The projects in the maximum benefit-cost ratio category are those where flows are good, with the result that any negative effects have been overcome. This is true for Brindavan where, in spite of the accident resulting in collapse of the powerhouse, good generation has been possible; and Maniyar where shortfall in generation from 12MW to 8MW reduced the energy output in the initial years.

[12] The WACC is computed as interest rate x (1 – corporate tax rate) x debt percentage + (required rate of return on equity x equity percentage). With interest rate 12.5%, required return on equity 15%, corporate tax rate 30%, and debt equity ratio 70:30, the WACC is 10.625%.

Part 4 .3 Ranking of the Projects

To rank the projects in a merit order, the following parameters from the economic and financial analysis and from the plant performance were selected:

- Benefit-Cost Ratio
- Net Present Value per kW
- Financial Internal Rate of Return
- Cost per kWh
- Plant Load Factor
- Cost per kW
- Time Period for Implementation
- Period for which the plant has been functioning and reliable data available

The projects were evaluated state by state to establish the merit order within the state. This is preferred due to differences in hydrological regimes as well as financial conditions such as tariffs amongst the states.

For each general parameter given above, the evaluated project-specific parameter from the financial analysis was given marks with zero being assigned to the lowest value of parameter obtained in the group of projects in the state and 1.0 (or hundred percent) to the highest value. Thus each project parameter was converted into marks by proportion using the type of relationship below, which applies to the benefit-cost ratio:

$BC_{marks} = (BC_{project} – BC_{min})/(BC_{max} – BC_{min})$

Where BC_{max} and BC_{min} are maximum and minimum values for the projects in the state.

For a parameter where a lower value is desirable - e.g., cost per kW, the following type of relationship was used:

$CkW_{marks} = (CkW_{max} – CkW_{project})/(CkW_{max} – CkW_{min})$
Where CkW_{max} and CkW_{min} are the maximum and minimum values of cost per kW in the group of projects.

The individual marks for the eight parameters were equally weighted to compute the overall project mark. These are given in the Table 12-4.

As a result, the following distinctions have been made amongst the projects.

Table 4-13 Merit Order of the Projects

Category	Marks (%)	Projects
Excellent	80-100	Lower Bhawani Dam PH, Guntur BC 2, Adanki BC PH3, Guntur BC 3
Very Good	60-80	Maniyar, Kutiyadi, Lower Bhawani Canal PH, Maddur Scheme 1 (Malligere), Brindavan Scheme 1, Adanki BC PH 1, Shahapur 1, Shahapur 5, Maddur Scheme 2, Nugu Scheme 2, Brindavan Scheme 2, Shahapur 4, Shahapur 2, Harangi Scheme 1
Good	45-60	Shahapur 3, Guntur BC 1, Kabini Canal, Harangi Scheme 2, Kabini Dam, Adanki BC PH 2, Lower Manair
Fair	25-45	Guntur BC 5, Guntur BC 4, Nugu Scheme 1, Guntur BC 6, Perunchani, Thirumurthy
Not Successful	Below 25	Attehala, Sathanur, Amaravathy, Lock-in-Sula

The projects in the Excellent category owe their success to good flows and have all been functioning for more than ten years with debt fully repaid. Variations in energy output due to bad years have been swamped by a number of good years.

Projects in Very Good and Good category are mostly those with good generation and repaid loans except Brindavan Scheme 1, which is operational for only two years but has however achieved a load factor exceeding 45% in the last two years.

The projects categorized as Not Successful are projects with reduced inflow (Lock-in-Sula) or with oversized installed capacity (Sathanur) – with the exception of Amaravathy, which has been in operation for only two years with below average generation. During the years to come, generation at this project will improve with hydrological conditions.

Part 4 .4 Comparison

Projects with a score of more than 50 are listed below and can be considered successful. For Tamilnadu state, the score is relaxed to 40 since it is a water short state.

Table 4-14 Successful Projects

State	Successful Projects
Karnataka	Brindavan Scheme 1, Brindavan Scheme 2, Harangi Scheme 1, Harangi Scheme 2, Kabini Canal, Kabini Dam, Maddur Scheme 1 (Malligere), Maddur Scheme 2, Nugu Scheme 1, Nugu Scheme 2, Shahapur 1, Shahapur 2, Shahapur 3, Shahapur 4, Shahapur 5
Andhra Pradesh	Adanki BC PH 1, Adanki BC PH 2, Adanki BC PH3, Guntur BC 1, Guntur BC 2, Guntur BC 3
Tamilnadu	Lower Bhawani Dam PH, Lower Bhawani Canal PH
Kerala	Maniyar

A comparison between the anticipated additions to capacity and energy as per the pre-investment study and that achieved is given below.

Table 4-15 Comparison between Planned and Implemented Capacity and Energy

STATE	DESIGN RECOMMENDATION			AS IMPLEMENTED		
	INSTALLED CAPACITY (MW)	ENERGY (GWh)	LOAD FACTOR (%)	INSTALLED CAPACITY (kW)	ENERGY (GWh)	LOAD FACTOR (%)
KARNATAKA	28.5	130.25	50.15	66.7	193.17	34.28
ANDHRA PRADESH	21.1	96.6	50.35	27.9	94.5	36.93
TAMILNADU	20.5	75.4	43.64	30.75	79.76	28.66
KERALA	19.5	84.2	61.54	17.25	51.9	35.7
TOTAL	89.6	386.4	51.42	142.6	419.33	33.89

From the above, it can be observed that expected capacity additions were achieved and in fact exceeded in most of the states (especially in Karnataka) and in the southern region as a whole. Specifically, installed capacity additions and energy output deviated from the expected values by the following values.

Table 4-16 Percentage Differences between Planned and Implemented Capacity

	Installed Capacity	Energy
Karnataka	+134%	+48.3%
Andhra Pradesh	32.2%	-2.2%
Tamilnadu	50%	+5.78%
Kerala	-11.5%	-38.3%

Part 4 .5 Cutoff Analysis

Table 12-4 gives various financial parameters such as the rate of return, benefit-cost ratio, etc. For the following cutoff values, projects achieving values below the cutoff are listed.

Table 4-17 Unsuccessful Projects as per Cutoff Analysis

	Internal Rate of Return < 10.6%	Payback period > 8 years	BC < 1.0
Karnataka	Attehala	Attehala	Attehala
Andhra Pradesh	Lock-in-Sula	Lock-in-Sula	Lock-in-Sula
Tamilnadu	Amaravathi, Sathanur	Amaravathy, Sathanur	Sathanur
Kerala	-	-	-

Part 4 .6 CDM Benefits

Some of the projects companies have registered the project as a Clean Development Mechanism (CDM) activity. Approval and registration of the project as a CDM activity enables the project proponents to access additional revenues by selling certified emission reductions (CERs).

This additional revenue, along with the fact that CER revenues are in hard currency, help the promoter to achieve enhanced overall return on investment and mitigate some financial risks. The amount of avoided GHG emissions due to the implementation of the projects is estimated below.

The procedure is to calculate the baseline emission based on the methodology of operating margins and build margins. The operating margin is the emission per unit of energy for existing plants in the system, and the build margin is for the projects under construction. From these values, the baseline emission is calculated as the mean of the two values. Normal values of baseline emission for the southern region are 798 t CO_2/GWh based on the mean for the years 2002-03 to 2005-06.

Total potential CER credits are about 334,625 through these projects. At 8 Euros per credit with an exchange rate of Rs.53 per Euro, the total potential additional revenues are about Rs. 141.9 million. This translates to additional revenue of Rs.0.33 per kWh, which can be shown in the benefit stream in the financial analysis.

Table 4-18 GHG Reduction and CDM Revenues

STATE	INSTALLED CAPACITY (kW)	ANNUAL ENERGY (GWh)	ANNUAL AVOIDED EMISSIONS (t/CO_2)	ANNUAL REVENUE IN M.Rs @ 8 EURO and Rs.53/EURO
Karnataka	66.7	193.17	154,150	65.35
Andhra Pradesh	27.9	94.5	75,411	31.97
Tamil nadu	30.75	79.76	63,648	26.98
Kerala	17.25	51.9	41,416	17.56
TOTAL	142.6	419.33	334,625	141.86

Section 5 Key Drivers of Success / Failure, Lessons Learned, and Recommendations

Part 5 .1 Key Drivers of Success/ Failure

The subsections 5.1.1 to 5.1.18 outline the reasons that determine the degree of success of the projects.

5.1.1 *Planning*

In many of the examined projects, alternative electro-mechanical equipments were not considered or evaluated in the plant layout. Instead, the downstream elbow type turbine was adopted – probably due to the common practice and influence by the equipment supplier. Examples are the Maddur Scheme 2 and Brindavan, where the powerhouse is large and about thrice the volume compared to that required for a vertical shaft turbine configuration (Figure 9-1).

A cost-benefit optimization analysis for each alternative type of E&M equipment with associated costs of civil works, E&M, H&M, and T&D costs is required as outlined in Section 10 on Optimization Analysis. This is to be compared with the benefit stream from each alternative to decide the best type of equipment.

Graphs showing various benefits vs. costs should be plotted for different capacities of the selected equipment and the installed capacity determined at either minimum cost per kWh, or at a benefit-cost ratio cutoff.

Plants operating with low load factors have not been sized properly in cases such as Sathanur 1, with 7500kW instead of 2 of 2500kW, Shahapur 1 with 1300kW instead of 3 of 350kW, and Kabini Canal powerhouse with 2 of 1500kW instead of 3 of 650kW.

5.1.2 *Cost Overruns*

Cost overruns in mini-hydro projects are common due to a number of factors. Amongst the factors contributing to overruns are unrealistic estimates at the feasibility phase and unexpected problems during construction. This has occurred in Sathanur project in Tamilnadu where the project estimated to cost Rs.170.3 million as per supplementary detailed project report in October 1992 was actually completed at a cost of Rs.357. 5 million in March 1999 due to changes in specifications of hydro-mechanical[13] works and generator.

5.1.3 *Design Staff*

Considering the fact that most of the projects are established by companies whose core competence is not hydropower, many have sourced technical advice from outside the company. The easiest access to technical manpower was to absorb personnel retiring from the SEBs as in-house engineers. This had drawbacks since very few of these personnel have actually had hands-on experience in mini-hydropower, even though they might have had considerable experience in design of large hydropower schemes and their operation and maintenance during their tenure in the SEBs. Consulting firms mostly founded by such personnel experienced in large hydropower projects often fail to adopt innovative techniques to reduce the costs of mini-hydro. This is seen for example in Brindavan, where a massive rock has been excavated for the power canal. Also unnecessary was a large surge tank provided at the downstream toe of the dam in Kabini left bank canal and Nugu powerhouses. Other examples include a hydraulic design mistake in Attehala and an oversized powerhouse structure in Maddur Scheme 2.

[13] Hydro-mechanical equipment refers to the gates and valves with operating equipment. Electro-mechanical refers to the turbine, generator and auxiliaries.

5.1.4 *Construction Period*

The layout selected should be such that a project of magnitude less than 2000kW should be completed in about 18 to 24 months, and larger ones should not take more than 36 months to implement. This would include the time spent on planning, feasibility study, detailed engineering, tendering, tender evaluation, contract award, construction and commissioning. This requires a very high degree of expertise from the project developer who has to prepare the design for the tender with considerable foresight which is site-specific instead of merely following a previous case. The risks involved are illustrated by the case of Maddur at Hulivana project, where implementation has stretched to about 15 years.

5.1.5 *Specifications*

The engineer who develops the specifications for the scheme has to be well versed in all aspects of mini-hydro. Examination of some of the tenders under review has revealed that they were very elaborate and overloaded with detailed specifications. At the same time, they were often repetitive from project to project. The specifications need to be tailored and developed for the project at hand. The key issue is to fix the most economical project layout and then develop the specifications.

5.1.6 *Tendering*

The tendering process followed in most cases is an elaborate procedure comprising tender preparation, sale of tenders, pre-bid meeting, bid submission, bid opening and evaluation, etc. For small projects, such an elaborate procedure is not necessary.

5.1.7 *Detailed Engineering*

The approach to detailed engineering should be commensurate to the scale of the project. Many projects are built as scaled down versions of large hydropower installations. A new set of design criteria is required for use in the detailed engineering for mini-hydro projects. For example at the Attehala plant, all requisite conditions for production of hydropower exist. But due to improper hydraulic design of the power channel and wrong selection of equipment, required flows were not able to enter the turbine and low flows could not be utilized. The result was that energy production is severely reduced. The civil structures now need to be redesigned for rehabilitating the project.

5.1.8 *Changes in Hydrological Conditions*

Hydropower projects are most affected by changes in the hydrological conditions, which may either be natural or intentionally introduced. The hydrological data used in the pre-investment report and this report are based on actual releases at the dams into canals and measured flows in the canals at the appropriate locations. The data take into consideration conditions imposed by irrigation and are distinct from the natural flows determined by natural hydrological changes alone.

During dry years such as those of 2002 and 2003, many reservoirs did not fill up, resulting in reduced power generation for most projects. In projects where a couple of dry years immediately follow the year of commissioning, the debt service and cash flows are affected. This happened at the Lock-in-Sula and downstream of Nippulavagu plants. The IPP reported its problems to IREDA, who accordingly agreed to extend the loan tenure from seven years to twelve years, in addition to waiving the interest during the period of 2002-03.

5.1.9 *Unforeseen Risks*

Accidents can occur due to improper design, adversely affecting the viability of the project. For instance, at the Brindavan scheme, deep excavation of the left flank for the diversion of reservoir water to the powerhouse and improper selection of electro-mechanical equipment resulted in inappropriately large amount of civil works, which led to flooding and collapse of the powerhouse before commissioning. As a result, two years of energy production, which is about 90 million kWh, were lost resulting in cash flow deficit for the IPP.

5.1.10 *Water Rights and Conflicts*

The IPP is given the rights to generate power at dams by releasing available flows in the canals through the powerhouse. The flow is specified by the irrigation department on a daily basis. The IPP cannot alter the flow patterns set by the irrigation department. The irrigation department can stipulate an increase or reduction in the flows from present patterns to suit the irrigation requirements. Any reduction in plant energy output due to this is a risk the IPP has to assume and no compensation can be claimed from the irrigation department.

Water availability in the future after project implementation depends on the command area development in the proposed irrigation area. Irrigation projects are usually commissioned and new branch canals are added subsequently over a period of time. The releases at the dams into the main canals will experience an increase to meet demand whereas they will decrease in branch canals due to increased upstream utilization over a period of time.

Conflicts can arise in water use between the project and the local community that uses water for irrigation. For example, the irrigable area may steadily increase over a period of time, resulting in reduced flows in the canal due to upstream utilization. Energy output will hence reduce. This has occurred in the case of Shahapur branch canal projects, where construction of an additional canal at the head regulator of Shahapur branch canal has resulted in intermittent flow pattern due to diversion of water to a new canal for 15 days every month.

5.1.11 *Community Involvement*

To aid the project development, the affected communities should increase their participation in the projects. For example, in a recent review of the renewable energy policy in Karnataka, it is proposed that five percent of the ownership of a renewable energy project should vest with the local community. This will help in reducing delays for obtaining approvals from local agencies.

5.1.12 *Tariffs*

India has a long history of tariff supports for renewable energy, including small hydro. However, the feed-in tariffs for small hydro producers have often fallen short of adequately compensating the IPPs for the high resource and other operational risks faced by them over the long time horizon of such projects. The Government has announced a tariff policy in 2006 wherein the State Electricity Regulatory Commissions (SERCs) are required to fix tariffs in their respective states and also decide about the renewable energy purchase obligation. Small hydropower projects are now governed by these policies and the tariff is decided by the SERCs.

There have been some recent upward revisions of the feed-in tariffs in some states – e.g., to Rs.3.40 per kWh in Karnataka. However, prior to this, the tariff was Rs.2.80 per kWh and was not revised for well over five years. In the meantime, increase in steel and cement prices had caused construction costs to escalate. Suitable escalation in tariff related to a cost index should be incorporated.

In some states, the tariff policy has been subject to sudden changes with unclear rationales. For example in Andhra Pradesh, the initial policy allowed IPPs to sell power to third parties by wheeling arrangements with a 2% wheeling charge. Many IPPs had entered into PPAs with third parties at lucrative rates. However, in 2001 the Andhra Pradesh Regulatory Commission prohibited third party sales, and IPPs were directed to sell power only to APTRANSCo at Rs.2.25per kWh. Further in 2004, the regulatory commission proposed declining tariff starting at Rs.2.60 in the first year and reducing to Rs.1.88 per kWh in the tenth year of project operation. These moves have discouraged the IPPs and some have resorted to litigation.

5.1.13 *Changes in Government Policy*

Other sudden changes in government policy, such as introducing new levies or abruptly increasing existing rates, discourages developers and can affect financial returns on projects. For example, in Andhra Pradesh, measures such as a sudden and large increase in wheeling charges paid to the network owners, imposition of water use cess, and canceling carry-over of energy banking were opposed by the IPPs and challenged in the high court. The high court ruled in favor of the IPPs and the electric regulatory committee has gone on appeal against the order to the Supreme Court, where the matter is still pending.

5.1.14 *Wait time*

The order books of the few E&M manufacturers within the country are full – with the result that wait times between equipment order and supply are steadily increasing due to the limited number of machines that can be produced. This slows down project implementation.

5.1.15 *Delays in E&M Supply*

For the Sathanur Project, out of the implementation period of 42 months (from October 1995 to March 1999), a delay of 36 months was caused by the supplier of the generating machinery. As a result, 1012 million cubic meters of utilizable discharge from the Sathanur reservoir had gone to waste resulting in an energy generation loss of 73.14 million kWh with a consequential revenue loss of Rs.136.2 million.

5.1.16 *Energy Cost*

Small hydropower is known to be one of the most economically viable forms of renewable energy in India, with a cost of generation that can be close to that of conventional energy. However, capital cost overruns and low plant load factors can ruin this advantage. For the Sathanur project for example, while the anticipated cost in October 1992 was Rs.1.59 per kWh, the actual cost was Rs.3.67 per kWh (as per SEBs working) on completion of the project in March 1999. This was very high compared to the average off-take price of Rs.2.10 per kWh received during 1999-2000, with the consequential loss of Rs.1.57 per kWh generated.

5.1.17 *Import of Equipment*

Various types of electro-mechanical equipment available worldwide and suitable for reducing the civil work needs may be expensive[14] if imported compared to locally available equipment. If the consultants suggest appropriate E&M equipment, manufacturers will be compelled to start producing the same to meet the demand after discontinuing production of the uncompetitive types.

5.1.18 *Cap on Load Factor*

The State Electricity Regulatory commission in Andhra Pradesh is now limiting the load factor of hydropower plants to 35 percent. The effect will be to curtail the output of plants operating at higher load factors and such IPPs may be forced to increase the installed capacity.

Part 5 .2 Lessons Learned

5.2.1 *Project configuration*

The IPPs should give importance to E&M equipment selection and plant layout for reducing costs and the construction period.

[14] Some of the imported equipment becomes expensive due to exchange rate between the Rupee and major European currencies. The usual mechanism adopted to make the equipment competitive is to have Indian manufacture through collaboration with the foreign supplier.

5.2.2 *Industrial Demand*

In the state of Andhra Pradesh, many of the mini-hydro projects are implemented by industries which wheel[15] the power through the state grid. The state has a declining tariff for purchase of energy from 1st year to 10th year. This does not affect the industries which consume the low-cost energy produced from mini-hydro rather than buying it from the grid. However, this does affect the IPPs selling power to the grid, whose revenues would fall every year. This has led to more industries but fewer IPPs wishing to implement mini-hydro projects. The average price paid for grid energy by industries is Rs.4.19 per kWh. After repayment of debt, cost of generation from mini-hydro is about Rs.0.50 to Rs.1.00 per kWh. The savings are thus significant for the industries.

Banking of energy by the SEB is a desirable option to the industry to reduce the timing difference between generation and industrial demand. Projects with installed capacity up to 500kW can be successfully implemented by startup companies.

5.2.3 *Nodal Agencies*

Availability of personnel to review the design of mini-hydro projects is scarce. The nodal agencies should be strengthened technically to undertake effective assessment of project design and suggest corrective measures before awarding technical clearance. The nodal agencies could in this way enforce design standardization effectively by functioning as a coordinating body for equipment procurement. This would lead to multiple orders for the electro-mechanical equipment for a number of projects resulting in cost savings for the IPP.

5.2.4 *Construction*

Mini and small hydropower plants should be planned so that implementation period does not exceed 18 months. Exceeding this period results in mounting interest during construction and cost overruns.

5.2.5 *Transmission*

The SEB pays for energy delivered at the grid interconnection point (substation). Transmission lines are on an average about 5 to 8km in length and usually are 11kV or 33kV. The design of the line is important to reduce the energy loss in the line and increase revenue.

5.2.6 *Operation and Maintenance*

Corrosion of hydro-mechanical equipment is an issue in some of the mini-hydro plants especially those in Adanki Branch Canal. Present practice of annual maintenance by painting is not effective. Some modern practices like cathodic protection will reduce recurring maintenance costs. Specifications for electro-mechanical equipment should take into account water quality analyses such that suitable materials can be selected during manufacture.

5.2.7 *Electro-Mechanical Equipment*

There are over 50 manufacturing plants worldwide producing mini-hydroelectric equipment. Careful sourcing of equipment coupled with indigenous manufacture will be helpful for technology transfer.

[15] Wheeling of power refers to use of an existing transmission network belonging to any other agency to transmit power from the source of generation to the point of use. A charge equal to a percentage of the energy wheeled is paid to the owner of the transmission network to compensate for increased losses in the network.

Part 5 .3 Recommendations

5.3.1 *General*

Mini-hydro development at irrigation dams and canal drops has considerable potential to contribute as significant component to renewable energy, especially in countries where extensive irrigation infrastructure exists. The schemes should however be planned, designed, and constructed with an appropriate techno-economic approach so that implementation period is reduced to about 18 to 24 months.

5.3.2 *Approvals*

Single-window clearance scheme, in which the state nodal agency obtains the various permits including land transfer for project development from other government departments, should be set up to enable IPPs to obtain clearances with ease and to save time and effort.

Project design should preferably be such that land requirements should fall within government lands to enable permissions to be obtained easily.

5.3.3 *Monitoring*

The state nodal agencies should have frequent interactions with the IPPs. The nodal agencies should endeavor to keep a complete record of the project particulars in their office. During this review, none of the nodal agencies had any information on the projects, and it was necessary to approach each of the IPPs individually to obtain the necessary information and request permission for site visits.

5.3.4 *Nodal Agencies*

The nodal agencies usually charge an upfront fee at the time of project allotment and issue a technical clearance to the project after scrutiny of the project report. However the scrutiny is restricted to issuing a clearance letter based on other approvals obtained by the IPP, the key one being the irrigation department approval. No design checks are made. It would be beneficial to build up a pool of technical expertise in the nodal agencies, which the developers can rely on when required. The design team could, for instance, offer special advice on electro-mechanical equipment selection, civil works, and hydraulic modeling. This could be done in cooperation with universities, where the available technical know-how could be put into practice.

Technical services in the form of development of feasibility reports could also be offered. This will ensure a standardized approach to many projects instead of a varied design is adopted for mini-hydro.

5.3.5 *Electro-Mechanical Equipment*

A number of project sites with sub-megawatt potential exist in the country. However, most of the local electro-mechanical equipment manufacturers are set up for production of machines over 1000kW capacity. Sub-megawatt machines are at present more expensive per kW installed, which renders development of such projects expensive.

Manufacturing of sub-megawatt machines at an acceptable price within or in collaboration with firms from outside the country will improve contribution of mini-hydropower projects. The use of induction generators can reduce the cost of generating equipment and simplify control equipment.

5.3.6 *Construction*

Mechanized construction with simple construction equipment can reduce implementation period. The Government research institutions should undertake research into new construction techniques suitable for prefabrication.

5.3.7 *Operation and Maintenance*

Many canals are not lined, with the result that seepage losses are high. The increased water table in the vicinity of the canals is a cause for entry of water into the lower levels of some powerhouses requiring energy for pumping. Lining of canals will prevent this and also reduce losses, leading to increase in water availability for irrigation and reduction in breaches during monsoon, which results in canal closure and loss of generation as reported at Harangi.

Part 5 .4 Advice for Practitioners

- At irrigation dams, efforts must be made to utilize the existing sluices for the powerhouse by using sluice liners. This would minimize civil works required for the waterway.
- Energy generation estimates and flow duration curve analyses as outlined in Section 7, electro-mechanical equipment selection from types given in Section 8, and optimization as outlined in Section 10 will help in deciding correct equipment, design parameters and layout.
- Forebay and surge tanks on the downstream of dams as provided in some of the reviewed projects are unnecessary and increase the civil works.
- Layouts involving construction of deep power canals to accommodate the large variation in reservoir water level should be avoided. Conduits are preferred.
- In canal drop based projects, land acquisition should be minimized by avoiding long headrace and tailrace canals. The cost of installing power stations at each drop should be compared carefully with the savings in land acquisition and civil works for the case of combining the head from several drops.
- The powerhouse design should be simplified and the super-structure should not extend more than a few meters above the existing ground level.
- The use of overhead cranes should be avoided and provision made for mobile cranes, which would decrease crane cost and reduce the powerhouse civil works.
- There should be multiplicity of units to better utilize available flows in which case turbines of semi-Kaplan type could be used, resulting in cost savings.
- Multiple units allow for adapting to changes in hydrological pattern since one or two units could be shifted to other locations.
- Since most power stations connect to the 33kV grid, the use of induction generators results in simpler control equipment and reduced costs.
- Reduction in cost of the computer control system should be considered, e.g., by reducing the number of control panels in the control room.

- The hydrological assessment should be made over a thirty-year period, and plant design should cater to changes in the expected flows. The design of the plants is based on available historical flow data of releases from dams into canals. As many of the irrigation projects were implemented in the 1960s, data for thirty years was available at pre-investment study time in the 1990s. The flows in the thirty year period included critical years whose effect on reducing energy was forecasted. There should be sufficient risk mitigation to offset occurrence of such critical hydrological events during the loan period. If the available historical observed river flow happens to be less than 30 years at the commencement of the power project, a rainfall runoff relationship in the catchment has to be established for the period of actual available flow data (daily/monthly discharge). This will consider the land use pattern through satellite imagery. The developed relationship between rainfall and runoff could be used if flow data is not available for 30 years on the basis of available rainfall in the catchment.

- Electro-mechanical equipment should be carefully selected through evaluation of overall cost of installation for several alternatives.

- Low-head projects which utilize a butterfly valve in addition to the gate control provided upstream of sluices have significant head loss. It was found to be 0.1kg/cm2 in case of Thirumurthy, which is equivalent to a 1m head loss. The reading was equal to a 10% loss in head since the net head for the project is 10m. Thus, the use of a butterfly valve for low-head schemes should be avoided.

- The use of a gearbox results in an overall efficiency lower by about two percent compared to direct coupling. In the case of Thirumurthy project, in which direct coupling between turbine and generator is used, better efficiency is obtained.

- Equipment reliability is very important. Imported equipment of higher cost may be more reliable than low-cost locally available alternatives. Monetary value of lost generation due to outages may outweigh the initial savings in cost and this must be evaluated.

- Use of steel portal structures for the powerhouse reduces construction period compared to RCC structure in which formwork is involved.

- Cash flows during the loan period need to be carefully evaluated. The use of a ten-year annual energy generation series computed from the observed flow should be used instead of the constant average value of the ten-year long-term annual energy, which will not bring out the magnitudes of deficit in cash inflow patterns.

Part 5 .5 Policy Issues

5.5.1 *Private Sector Participation*

Some states like Tamilnadu have not permitted private sector investments in hydropower. This could be due to State Government’s desire to retain control over operation of the water resource projects. The impact of this has been that about 155 hydropower projects comprising 52 canal-drop, 20 dam-based and several run-of-river schemes aggregating to 373MW have not been implemented which could have contributed significantly to meeting the energy demand if handled by IPPs.

5.5.2 *BOOT Period 30 Years*

The concession period of 30 years initially awarded can be extended by another 20 years. IPPs of successful projects will prefer to extend the concession period. For unsuccessful projects, which are not earning enough revenue, the IPP has to incur expenditure on the project till the expiry of the concession period.

5.5.3 *Equity Amount 30 percent*

The required debt-equity ratio structure of 70:30 is suitable for successfully running industries but is difficult for new IPPs to raise unless the project is small and below 500kW in capacity. This may have the effect of not encouraging startup companies.

5.5.4 *Electricity Purchased at Substation*

The length of the transmission lines varies from about 1km to even 15km in some of the projects. Since the received energy at the substation is what earns revenue, about five to ten percent of generated energy is lost and projects not close to the substations may be viewed as not promising.

5.5.5 *Transmission Line Built at IPPs Cost*

In the case of transmission lines exceeding a few kilometers, the IPPs investment on the transmission increases. In addition, IPPs have to pay a Network Augmentation Fee, which is considerable. Right-of-way negotiations also take time. A policy whereby low-voltage network is built by the SEB will promote development of remote sites.

5.5.6 *Declining Tariff*

The purchase price for energy produced varies amongst the states. Andhra Pradesh has a declining tariff introduced from 2004 with Rs.2.69 per kWh for the first year that reduces progressively to Rs.1.69 per kWh in the tenth year.

IPPs who produce energy for sale to the grid expect to have a tariff structure with an ascending rate as opposed to industries, which consume the power produced through wheeling. Industries are keen to establish mini-hydro plants since their primary aim is to produce very low cost energy for meeting their industrial demand and returns from the investment is through sales of the industrial product. Thus in states which have a declining tariff structure for energy from the first to tenth year, many of the promoters of small hydropower projects are industries like in Andhra Pradesh.

5.5.7 *Income Tax Exemption*

Income tax exemption period of ten years is helping the IPPs to effect savings once the loan is repaid.

5.5.8 *Water Royalty*

Water Royalty was initially present but was abolished in Karnataka during 1996 as an incentive to encourage IPPs. Andhra Pradesh continues to have a royalty, which has to be paid. The canal projects, which normally have good flows in Andhra Pradesh, give higher load factors and hence revenues from royalty will contribute to the maintenance of the irrigation infrastructure without undue burden on the IPP.

5.5.9 *Load Factor Cap*

The cap or ceiling on load factor of 35% has been introduced by APSERC to bring the load factor of mini-hydro plants in line with the system load factor for hydropower plants. With the load factor cap of 35% in place for a 1MW plant, energy will be purchased by the SEB up to 0.35x8.76GWh - i.e. 3.06GWh at the applicable power purchase rate. Thereafter the purchase price will be Rs.0.25 per kWh.

Section 6 Good Practice Projects

Part 6 .1 Selection Criteria

The following criteria were used to select projects to represent good practice in mini-hydro development at irrigation dams and canal drops:

- The project planning, design or layout adopted resulted in cost savings.
- A feature was adopted which is suitable for replication in future projects to advantage.
- An approach suggested in the pre-investment study was adopted.
- Construction period was minimal.
- The projects selected illustrate a variety in type of layouts and range of installed capacity.

Detailed review reports for all the projects examined in this study with extensive photographs have been prepared and form reference material for this report. These reports contain detailed project description, monthly energy generation, and technical review of the projects along with features of the civil works and detailed parameters of the equipment.

Table 6-1 Good Practice Projects

Sl	Project	Capacity (kW)	Reason for selecting as good practice	E&M TYPE
1	Adanki Branch Canal	6268	Series of 3 projects in which standardization in design has been adopted resulting in cost savings. Scope for large scale application after review of design for cost reduction	OFV
2	Guntur Branch Canal 3 and 4	8250	Construction of projects within the main irrigation canal without clubbing successive drops and without bypass channels	RAD
3	Maddur at Malligere	750	Low head mini-hydro on canal drop implemented by a startup company with vertical Kaplan layout	OFV
4	Harangi	9000	Project constructed at existing dam through construction of a tunnel in left flank for intake without excavation of flanks	DSE
5	Lower Bhavani Canal PH	8000	Powerhouse built adjacent to the existing canal utilizing irrigation sluice and provision of a Howell Bunger Valve for bypass of irrigation water during powerhouse shutdown.	DSE
6	Maniyar	12000	Irrigation dam based project with diversion type development comprising intake, power tunnel, and forebay. First project to be completed by IPP in 1994 within 3 years	DSE
7	Kabini Canal	3000	Dam based low head project utilizing existing sluices with pit type turbine resulting in reduction of volume of powerhouse.	PIT
8	Nugu	1500	Canal and dam based powerhouse with common surge tank and using existing irrigation sluices. Powerhouse 1 has downstream elbow type turbine and powerhouse 2 has Francis turbines	DSE FRA
9	Thirumurthy	1950	Dam based powerhouse with downstream elbow without gearbox using steel liners in existing canal irrigation sluices	DSE
10	Amaravathy	4000	Dam based powerhouse utilizing water releases for downstream users with vertical shaft Kaplan turbines supplied by penstocks and steel liner in existing river sluices	VSK

The main reasons for success in these projects can be attributed to the layout being selected properly and the projects being executed without delays, thus avoiding cost overruns. Three projects were constructed by the SEB, which also had good experience in hydropower. Projects Adanki, Guntur, Kabini, Thirumurthy and Amaravathy have imported electro-mechanical equipment with some unique features. Reliability of these imported machines is better. In powerhouse at Nugu, Harangi and Maddur and Maniyar, the equipment is manufactured through collaboration with a foreign partner.

Part 6 .2 Adanki Branch Canal

The projects constructed by the Dhanalakshmi Cotton and Rice mills on the Adanki Branch Canal illustrate the advantages of standardization in design. Though there are three projects with differing heads and slightly reducing discharge, standardized design has been adopted for the three powerhouses, which are 2 x 1270kW, 2 x 794kW, and 2 x 1070kW. As a result, six identical turbines were ordered for the three powerhouses, which resulted in lower manufacturing costs. This resulted in cost savings for the IPP which had to prepare only one set of designs and procure only one set of spares for the three powerhouses. The electro-mechanical equipment selected for the three powerhouses is the concrete[16] spiral semi-Kaplan turbine. The cost of the electro-mechanical equipment was reduced as compared to full Kaplan turbine. This resulted in the powerhouse having compact dimensions and reduced super-structure costs. The electricity produced in the three power stations is transmitted by a 33kV transmission line to Piduguralla substation, which is 2km away. The electricity is wheeled to the cotton and rice mills, which belong to the IPP, located at a distance of about 20km.


View of the powerhouse 1 from upstream


View of the interior of the powerhouse 1

Photo 6-1 View of Adanki Branch Canal Powerhouse 1

Table 6-2 Parameters of Adanki Branch Canal Projects 1 to 3

Installed Capacity	Average Energy (GWh)	Capital Cost (Rs M)	Constructed
2 x 1070	7.88	100	1997
2 x 794	6.11	100	1997
2 x 1235	9.61	100	1997

The civil works are common for the three power stations, which facilitated the reuse of formwork in concreting. It is to be established whether concrete spiral case provides savings for the equipment manufacturer and increases civil works cost for the IPP. The design calculations need to be gone through in conjunction with electro-mechanical equipment designs to find out the efficiency guaranteed, actual efficiency obtained in each of the three power stations, and the results of the dry and wet commissioning tests.

[16] Concrete spiral cases are usually adopted in low-head hydro plants with large flows requiring a vertical shaft installation.

Part 6 .3 Guntur Branch Canal

The projects constructed by KCP Limited on Guntur Canal are five projects of standardized design. An important feature of these projects is that successive canal drops are not combined using bypass canals to concentrate the head on a single power station. Instead, power stations have been built at each canal drop in the main canal. This resulted in elimination of land acquisition from private landowners as well as minimizing civil works for water conductor system. The type of electro-mechanical equipment selected is the best and most aptly suited to the site conditions. The powerhouse is very compact having minimal width and length.

Installed Capacity	Average Energy (GWh)	Capital Cost (Rs.M)	Constructed
3 x 750	10.4	100	1999
2 x 750	4.2	80	1999
2 x 750	4.2	80	1999
2 x 750	4.1	80	1999
2 x 750	4.1	80	1999

View from upstream showing powerhouse constructed in the canal

View of the right angle drive turbine showing vertically mounted Induction generator

Photo 6-2 Views of Guntur Branch Canal Powerhouse 3

Standardization of design enabled the same set of construction formwork to be used in the powerhouses and only one set of spares to be kept.

Type of turbine adopted is such that the size of the powerhouse is more compact than if a downstream elbow machine “S” type had been adopted as has been done in the project upstream to this project. The powerhouses would have been thrice the width if S-type had been adopted, since the speed increaser and gearbox are located vertically, enabling a better utilization of the space from service bay to roof level.

The use of induction generator in the powerhouses is good practice with significant reduction in the cost of equipment and is more robust.

The above approach has extensive application provided the irrigation department agrees to the use of main canal with modifications of the existing canal drop structures. However, the overall cost of the five water conductor systems with five powerhouses constructed will have to be compared with the alternative of construction of a single powerhouse of larger unit capacity in the bypass canal. It needs to be considered that larger unit capacity rate per kW is less than the smaller unit capacity per kW.

Part 6 .4 Malligere

The Malligere scheme is an example of a low-head canal drop project located in Mandya district of Karnataka. The project has been implemented by a startup company and successfully completed within two years.

The new Maddur branch canal that takes off from the end of the Vishweshwaraiah canal at 46th km is designed to convey about 25 cumecs. The canal runs close to Mandya and Maddur towns and further branches off into old Maddur branch and Keragodu branch canal. At the 24.5 km near the village Malligere, the canal flows in a lined channel and there is a 4.5m drop structure about 100m downstream of the road bridge across the canal.

The project is among the smallest covered in the review being next in capacity to the Attehala scheme, which is 350kW. The essential components of this hydropower project constitute a short power channel and forebay, intake structure with gates and trash rack located at the end of the power channel, a bypass weir on the main canal with automatic gates, powerhouse with an installed capacity of 750 kW, tail race pool and tail channel. The water is diverted from the irrigation canal just upstream of the drop structure into the power channel and enters the powerhouse. After passing through the turbines, the water is conveyed back to the new Maddur branch canal downstream of the drop structure through a tail channel of about 41.65m length. The project was constructed at a cost of Rs.43.5 million and took three years to construct. It generates about 3.5 GWh of energy per annum.

The project comprises an open flume concrete spiral case turbine with fixed guide vanes with a synchronous vertical generator of capacity 750 kW coupled to turbine through a speed increaser gearbox mounted in the machine hall. The generated voltage at the generator terminals is 3.3 kV with a step-up voltage of transformer 3.3 / 11 kV. The evacuation of power is through 11kV transmission line to KPTCL's 66/11kV substation at Hampapura, which is at a distance of 6km.

	
View of the Malligere powerhouse with the Maddur branch canal	Interior view of powerhouse showing the gearbox and vertical shaft generator

Photo 6-3 Views of Maddur at Malligere Powerhouse

The noteworthy feature of this project is that the IPP constructed the scheme within 3 years. The layout and design appear to be good. The powerhouse was constructed rapidly due to use of steel frames as opposed to RCC[17] construction.

[17] Reinforced Cement Concrete requires steel and suitably shaped formwork in which concrete is poured and allowed to set and harden. Fabricating steel reinforcements and installing formwork takes more time and is an added cost compared to using steel structures.

Part 6 .5 Harangi

The project is located at Harangi dam in Kodagu District of Karnataka. Two power stations for generating electricity have been proposed at the dam. The first utilizing the head available between reservoir level and the left bank canal water level has been built with an installed capacity of 9MW. A tunnel of 5m diameter and 85m length constructed in the left abutment conveys water to the powerhouse. The powerhouse has two horizontal shaft Kaplan turbines with rated discharge of 26.2 cum/s of downstream elbow type, driving the generators through speed increasing gearbox. Power generated at 11kV is stepped up to 66kV and transmitted to the state grid by interconnection with the Kushalnagar substation through a 14km transmission line. The project has so far generated 262.00 GWh of clean electricity and earned a revenue of approximately Rs. 820 million.

The work on the project started in April 1997 on EPC basis. The project cost of Rs. 445 million was financed by a term loan from IFCI and IDBI of Rs 240 million, public issue at par in October 1998 for Rs. 8 million and promoters' equity of Rs. 125 million.

The EPC contract for the project was awarded to Sulzer Flovel Hydro, a joint venture between Sulzer Hydro, Germany (51% stake), and the promoters of Flovel, India (49%). The power purchase agreement has been signed with Escorts Mahle, an Escorts group company engaged in the manufacture of pistons. It will consume at least 30 GWh per annum from the project.

	
View of the powerhouse from downstream	Interior view of the powerhouse

Photo 6-4 Views of Harangi Project

The project is well designed and executed. The only drawback is the use of downstream elbow turbine, which has resulted in considerable rock excavation and a large powerhouse. The tunnel was bored in the rock in the left flank. This approach should have been adopted in Brindavan dam project wherein open excavation of the left flank and incorrect design led to failure of the retaining wall and a loss of about Rs.270 million through lost generation and another Rs.260 million in equipment damage. The knowledge of the IPP at Harangi was not used by the IPP at Brindavan despite being located only 75km apart.

Part 6 .6 Lower Bhavani Canal PH

The Bhavanisagar dam and reservoir, also called Lower Bhavani dam, is located on the Bhavani river between Mettupalayam and Sathyamangalam in Erode District, of Tamilnadu State. The dam is situated 16 kilometers west of Satyamangalam and 36 kilometers north-east of Mettuppalayam, and 70km from Erode and 75km from Coimbatore.

Two power stations for generating electricity have thus been built at the dam. The riverbed power house (RBPH) has an installed capacity of 4 units of 2MW each, and the canal powerhouse (CPH) has an installed capacity of 2 units of 4MW. Thus a total of 16MW is installed at the dam.

Photo 6-5 Views of Lower Bhavani Project

For utilizing the discharges in the canal, sluice liners fabricated of 38mm thick steel have been inserted into the sluices, which transit to penstocks of 2.9m diameter. The penstocks are fitted with butterfly valves inside the powerhouse which has two horizontal shafts downstream elbow Kaplan turbines. The turbines drive synchronous generators of 4MW capacity each through a speed increasing gearbox. The powerhouse flow joins the canal through a short tailrace channel. An energy-dissipating valve is provided through which the flow in the penstock is diverted into the canal in case of sudden closure of the guide vanes.

Both power stations have a common switchyard which steps up power from 11kV to 110kV with a single power transformer of 25MVA. Since the induction generators in the RBPH are 3.3kV, four unit transformers are provided to step up voltage to 11kV, which is the power transformer primary voltage. The power is transmitted to two substations Gobi and Moyar. The project was constructed at a cost of Rs. 404.3 million and generates 18.58 GWh of energy per annum.

Part 6 .7 Maniyar

The Maniyar hydroelectric project is located on Kakkad river in Kerala State. The project is owned by Carborundum Universal Murugappa Limited CUMI, which is a tripartite collaboration between Murugappa Group, Carborundum Company USA & Universal Grinding Wheel Company UK. Headquartered in Chennai, the (USD 3 billion) Murugappa Group is one of India's leading business conglomerates. The company manufactures abrasives, electrominerals and ceramics with a range of 20,000 different products.

The project was the first to be developed as a private sector project. The construction period was only about 3 years, and implementation cost was Rs. 17500 per kW. Though there are some technical flaws in the design, which restricted the power output to a maximum of 8MW instead of 12MW, the project has earned good revenues. Subsequent to technical rectifications in the water conductor system comprising the intake structure and tunnel, power output increased to 10MW.

The civil works comprise an intake structure on the right bank and a tunnel, which diverts the flows to a forebay. Three 4MW downstream elbow turbines are installed in the powerhouse.

View of Maniyar river with Maniyar Dam.

Photo 6-6 View of Maniyar Barrage

Part 6 .8 Kabini Canal Powerhouse

The Kabini dam was built across Kabini river in 1974 to provide irrigation. Water is released from the dam both through river sluices and canal sluices. There are two irrigation canals, one on the left bank and one on the right bank. The larger canal on the right bank can irrigate a total of 110,000 acres and is designed to convey 73.1 cumecs.

The pre-investment study concentrated on utilizing existing civil works to the maximum extent. Since the irrigation canal is fed by sluices, the same were planned to be extended on the downstream by inserting sluice liners as has been recommended in all design alternatives suggested in the pre-investment report where sluices are available to feed irrigation canals. The electro-mechanical equipment selected was a straight flow turbine with a right angle bevel gear driving vertically mounted generators.

The IPP has mostly followed the pre-investment report approach except for the large surge tank (considered not necessary subject to design proof through calculations by SECSD), and a minor variation in the electro-mechanical equipment, which results in a horizontal generator instead of vertical layout, as suggested in the pre-investment report. The selected PIT type machine renders the machine hall clear of all machinery and presents a neat appearance with ample space available for carrying out assembly and repairs just adjacent to the pits. Thus the size of service bay is considerably reduced and is absent in the powerhouse design. The draft tubes are straight and hence have reduced rock excavation and concrete requirement compared to the usual practice of adopting downstream elbow turbine. The length of the draft tube was however found to be less than the length suggested in normal practice. This might have a slight reduction in the efficiency.

Average energy production at 6 GWh per annum confirms the pre-investment report estimate. The project's load factor of 24% could be higher as per pre-investment study estimate where three units of 650kW were provided with installed capacity of 1950kW against 3000kW now. This is an instance of lower load factor through installation of higher installed capacity without considering water availability through flow duration curve.

	
View of the powerhouse from downstream showing the right bank canal	Interior view of the powerhouse showing the generator in a pit in the machine hall.

Photo 6-7 Views of Kabini Canal Powerhouse

Part 6 .9 Nugu

Nugu Dam was built in the year 1959 on Nugu river near Berewal village, in Heggadevankote taluk of Mysore district in Karnataka. Nugu river is a tributary to river Kabini that joins Kaveri river. The IPP during the course of feasibility studies decided to harness the surplus flood flows and riparian releases from the dam. Hence two power stations located adjacent to each other with a common intake structure and power transmission system were built. The water stored in the reservoir is released through Powerhouse I to the canal for irrigation and is situated higher on the banks. Powerhouse 2, through which flood flows and riparian flows are released, is situated at a lower level. A surge tank feeds both powerhouses, with Powerhouse 1 operating under a head of 12m and Powerhouse 2 under a head of 28m. Powerhouse 1 contains two horizontal axis downstream elbow type Kaplan turbines with speed increasers and alternators, whereas Powerhouse 2 contains two horizontal axis Francis turbines with speed increasers and alternators. Power generated is stepped up from 3.3kV to 66kV and transmitted to the grid through interconnection at Sargur Substation with a transmission line of 7.4km length.

The energy produced in the project saves about 7000t of carbon dioxide emissions per annum. To date, the project has generated about 44 GWh of energy. The total revenue is Rs. 160 million since project operation. The initial capital expenditure of Rs. 163 million has been recovered.

View showing Powerhouse 1 in background and Powerhouse 2 in foreground with common surge tank behind

Interior view of Powerhouse 2 showing the Francis turbines.

Photo 6-8 View of Nugu Powerhouses 1 and 2

The project has unconventional features, such as a common intake structure at inlet to the sluices in the earth dam feeding a large surge tank at the downstream toe of the embankment. The surge tank in turn supplies water to the two powerhouses. Analysis of water hammer and surges during powerhouses operating individually or together at various loads with the corresponding plant efficiency needs to be determined. The analysis was not available from the IPP. With this analysis, considerable knowledge exchange could take place.

Part 6 .10 Thirumurthy

Thirumurthy Dam is located in Tamilnadu on the Palar river near Udumalpet. It is a tributary of Bharatapuzha, which is an important west flowing river. The dam was built in 1966 for irrigation. Water is let into the two irrigation canals from sluices located in the earthen embankments of the dam. The main canal is located near the right bank and water is released through three sluices of 1.8m x 1.8m.

The powerhouse is located adjacent to the canal. Three steel liners of 1.30m x 1.12m have been used in the existing sluices, which then transit to penstocks of 2050mm diameter. The penstocks are connected to butterfly valves and to three 650kW horizontal axis downstream elbow type Kaplan turbines. The turbines are directly coupled to the alternators, thus eliminating the use of a gearbox. This results in a higher efficiency since the losses in the gearbox are eliminated. The turbines are designed to operate most efficiently at 10m head and each turbine is designed to allow a flow of 8.8 cumecs.

The powerhouse was commissioned in the year 2000 though commercial operation started only in 2002. Since 2002, the project has produced 29.7 GWh of energy in eight years of operation.

Considering an average CO_2 emission of 758kg/MWh from an oil-fired power station, the reduction in emission due to the installation of hydropower generating facility at Thirumurthy dam comes to 22,513 tons of CO_2.

View of the powerhouse with dam in the background

View of the downstream elbow turbine

Photo 6-9 Views of Thirumurthy Powerhouse

The project was built at a cost of Rs. 99 million and generates about 3.61GWh of energy per annum. The installed capacity of 3 x 650kW recommended in the pre-investment report was adopted. Efficiency tests conducted at the plant can give considerable knowledge on the performance of the equipment, especially due to avoiding a gearbox. The generator with lower synchronous speed may eliminate vibration problems on the draft tube deck. The areas near the project area have extensive wind turbine farms and need reactive power, which is partly met by the hydropower station.

Part 6 .11 Amaravathi

Amaravathy dam is an existing irrigation dam, which was constructed during the period 1953-58 across the river Amaravathy. The dam is situated in Coimbatore district in Udumalaipet Taluk near Andikoundanur.

The dam is provided with five river sluices of dimensions 1.52m x 1.83m with sill elevation of 330.7 msl. Water is released to the main canal by two sluices of 1.52m x 1.83m situated adjacent to the river sluices. An additional sluice is provided in the earth flank of dimensions 1.52 x 1.83m for releasing water to the right bank channel.

Water stored in the reservoir is not only used for irrigation through the canals, but also released to the river downstream at a constant rate so that it is picked up at a series of small weirs constructed downstream and diverted for irrigation. Thus the dam effectively regulates the river providing water in the river throughout the year.

The water, which was released through the five sluices to the downstream, has now been diverted through the powerhouse, where it produces electric energy and thereafter flows into the river downstream.

The powerhouse is constructed downstream of the dam in between the river sluice channel and the left bank canal. The powerhouse contains two vertical-shaft Kaplan turbines coupled to synchronous generators. The turbines are designed to use a flow of 11.3 cubic meters per second each. The turbines can operate within a head range of 28.46m to 12m – i.e., till the reservoir is depleted to 342.6 msl.

View of the powerhouse	Interior view of the powerhouse with vertical shaft Kaplan turbine

Photo 6-10 Views of Amaravathi Powerhouse

TNEB has followed the pre-investment report recommendations with respect to unit capacity, net head, installed capacity and location of the powerhouse, but with a slightly reduced length of the penstock, which is considered to be an improvement. The design alternative indicated in the pre-investment report was an upstream elbow turbine, but vertical-shaft Kaplan has been adopted. The project can be considered technically correct and cost-effective, but the designs and drawings as built were not given.

The project was constructed at a total cost of Rs.224.6 million and produces on an average 8.28GWh of energy per annum. The areas near the project area have extensive wind turbine farms and need reactive power, which is partly met by the hydropower station in conjunction with the Thirumurthy project.

Section 7 Turbine Efficiency and Flow Duration Curve

A description of how to select the capacity and number of turbines for best utilization of available flows and maximizing energy production is given in this section. The illustrations cover Shahapur 1, Maddur 2, and the Attehala Scheme.

Part 7 .1 Efficiency Variation

The efficiency of all types of turbines varies with changes in head and flow. Kaplan turbines have guide vanes that optimally direct the flows onto the runner blades which rotate, converting the pressure energy of water into mechanical energy. The guide vanes and blades are pivoted and their angles can be changed relative to the flow of water to maintain efficiency even at reduced flows. The standardized Kaplan type turbines are available in the following variants:

- Propeller or non-regulated type in which the angle of the blades and guide vanes are fixed,
- Semi Kaplan or single regulated in which the guide vane angle can be changed but blade angles are fixed or vice versa, and
- Full Kaplan or double regulated where the angle of the guide vanes and blades can be changed.

The Full Kaplan units have a high efficiency over a wide varied range of flow whereas for the propeller the efficiency is maximum only at the design flow and rapidly reduces for other flows. Semi Kaplan units have intermediate values. Typical efficiency values as a function of load with the curves are given in the following table and figure.

Table 7-1 Typical Efficiencies[18] of Various Propeller Turbines

LOAD	Adjustable Blades and Guide Vanes (A)	Adjustable Blades and Fixed Guide Vanes (B)	Fixed Blades and Fixed Guide Vanes (C)	Fixed Blades and Adjustable Guide Vanes (D)
110	88.0	85.0	-	-
100	91.0	92.0	92.0	92.0
90	91.5	91.0	65.0	91.0
80	92.0	90.0	-	85.0
60	91.0	87.0	-	70.0
50	90.0	85.0	-	60.0
30	80.0	75.0	-	-

Fixed-blade propeller units operate at maximum efficiency over a very narrow range of flows but are lesser in cost due to absence of the complex blade operating mechanism. Full Kaplan turbines have good efficiency over a wide range but need hydraulic equipment to operate the blades and guide vanes and hence are more expensive than Semi Kaplan type.

[18] Efficiency values of turbines obtained through model tests in the laboratory may not be actually obtained in the project due to departures in actual construction (prototype). SECSD were not able to obtain efficiency values of proto from any of the projects.

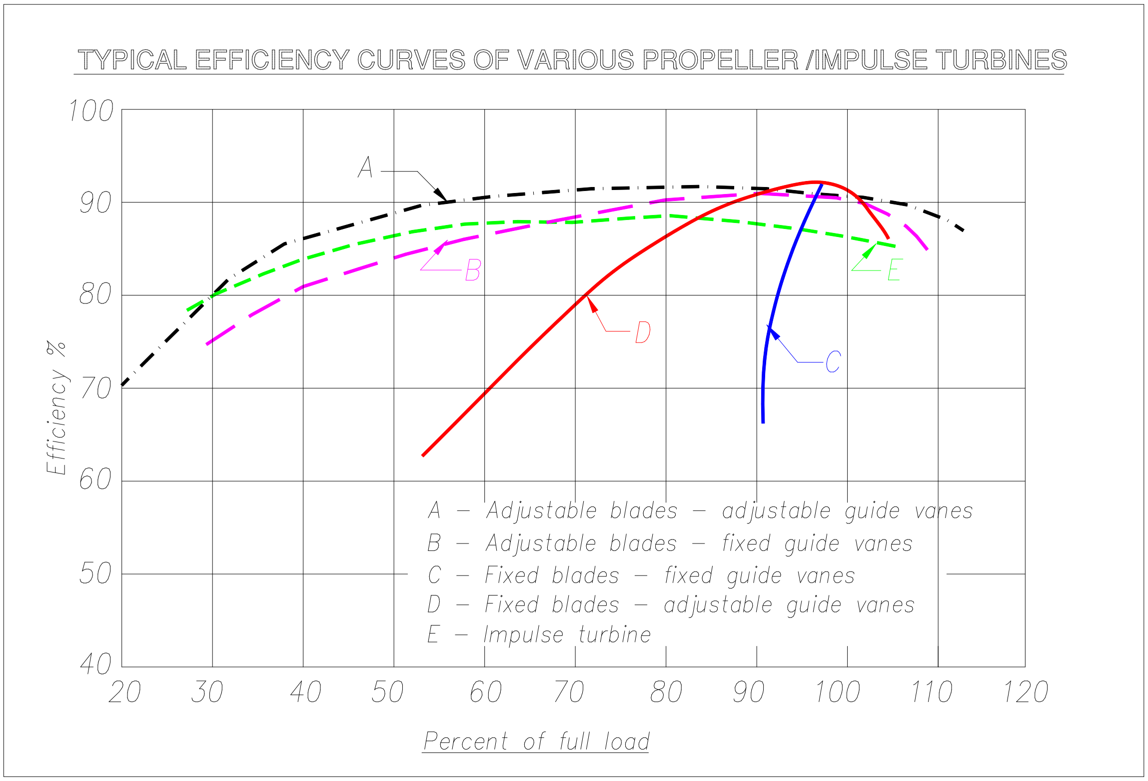


Figure 7-1 Efficiency Curves

Part 7 .2 Shahapur

A flow duration curve analyses for the Shahapur scheme 1 project is given in this section together with a description of the efficiency variation with load.

The flow duration curve shows the percentage of time during a year for which a particular flow is exceeded. The area under the curve is proportional to the energy that can be produced for a given head at 100% efficiency. Each grid block unit (20% exceedance and 10 cumecs flow) is equal to 3782kWh at 100% efficiency at 6m head.

Typical efficiency versus load curves for turbines are given in Figure 7-1 from which it is seen that for turbines with adjustable blades[19] and gates, efficiency is maximum at about 80% of full load with a value of 92%. This drops to 80% at 30% load and is about 70% at 20% load. For turbines with fixed blades and adjustable gates efficiency is very dependent on the load, with peak efficiency of 92% at rated load which drops to 70% at about 60% load.

The pre-investment report recommendation was to install three machines of 350kW of Semi Kaplan type to maximize energy production from the available flows. Typical turbines cannot use flows less than about 20% of the rated flows. Thus as per the pre-investment recommendation

[19] Many of the projects have been implemented with one or two large capacity turbines with adjustable blades. Smaller units with fixed blades and adjustable guide vanes are preferred in mini and small hydro due to cost reduction, provided fairly uniform discharge and head are available for a larger part of a year. Most duration curves of the pre-investment report have varying flows. Moreover, monthly duration curves are required for a safe design especially with fixed blades only.

Unit sizes range from 6MW for Brindavan to 350kW at Attehalla. Even in Attehalla the 350kW fixed blade unit is being converted to a full Kaplan type to utilize low flows.

which envisaged turbines rated at 8 cumecs each, only the flows below 1.6 cumecs cannot be utilized. Flows that cannot generate energy are shown hatched in red.

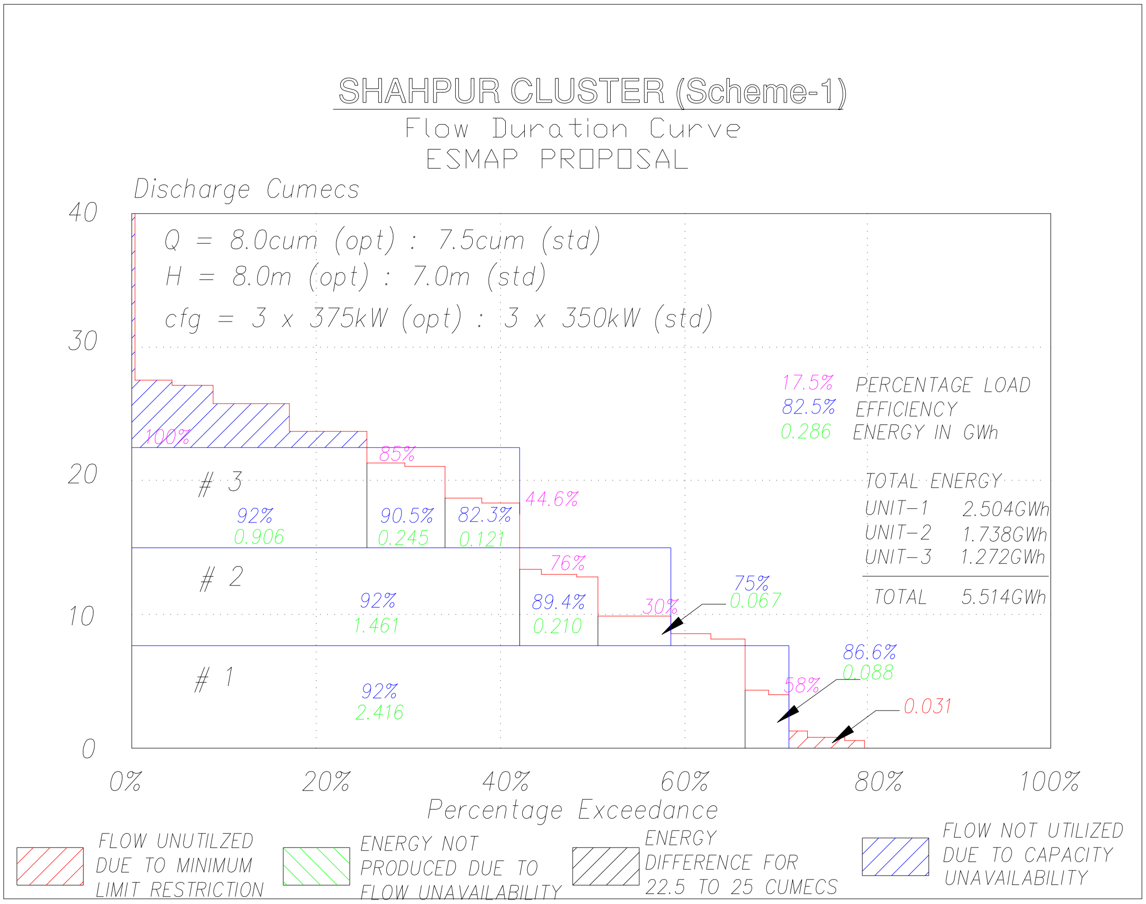
The efficiency of the turbines depends on the loading and for each of the three units the percentage loading for each flow value is indicated in magenta. For each loading the corresponding efficiency is obtained from the curve for the Fixed Blades, Adjustable Guide Vanes column of the efficiency table. The efficiency values are indicated in blue color. The area of the blocks is then calculated and multiplied by the efficiency value to get the energy of each block, which is shown in green color.

The three turbines (units #1, #2 and #3) produce energy of 2.504, 1.738 and 1.272 GWh - i.e., a total of 5.515 GWh from an installed capacity of 1050kW. The hatched area shown in blue color shows the flows which cannot be utilized in the power plant due to unavailability of turbine capacity.

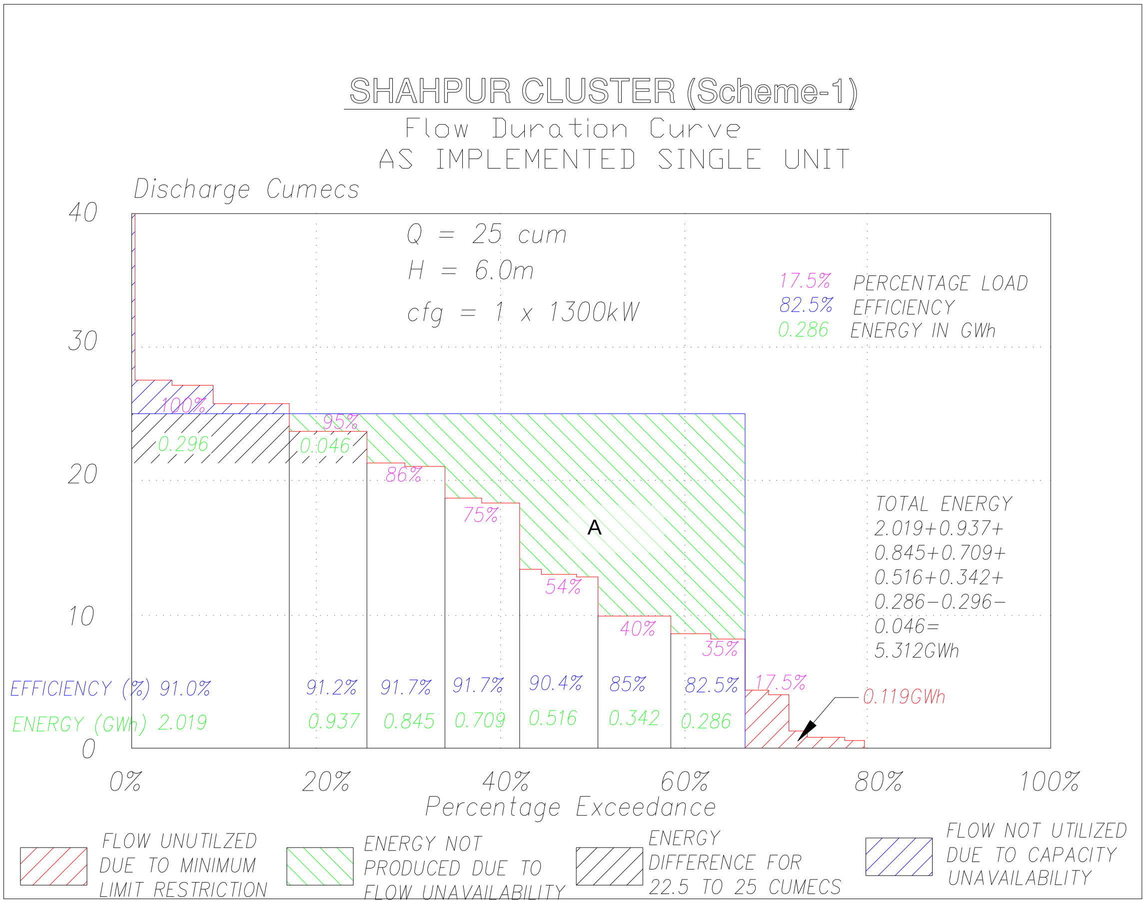
For comparison, the same flow duration curve is shown with a single unit as constructed, which is a large unit with a rated flow of 25 cumecs and 1300kW. Applying the same principles, the hatched area representing the unproductive flows is seen to be much larger.

The area under the duration curve is computed in vertical blocks with the loading and efficiency values corresponding to each block indicated in magenta and blue color. The values of each block are indicated in green. The total energy produced is 5.312GWh per annum at 1050kW power output.

This value is seen to be lower than that obtained from the use of three Semi Kaplan units. The point to be noted is that multi unit Semi Kaplan units which are only about 65% of the cost of the Kaplan type are able to produce the same amount of energy as the Kaplan units. This leads to considerable economy in the plant design. Secondly, the installation of multiple units provides for redundancy and partial operation of the power plant in case of outage on the unit.



Flow Duration Curve prepared from daily flow data in (red) and included in pre-investment report 139A. The figure shows the unit flow distribution amongst the three units of 650kW each with 8 cumecs discharge. The hatched portion in red shows the flows which cannot be utilized due to turbine minimum constraints (normally minimum discharge should be more than 20% of the rated discharge).



Flow Duration Curve showing the single unit of 1300kW with 25 cumecs rated discharge as constructed by the IPP. The minimum flow constraint is now 5 cumecs and flows below this cannot be utilized through the large machine resulting in loss of generation, which is shown hatched in the figure in red. The area above the red line and below the blue line marked "A" shows that the turbine is deprived of flow for nearly 40% of time i.e. four months.

Figure 7-2 Flow Duration Curve of Shahapur 1 Project

The single 1300kW unit which has been provided is now running at part load because of reduction in flows in the Shahapur branch canals due to diversion of water to other branch canals. If multiple units of 650kW had been provided as recommended in the pre-investment report, one unit could have been removed and installed elsewhere thereby adjusting the plant capacity to reduction in inflows. With the single large turbine, there is no scope for any alteration.

Photo 7-1 Shahapur 1 Powerhouse with Single Large Capacity Turbine

Part 7 .3 Maddur

The flow duration curve below illustrates the variation in the canal flow for different years[20], which are depicted in various colors. The curve shown in red is for a dry year with minimum flow. It is seen that flow is available only about 55% of the time as compared to about 94% of the time for a wet year, which is shown in blue. In an average year, flow is available for about 60% of the time as indicated by the curve shown in green. Thus it is necessary to evaluate plant capacity and performance for various flow conditions. The shape of the curve is suitable for using a semi-Kaplan turbine that is lower in cost for up to 10 cumecs flow and a full Kaplan unit to obtain good efficiency for the varying flows from 10 cumecs to 20 cumecs.

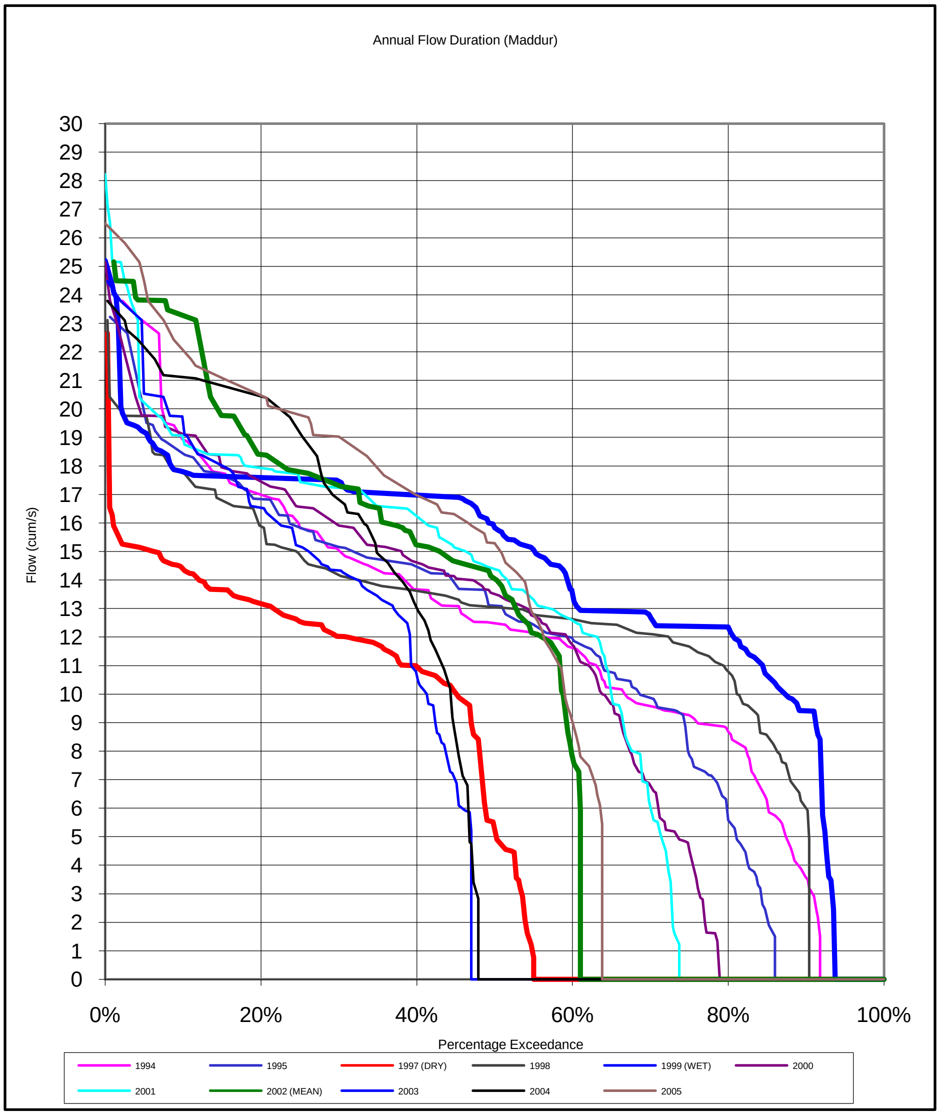


Figure 7-3 Flow Duration Curve of Maddur 1 Project

[20] The flow duration curve is based on measured flow in the canal and hence represents the releases as per the flow requirements of irrigation.

Part 7 .4 Attehala

Another flow duration curve, which pertains to the Attehala project, is shown below. For the best utilization of the flows, a turbine with 7.5 cumecs rated discharge of Kaplan type, which allows a large variation in flow with good efficiency, would enable good utilization of the flows. In the project as implemented, a single semi-Kaplan turbine with 9 cumecs rated discharge is provided, with the result that all flows below about 4 cumecs are wasted, leading to very low energy production.

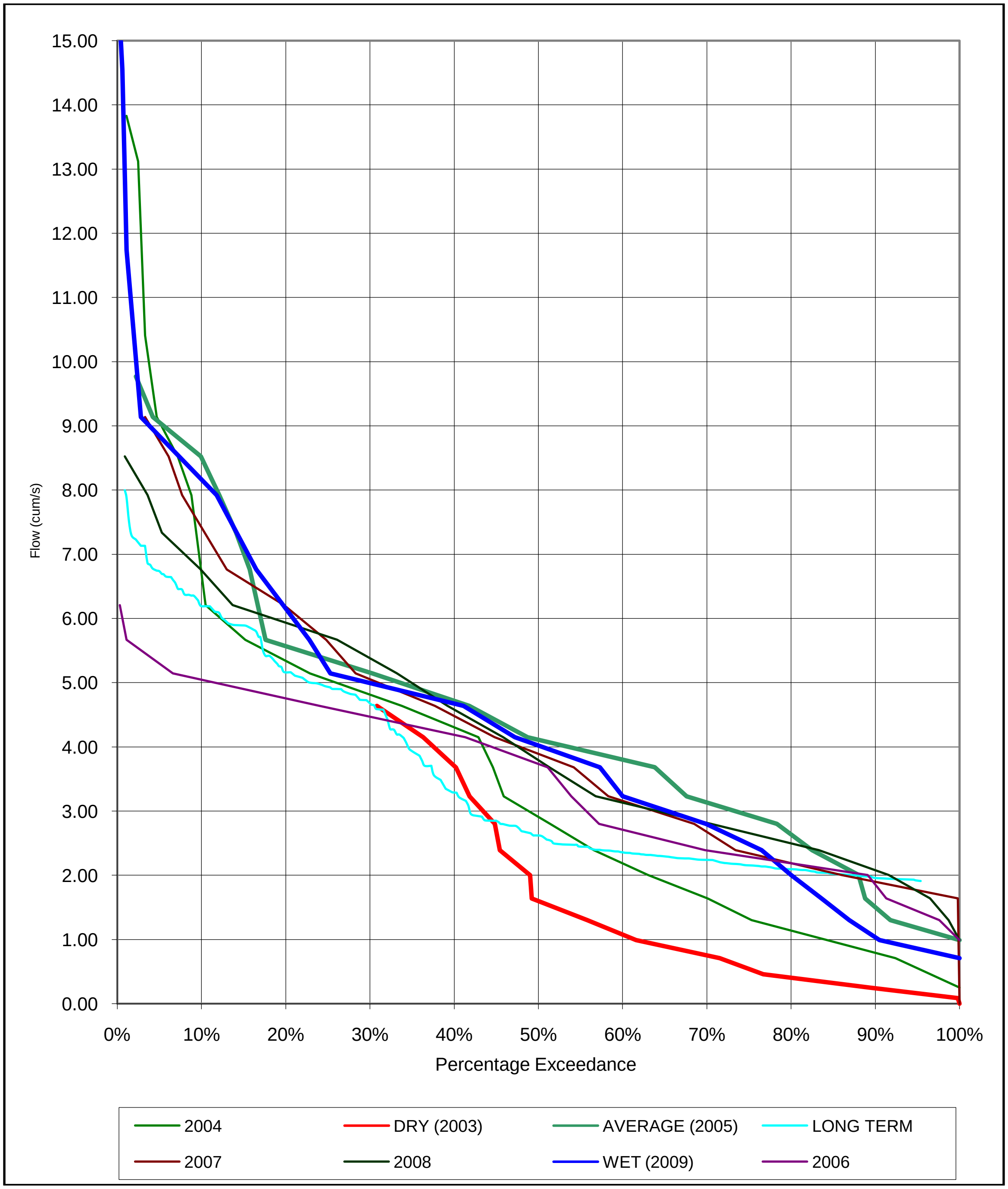


Figure 7-4 Flow Duration Curve for Attehala Project

Section 8 Electro-Mechanical Equipment Types

Part 8 .1 Turbine

There are two basic types of turbines denoted as impulse and reaction type. In an impulse turbine, the available head is converted to a high velocity jet, which impinges on a wheel having suitably shaped buckets causing the wheel to rotate producing mechanical energy. In a reaction turbine, the pressure energy is directly converted into mechanical energy by the reaction of the water leaving the runner. There are two types of reaction turbines: Kaplan and Francis.

As opposed to medium and large hydropower projects in which there is not much choice in the selection of electro-mechanical equipment, research into turbines for mini-hydropower in various countries has resulted in a number of variants of the basic Kaplan turbine – well suited for site conditions prevailing in low-head applications, especially in the 2-12m range. Each of these turbine types has specific advantages and drawbacks, which have to be studied in relation to the project under consideration. An analysis of the cost of the equipment with associated civil works for each variant is required, together with time frame required for project implementation if the particular variant is adopted. The least-cost option is to be selected for project implementation. In this section, the various types of equipment available are shown highlighting the merits and demerits.

Table 8-1 Types of Hydro Turbines

	Types	Application Range
Impulse	Pelton	Suitable for heads over 100m
	Crossflow	Suitable for very low heads
Reaction	Kaplan	Number of variants available especially suited to mini-hydro for head range of 2m to 20m and available in standardized sizes. These turbines come in variants called “propeller” where the angle of the blades and guide vanes are fixed, or Semi Kaplan in which the guide vane angle can be changed but blade angles are fixed and Kaplan where the angle of the guide vanes and blades can both be changed. The Kaplan units have a high efficiency over a varied range of flow whereas for the propeller the efficiency is maximum only at the design flow and rapidly reduces for other flows. Semi Kaplan units have intermediate values.
	Francis	For heads more than 20m up to 100m

Part 8 .2 Speed Increaser

In a mini-hydropower installation, the speed of the turbine is normally in the range of 200rpm to 400rpm. However, commercially available small generators normally operate at 750 to 1000rpm. For a given capacity, the size of the generator reduces as the rated speed increases. Hence a gearbox is normally used in mini-hydropower plants to match the slow speed of the turbine to the higher speed of the generator and reduce generator cost.

Part 8 .3 Generator

The generator converts the mechanical rotational energy produced by the turbine into electric energy. Generators are of either induction or synchronous type. Induction generators are very robust and are heavy-duty industrial motors driven above the synchronous speed, which reverses the power flow, making them function as generators. The controls and protection required for such generators are very simple, but they require a capacitor bank to function.

Synchronous generators however require excitation (a DC power supply to provide magnetism) to work and need to synchronize to the grid. They are more complex than induction machines and the control and protection equipment is more expensive than for induction generators. Synchronous generators are however preferred in stand-alone grids since they can regulate the frequency very closely and their power output can be easily controlled to suit the demand of active and reactive power separately.

Part 8 .4 Controls

Control panels are provided in the powerhouse to monitor, measure, and record the performance by display of suitable parameters such as currents, voltages, power outputs, temperatures of windings, etc.

In addition, protection equipment is also provided to detect faults and shut down the plant to avoid damage to the expensive machinery.

Part 8 .5 Auxiliaries

A number of auxiliaries are provided in the powerhouse depending on the complexity of the equipment. These include pumps for cooling water, oil coolers, hydraulic equipment for operating gates and valves, pumps for dewatering draft tubes, etc.

Part 8 .6 Crane

Since most of the electro-mechanical equipment is heavy in the powerhouse, a crane is required to erect the machinery and also to remove equipment for maintenance and servicing. An overhead crane either electrically or hand operated is provided in the powerhouse. In mini-hydro practice, mobile cranes should be preferred with access hatch in the roof for maintenance.

In the Shahapur schemes 1 to 5, which are identical and have been developed by the same IPP along the stretch of Shahapur branch canal, each project has been provided with its crane in the power house. The projects are also located in an arid area and hence weather protection is not difficult. Use of a single mobile crane would have been more cost effective since the size of the power house would have been minimal. The cranes could also be used to operate the various hydraulic gates at the project.

Part 8 .7 Types of Turbines

8.7.1 *Upstream Elbow (UEB)*

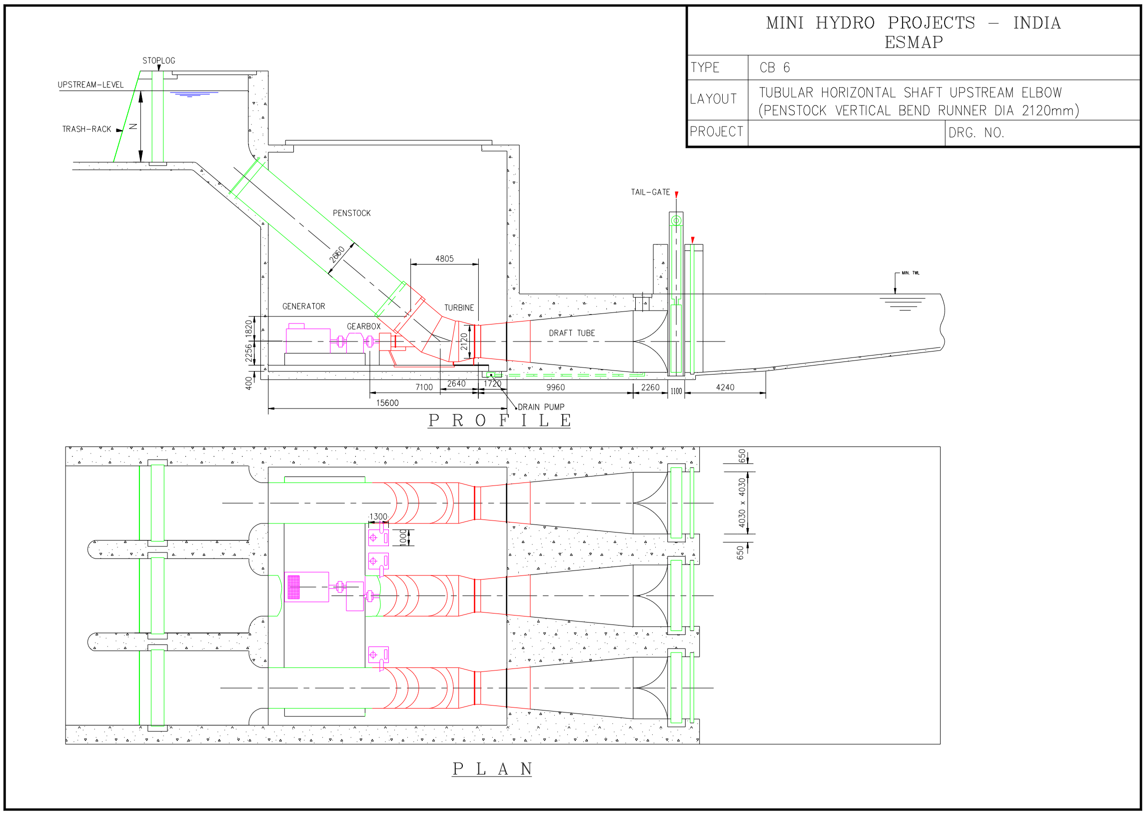


Figure 8-1 Plan and Profile of Upstream Elbow type Turbine

The upstream elbow turbine is suitable when the head is about 10 to 12m as the penstock enters the powerhouse and the turbine and generator rest on the floor. The straight conical draft tube is an advantage instead of the bend in a downstream elbow. The generators are located below the penstocks and hence removal is difficult. This can be changed by having the penstock enter the power house at an angle. Another advantage is that the resultant force at the junction of the penstock and runner chamber acts downwards and provides a stabilizing force. This type has been installed at some dam-based locations in Kerala.

The hydraulic losses in the bend of UEB type are negligible. For instance for a deflection angle of 40 degrees (usually about 40 to 45 degrees), the head loss coefficient is 0.07 to 0.08 for a ratio of Radius to Diameter (R/D) of the bend equal to 6 or 4 or 2. The friction loss in the bend comes to 0.036m in a 2MW unit with 10m head, 24 cumecs discharge, which is negligible.

8.7.2 *Downstream Elbow (DSE)*

This is the most common type of low-head, mini-hydro plant arrangement, and is now available from most manufacturers as a pre-engineered unit. Runner sizes range from 1.0m up to about 4m, heads from 5m to 25m, with power output up to about 12MW. There is a small upstream bulb containing controls for the Kaplan blades, and the thrust bearing.

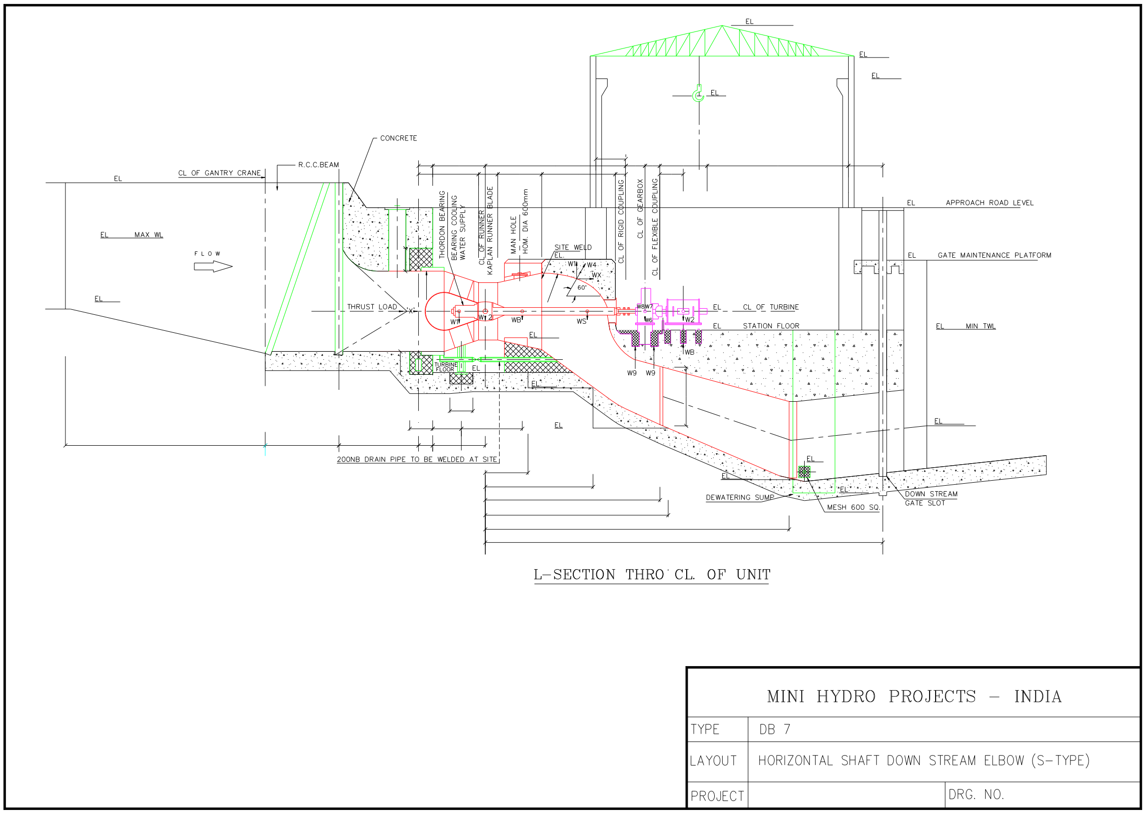


Figure 8-2 Profile of Downstream Elbow Type Turbine

The bulb is held in place by the stay vanes. Immediately downstream is the distributor ring with the wicket gates. The runner is located within a horizontally split throat ring, which can be removed for access to the runner. Downstream there is a long shaft to the draft tube gland and the turbine/generator guide bearing. A speed increaser or a direct connection to the generator is provided. Sufficient space in the powerhouse, downstream of the draft tube gland, must be provided to install and remove the long shaft, and this results in increased width of the powerhouse.

The thrust bearing forces from the upstream bulb are transmitted to the upstream powerhouse wall. No deflection is permissible in this wall, since turbine alignment will change. In some early units, problems with shaft failure were encountered. Failures were found to be due to fatigue cracking at the turbine flange from stress concentrations at the flange-shaft junction. Using a larger radius curve at the joint has rectified this deficiency.

With the runner enclosed by an exposed steel throat ring, the noise level in the powerhouse is higher. If there is a large rise in the tail water, access to the powerhouse has to be provided at a higher elevation, which requires a concrete block above the upper draft tube elbow. This significantly increases the volume of concrete and weight on the draft tube liner, which has to be of adequate thickness.

Another disadvantage is that this unit requires a deep setting – i.e., the runner must be installed to be below the minimum tail-water level with the result that, for heads greater than about 5 meters in hard rock conditions, the powerhouse becomes deep, and excavation and retaining wall costs go up considerably.

The installation of the speed increaser and generator, which are vibratory loads above the draft tube, also increases concrete requirement over the draft tube liner with the result that the draft tube liners have to be reinforced to take account of vibrations transmitted to the generator floor.

Hence, though the unit is available for large capacities and heads up to 12m at a very economical price, its use is not recommended except for heads up to 5m and small capacities up to 500kW since the cost of civil works goes up to offset savings in the turbine cost.

8.7.3 *Straight Flow Right Angle Drive (RAD)*

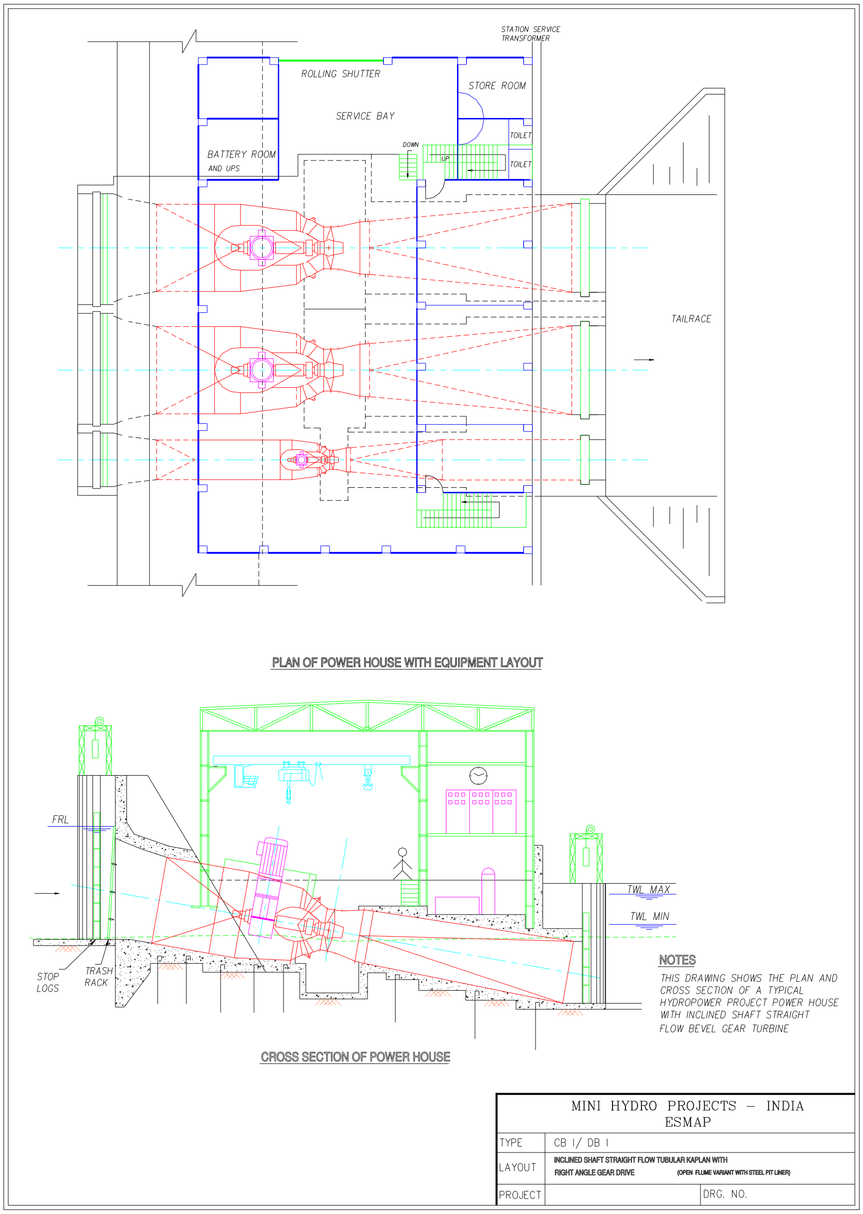


Figure 8-3 Plan and Profile of Right Angle Drive type Turbine

The turbine axis is usually inclined at an angle of 15 to 30 degrees to the horizontal. It is primarily intended for use in very low-head sites, where the net head is between 2 and 8 meters. Maximum unit capacity commercially available is about 2.6MW. The bevel gear bulb turbine has a bulb within the water passage with turbine thrust bearing and right angle gear drive; stay vanes and wicket gates; Kaplan runner and bent cone draft tube. The generator is mounted above the right angle gearbox and projects into the machine hall. The use of this type results in a powerhouse having minimal width, and the space utilization within the powerhouse is good since the generators are nearly vertical. Due to the inclination of the turbine, the excavation required is reduced considerably, which can result in significant cost savings in sites where the foundation is very hard rock. The plan shows dissimilar units in the power house in which the smaller unit is for utilizing low flows.

8.7.4 *Pit Type (PIT)*

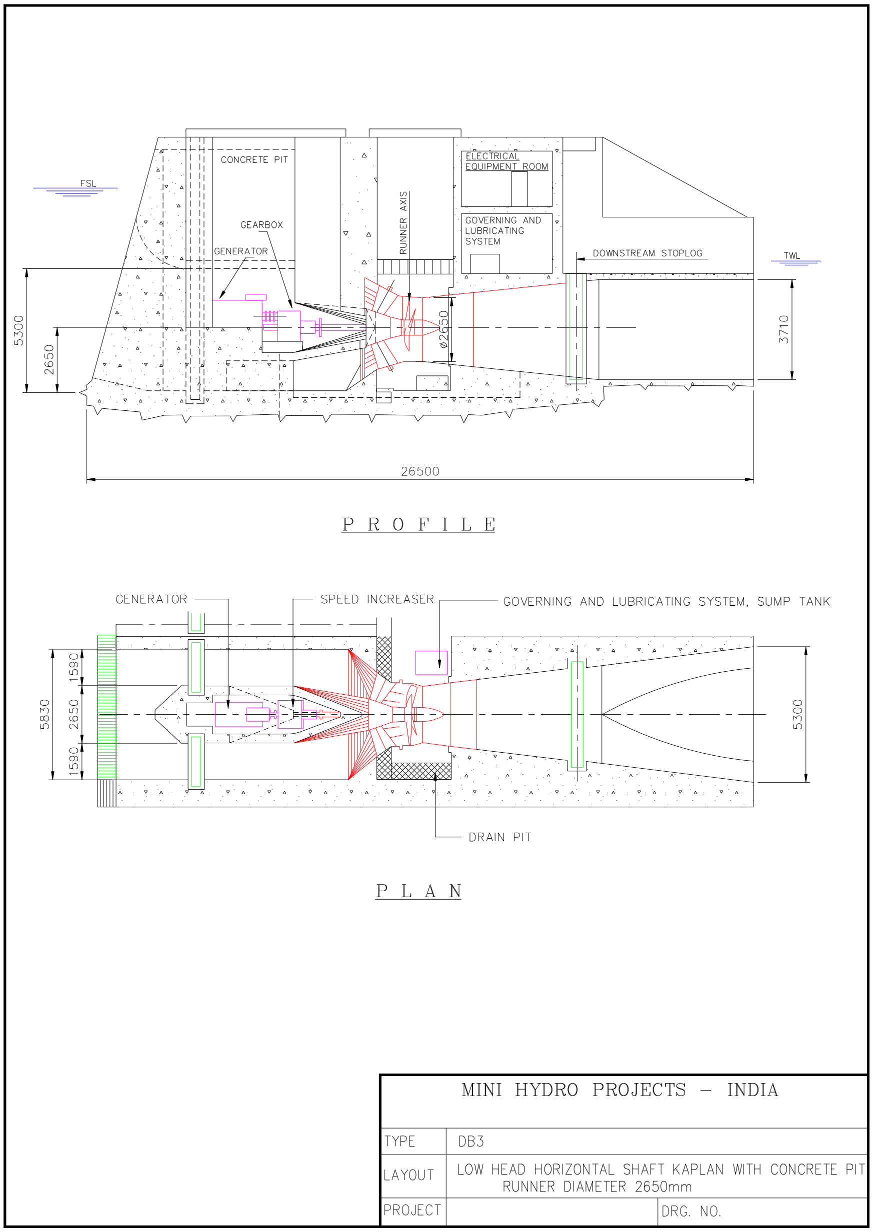


Figure 8-4 Plan and Profile of Pit type Turbine

In this layout, the generator is contained within either a bulb or in a pit within the upstream waterway. A pit installation has an enclosure open at the top, permitting access to the generator from the machine hall. To keep the generator size small, a gear unit increases the speed to between 600 and 1000 rpm. Gears may not be required for turbine speeds over 250 rpm in some cases as generators of a size suitable for installation in the pit may be commercially available. The generator can be either vertical or horizontal. In the vertical installation, the size of the pit is reduced, whereas in the horizontal case, it is made long enough to accommodate the gearbox and generator. This type of turbine has been adopted for the Kabini right bank canal powerhouse.

8.7.5 *Bulb Turbine (BUL)*

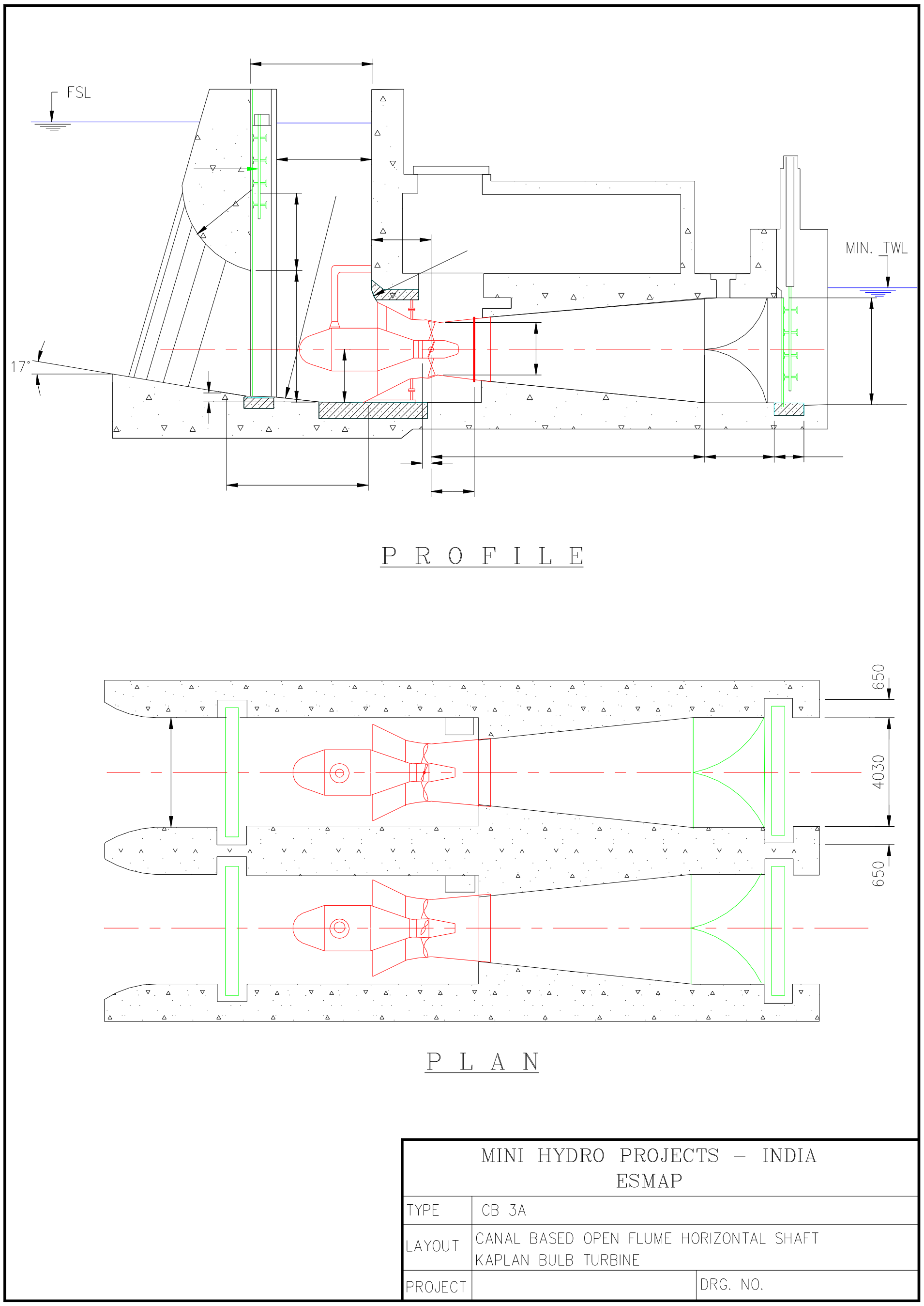


Figure 8-5 Plan and Profile of Bulb type Turbine

The description for the bulb turbine is similar to the pit turbine. However bulb units have larger runners, and normally not preferred due to the access problems, necessity for providing ventilation and cooling for the generators located inside the bulb. The foundation design is also more complex than for a pit turbine. Pit type units are thus preferred for smaller installations.

8.7.6 *Submersible Type (SUB)*

Submersible type units have the advantage that all the equipment is located underwater and no powerhouse is required. These units are common for capacities below 500kW and a number of plants can be found in Finland. An added advantage is that flow control equipment is integrated into the turbine and cooling of the generators is by the water that surrounds them. A number of variants are available – for example, each unit driving four generators arranged around the shaft. This design reduces space requirements.

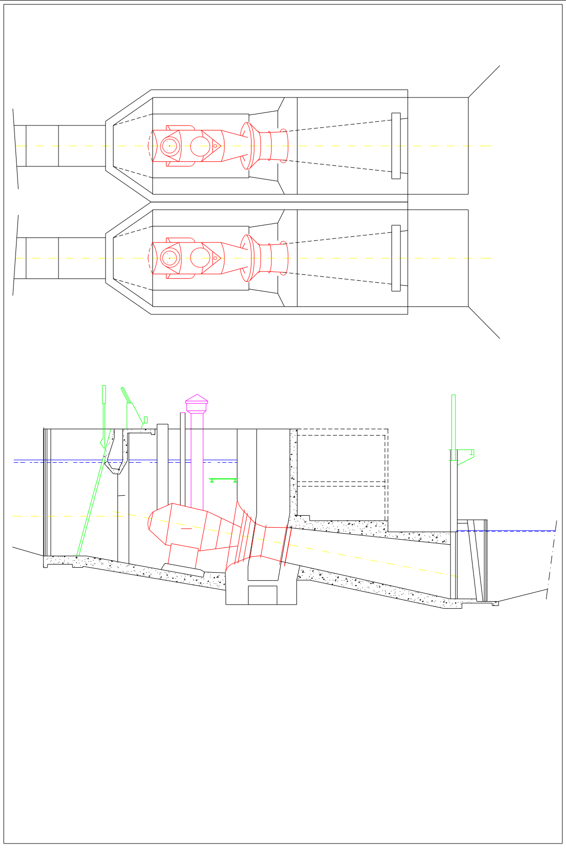


Figure 8-6 Submersible unit with horizontal configuration

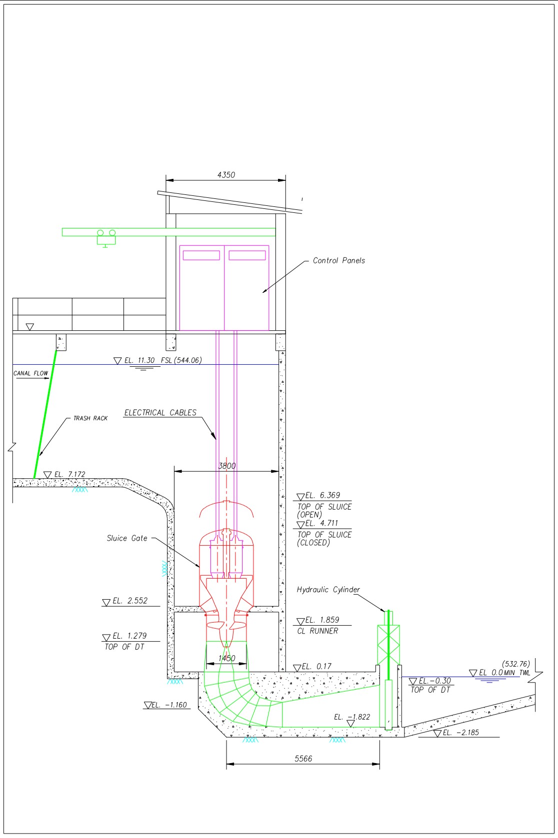


Figure 8-7 Submersible unit with vertical configuration

8.7.7 *Vertical Shaft Kaplan (VSK)*

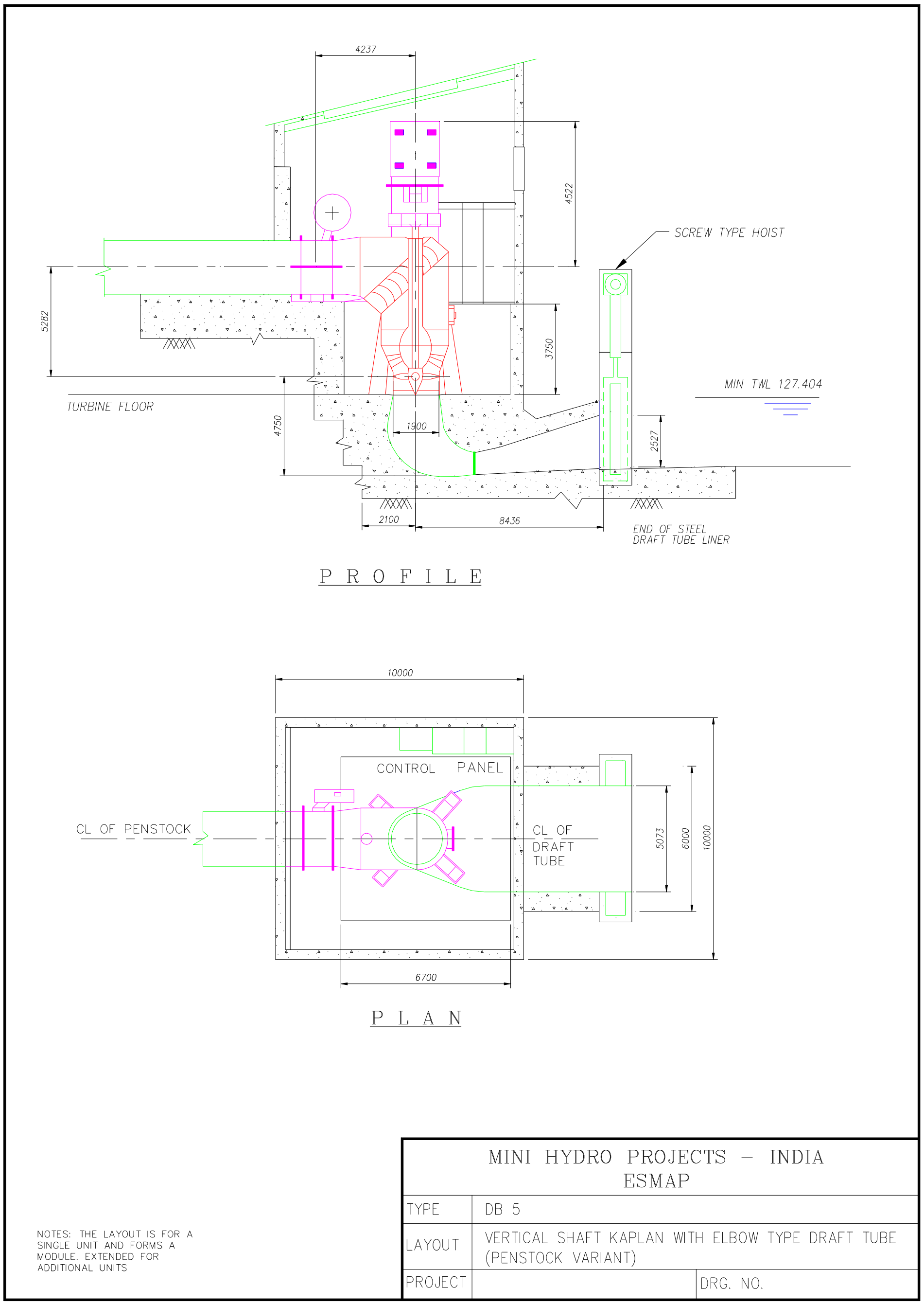


Figure 8-8 Plan and Profile of Tubular Vertical Shaft Kaplan Turbine

There are many arrangements for small vertical-axis Kaplan units. Often, they are set with the runner well above normal tail-water level, which is an advantage. The floor area required for a vertical shaft machine is considerably lesser than for a horizontal shaft machine and thus savings can be effected in layouts where the head is more than about 8m. They also come in standardized runner sizes. This type is used to illustrate reduction in civil works for Maddur Scheme 2 in Section 9.

8.7.8 *Vertical Shaft Flume (OFV)*

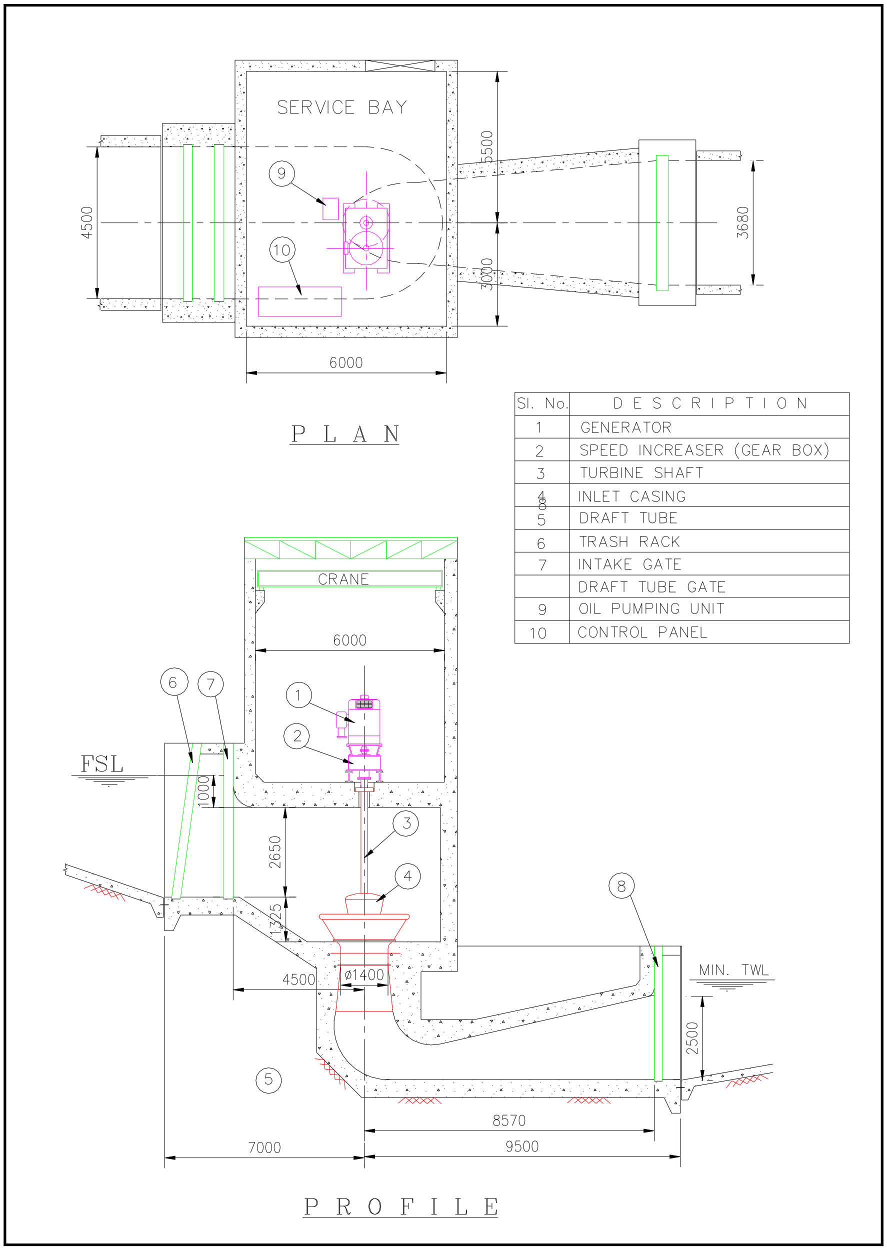


Figure 8-9 Plan and Profile of Vertical Shaft Flume Turbine

The powerhouse contains a semi-spiral concrete casing. The access to the turbine head cover is restricted, with insufficient headroom. If the length of the shaft and height of the turbine chamber is increased, more room can be provided for access during maintenance. The removal of the turbine runner requires removal of the generator and speed increaser, at added cost. However, installation procedure is very simple in this type of unit.

8.7.9 *Vertical Shaft Saxo and Other Layouts (VSS)*

This section shows a tubular package turbine, which can be installed in different layouts to suit the site-specific head and flow conditions.

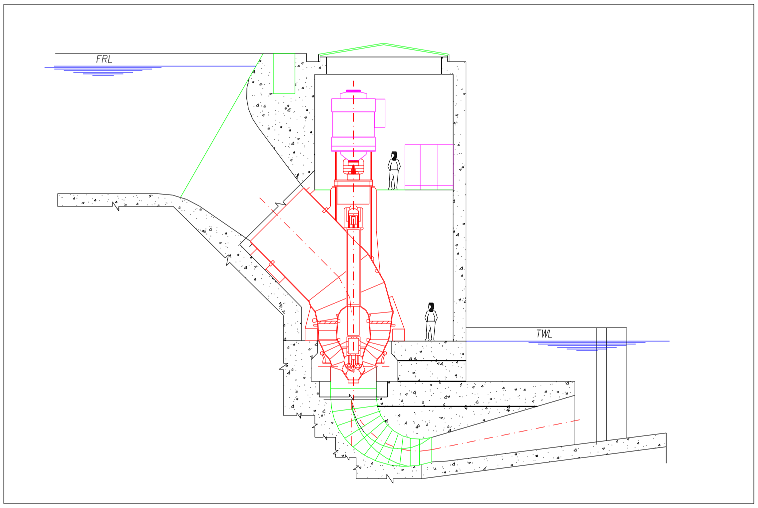


Figure 8-10 Layout for Saxo type

The layout above results in a compact powerhouse if heads are about 8m to 12m and space utilization within the powerhouse is good. The unit gets the name from the shape of the inlet.

Figure 8-11 Layout with Inclined Shaft

This variant is suitable for heads from about 5m to 6m and results in a compact powerhouse. The shaft is inclined and enters the machine hall from the upstream. Suitable ladders and platforms have to be provided for access to the generator for inspection.

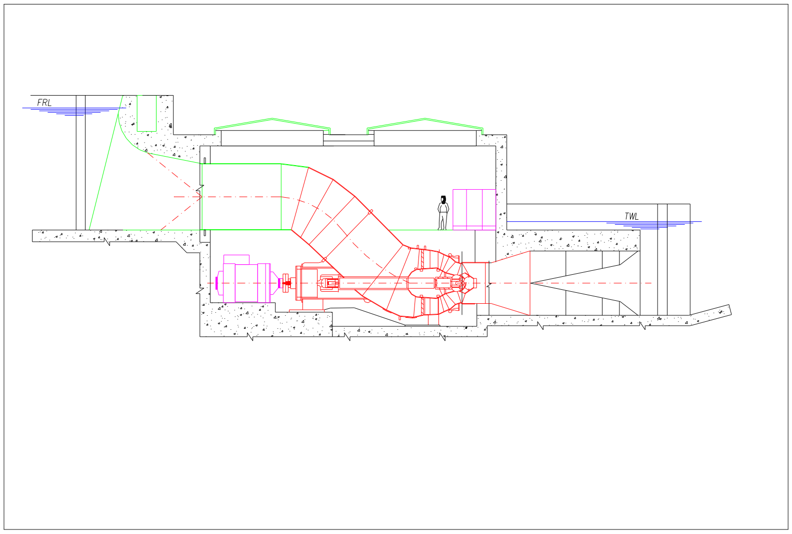


Figure 8-12 Layout with Upstream Bend

This type is suitable for low-head applications and has the advantage that the generator is located on the machine hall floor instead of on the draft tube in the downstream elbow type. Once installation is completed, hatches are provided for equipment maintenance with a mobile crane.

8.7.10 *Francis (FRA)*

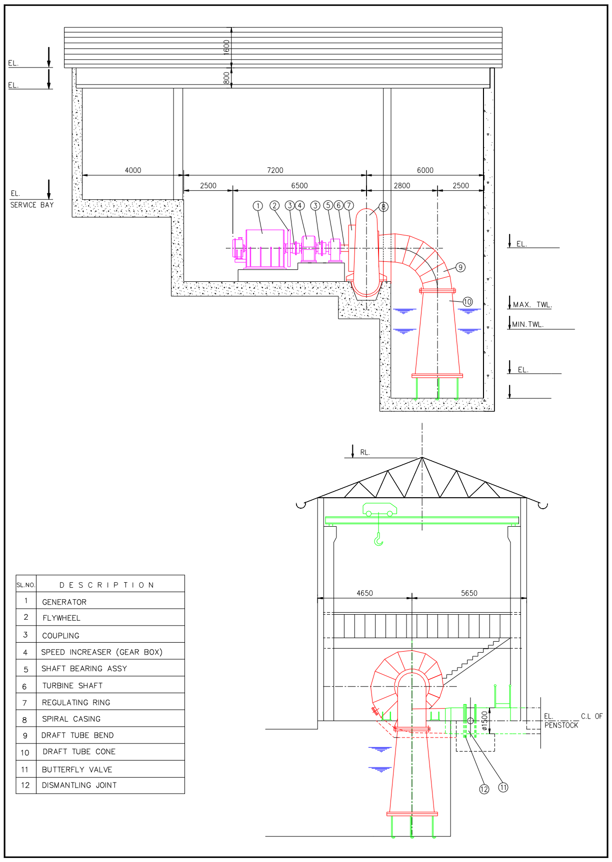


Figure 8-13 Plan and Profile of Francis Turbine

These units are only available with runner diameters less than about 1.8m. Above this size, the turbine requires a vertical shaft. Power is limited to about 12MW per unit.

Net head ranges from 20m to over 100m. The turbine is usually set just above tail water, with the bottom of the runner at least 0.3m above normal tail-water level. This avoids the necessity of draft tube gates, and facilitates access to the runner for inspection and maintenance. There are many manufacturers producing this type of equipment.

In single-unit power plants, a monorail hoist for installation and maintenance reduces cost. A mobile crane unit may also be used for equipment erection.

At some sites where the head is low for a single runner, a double-runner Francis unit could be selected instead. The layout is similar to that for a single runner, horizontal axis Francis unit, except for the shaft through both draft tubes, which reduces draft tube efficiency. However, this is countered by the ability to operate on only one runner, increasing the efficiency at low flows over that attainable with one runner. This type has been installed in Nugu power house 2.

8.7.11 *Siphon Tubular (SYP)*

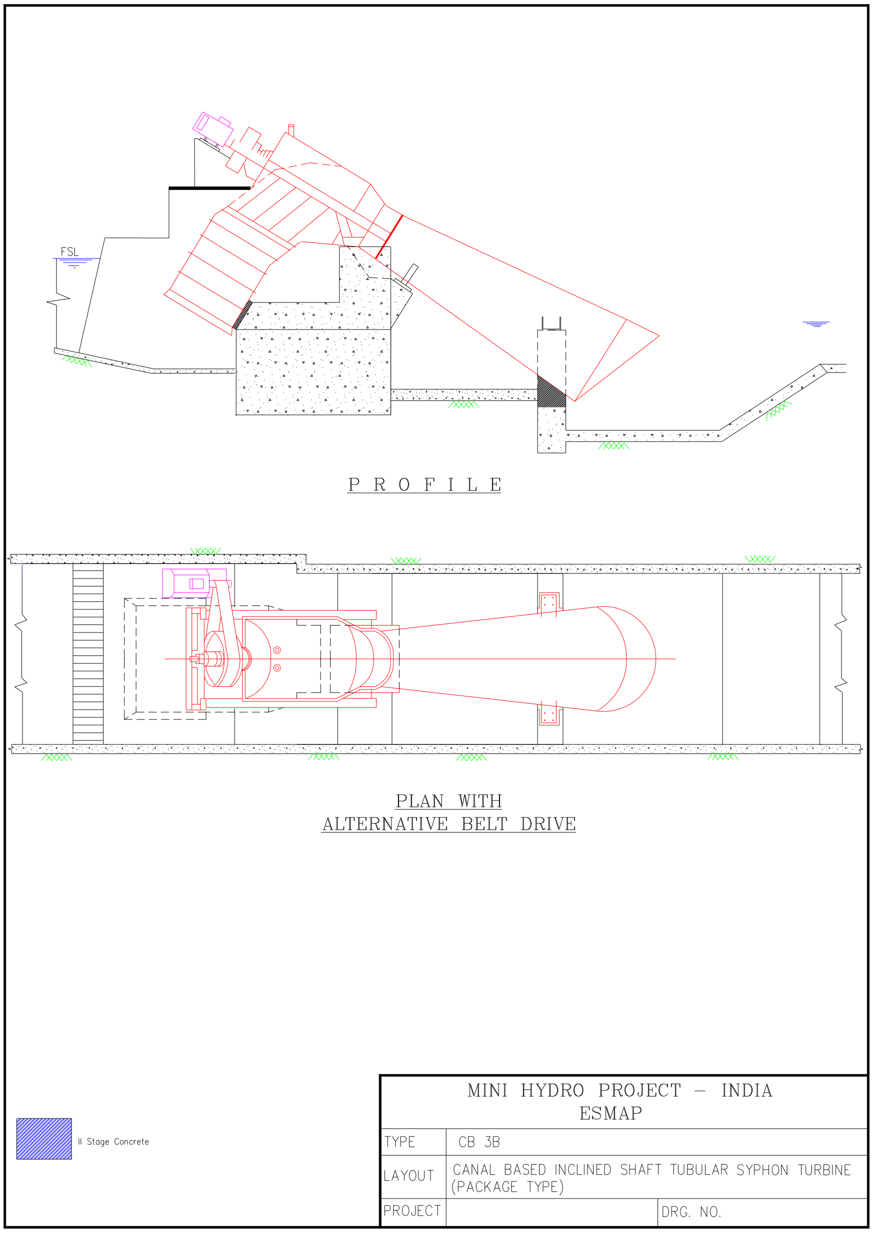


Figure 8-14 Plan and Profile of Siphon Tubular Turbine

A siphon tubular turbine is very useful in harnessing very low heads, even below 2m. The turbine generator unit is a package, which is normally installed over the drop structure with minimal civil works. Since there are a number of canal drops available, this type has considerable application.

8.7.12 *Siphon Concrete (SYC)*

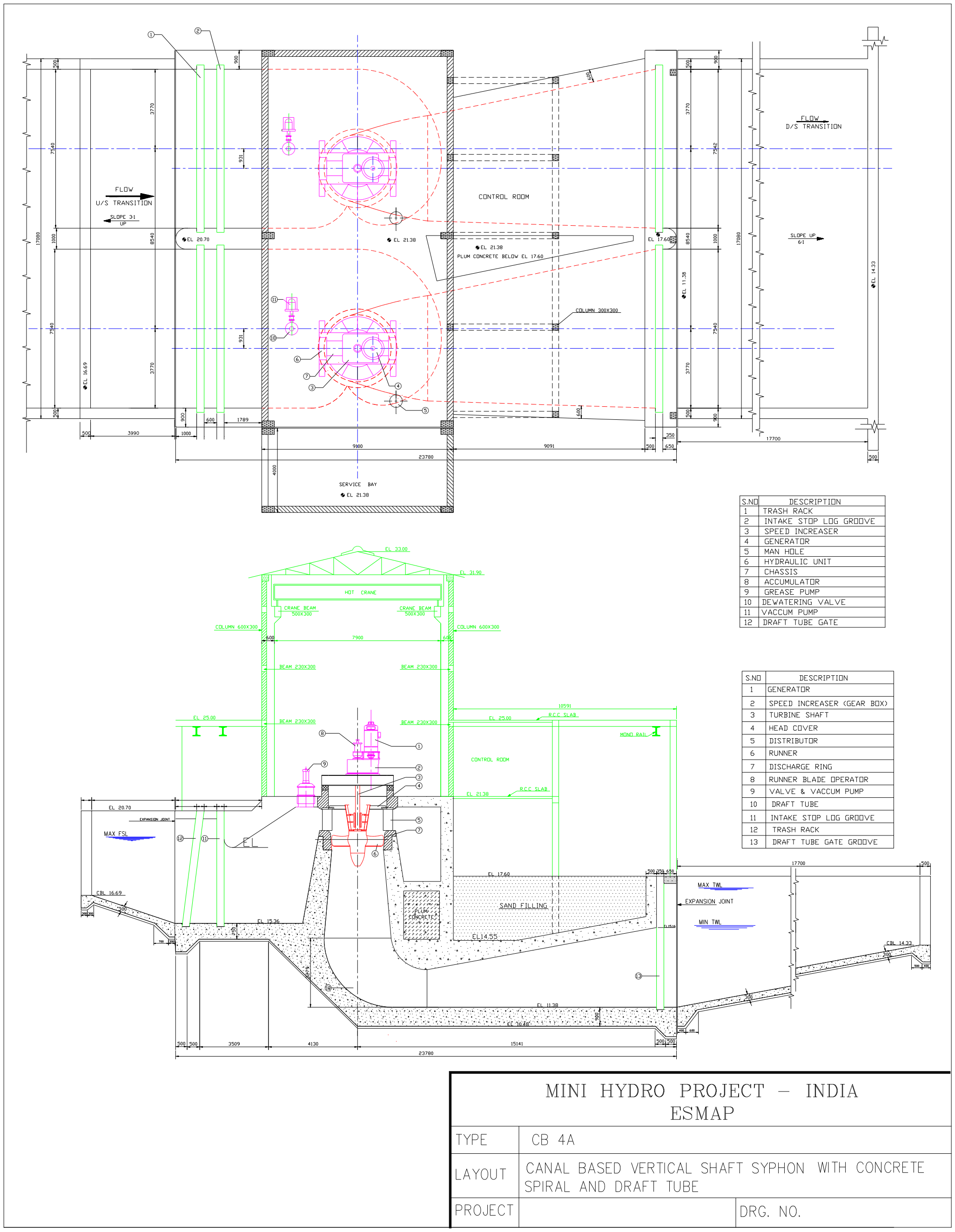


Figure 8-15 Plan and Profile of Siphon Turbine with Concrete Spiral

The siphon type is used for very low heads with a concrete spiral case. This type is suitable for large flows at low head. The turbine is Kaplan unit with a speed increaser mounted in the machine hall. The civil works for the spiral case require specialized formwork. A priming device with a vacuum pump is provided for starting, and air admission valve for stopping. No gates are required. This type has been adopted in the canal-based irrigation projects of Punjab state with heads as low as 2m.

Section 9 Layout Selection Case Studies

This section describes a few case studies, which illustrate how selection of correct electro-mechanical equipment types shown in the previous section can markedly reduce the complexity of the hydropower project. Of the five case studies are presented in this section, three are located at irrigation dams and two on canals.

Part 9 .1 Maddur

The Maddur at Hulivana project has been constructed with a downstream elbow turbine. The construction period was prolonged. The drawing shows the plan of the project and the longitudinal section. Three alternatives for the powerhouse location are shown in the drawing (Figure 9-1) as suggested in the pre-investment report during 1991. The powerhouse as constructed with the water conductor system is shown in the lower left and is seen to be very large, with poor utilization of the space within the powerhouse. The cross-section of the powerhouse with the adoption of a vertical-shaft Kaplan turbine as recommended in the pre-investment report is shown next. It is seen that the cross-sectional area of the powerhouse is considerably smaller with the lowest level of the powerhouse higher than in the downstream elbow alternative, resulting in savings on costly rock excavation. On the extreme right is shown a variant of vertical shaft Kaplan called the Saxo turbine due to the shape of the water passage. This alternative also results in a very compact powerhouse.

Part 9 .2 Harangi

Harangi powerhouse 1 has been constructed using a downstream elbow turbine. The powerhouse has been constructed downstream of the left flank of the dam. Water is conveyed to the powerhouse by a tunnel constructed in the solid rock in the left abutment. The powerhouse was constructed after excavation of a large rock outcrop. The drawing showing the project as constructed is shown in Figure 9-2.

The design recommendation in the pre-investment report was to use the existing sluices in the dam, which release water for irrigation to the canals. This is shown in the center of the drawing with penstocks inserted into the existing sluices. The powerhouse is shown downstream and has right angle drive turbines. The length of the water conductor system is seen to be very short compared to what has been constructed.

Part 9 .3 Guntur

Guntur Canal has a number of drops in succession. The usual practice of hydropower development at canal drops is to combine the head available in a series of drops by using a bypass canal constructed parallel to the main canal. This is shown in the top part of the drawing. It is however also possible to construct powerhouses in the canal adjacent to the drops. This option has been adopted by one of the IPPs. The layout is shown in Figure 9-3. This has several advantages since large earthwork and canal lining for the bypass are avoided, as is acquisition of large tracts of land for the canal.

Part 9 .4 Deverebelekere

Deverebelekere project is not yet constructed. It is planned to be constructed by cutting the abutment to allow water to flow out of the reservoir into the powerhouse to be constructed downstream of the powerhouse.

The pre-investment recommendation was to use the existing canal on the right bank and to use one of the spillways to which a steel bell mouth intake is constructed. Water is to be conveyed to the bulb type turbine downstream. This alternative will result in reduced civil works.

Part 9 .5 Brindavan

The Brindavan project is located at a Krishnarajasagar dam. The powerhouse has been constructed in the left flank. Large quantities of rock were excavated to construct a power canal to convey water from the reservoir to downstream of the dam where the powerhouse is located. After construction, the very high upstream retaining wall of the powerhouse collapsed, leading to flooding of the powerhouse and destruction of machinery, resulting in the loss of generation for two years of about 90 million kWh. The recommendation suggested in the pre-investment report of 1991 was to use the existing sluices and install tubular turbines just downstream of the dam. This layout is also shown in the Figure 9-5. Similar approach has been used in the projects of Tamilnadu – Amarvathy and Thirumurthy and at Kabini and Nugu in Karnataka. Had this approach been used, the failure could have been easily averted.

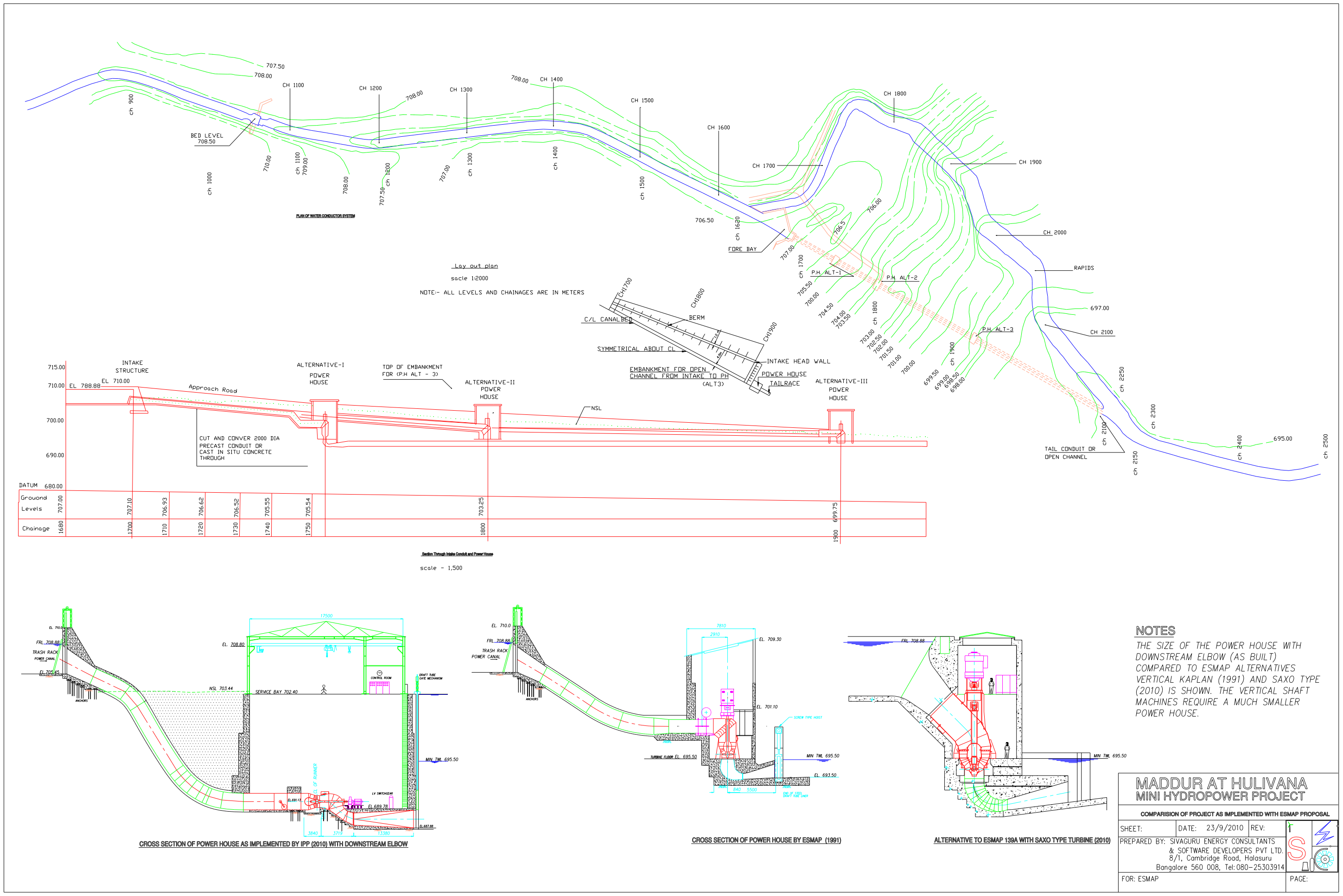


Figure 9-1 Maddur at Hulivana Project

The above figure illustrates the reduction in powerhouse size and civil works by adopting a vertical shaft machine. As implemented the project uses the layout on the left in which the powerhouse is very large and deep for a capacity of only 2MW

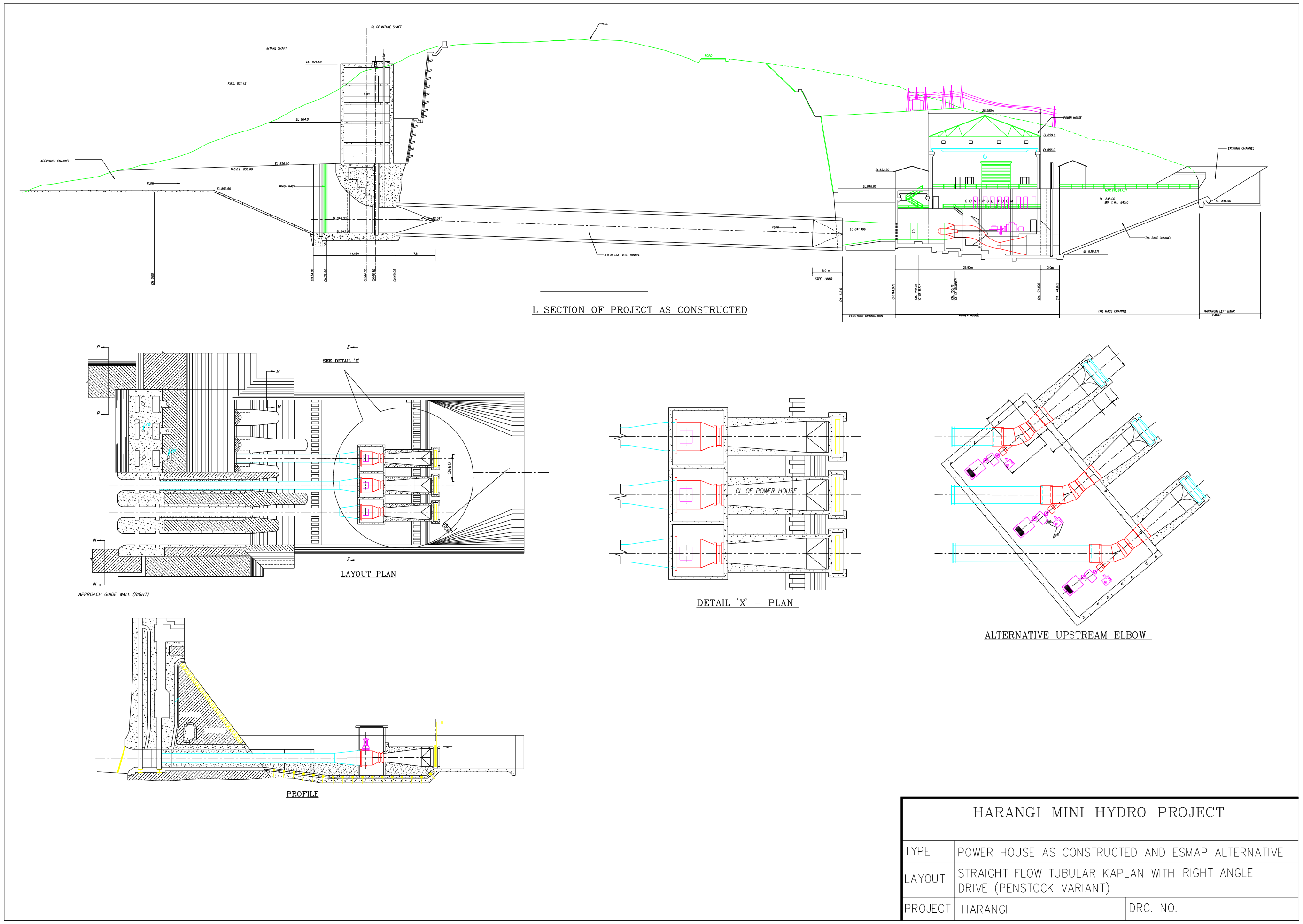


Figure 9-2 Harangi Powerhouse

The drawing illustrates the simplification of scheme if powerhouse had been installed using irrigation sluices. View at the top shows the tunnel excavated in left abutment, which is about 80m in length. View in the middle shows powerhouse with tubular right angle turbines installed at the sluices. Sluices have been used in Thirumurthy, Amaravathy, Nugu and Kabini projects for the powerhouse.

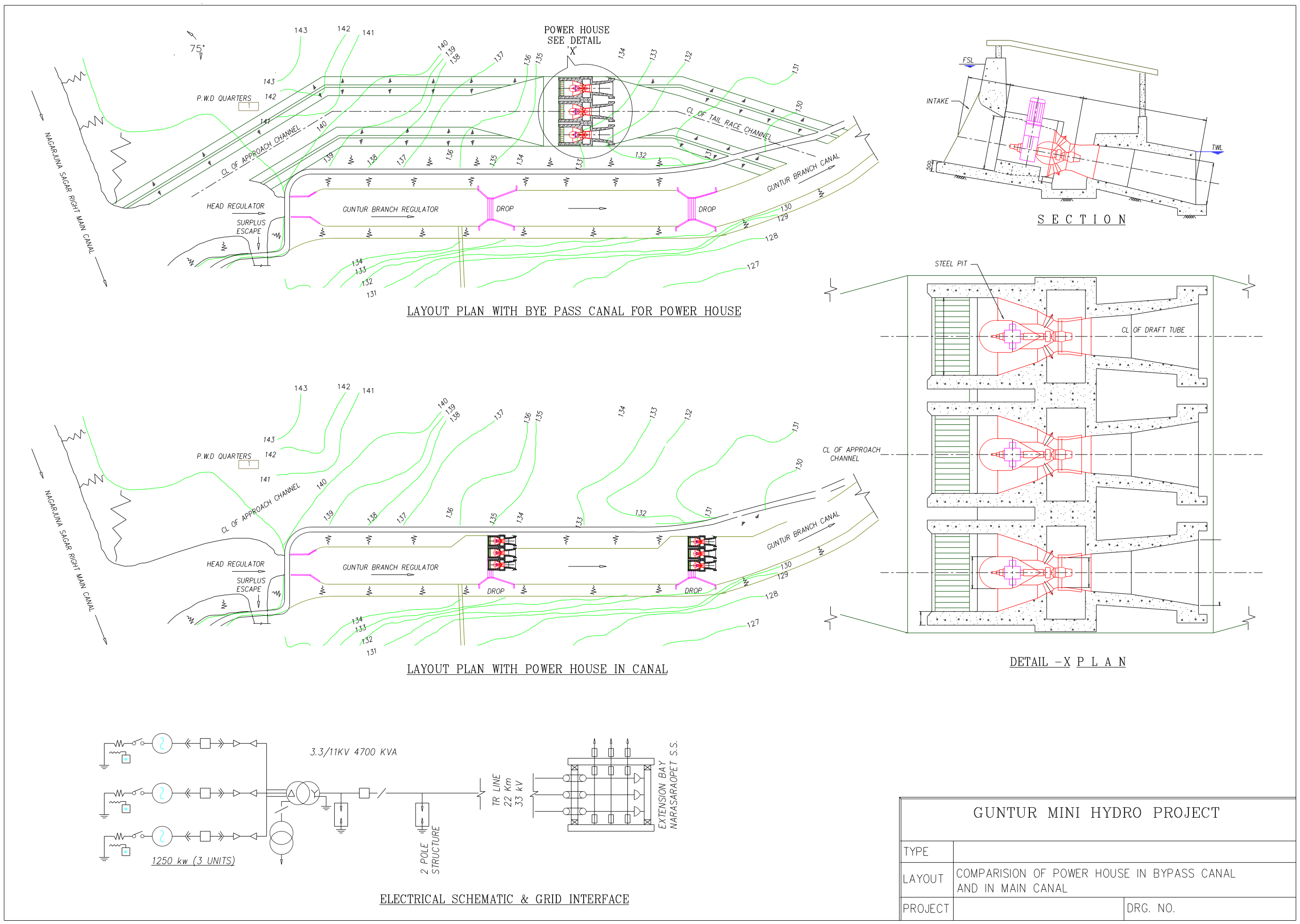


Figure 9-3 Guntur Branch Canal Project

The top view shows the project layout by combining successive drops with a bypass canal to concentrate the head on a single powerhouse. The middle view shows individual powerhouses at each drop on the main canal. The former approach has been adopted in Guntur BC 1,2 schemes and the latter in Guntur BC 3, 4 schemes

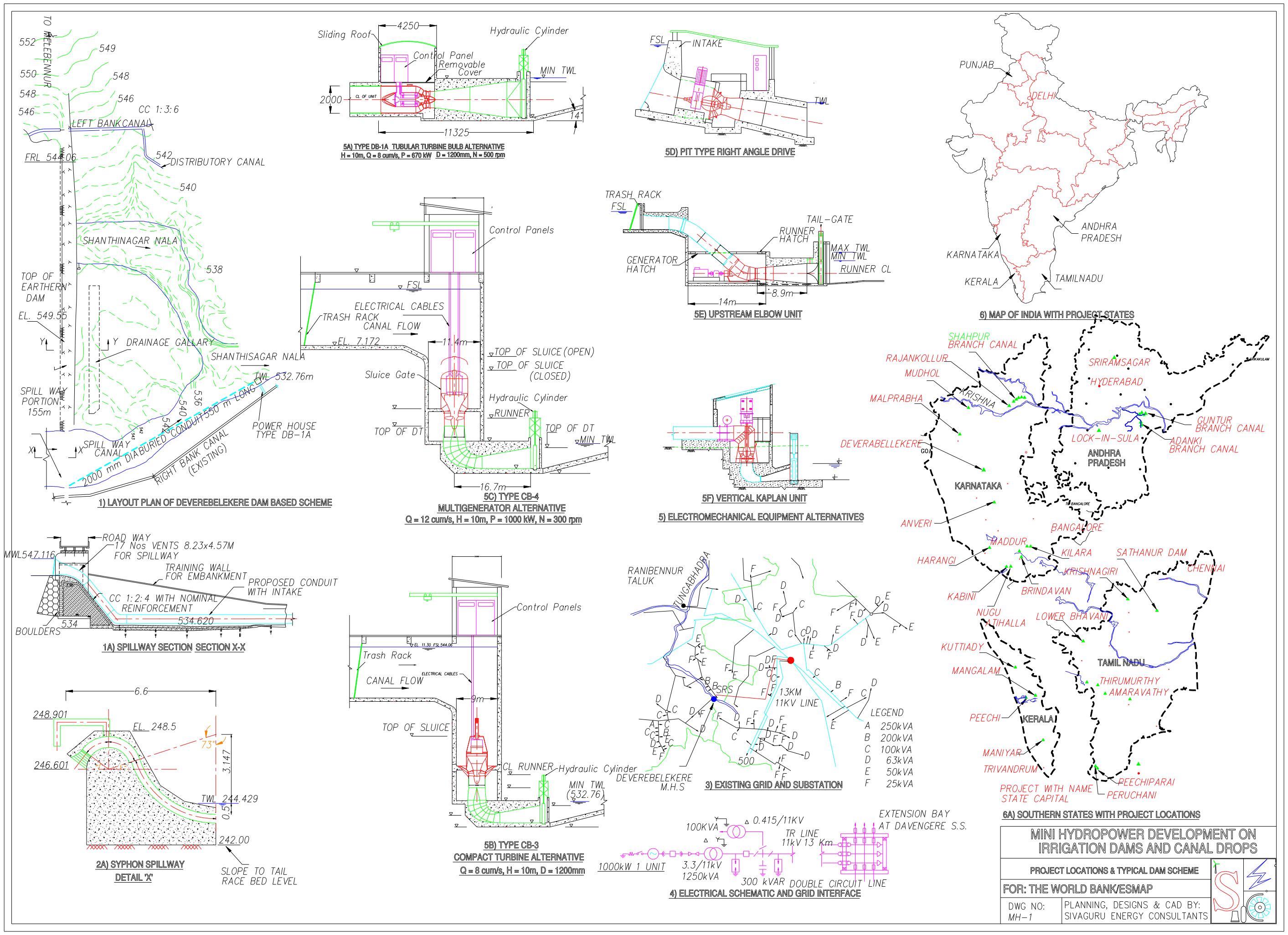


Figure 9-4 Deverebelekere Mini-hydro Project

Locations of mini-hydro projects and layout for Deverebelekere project showing use of submersible type and vertical Kaplan turbine units

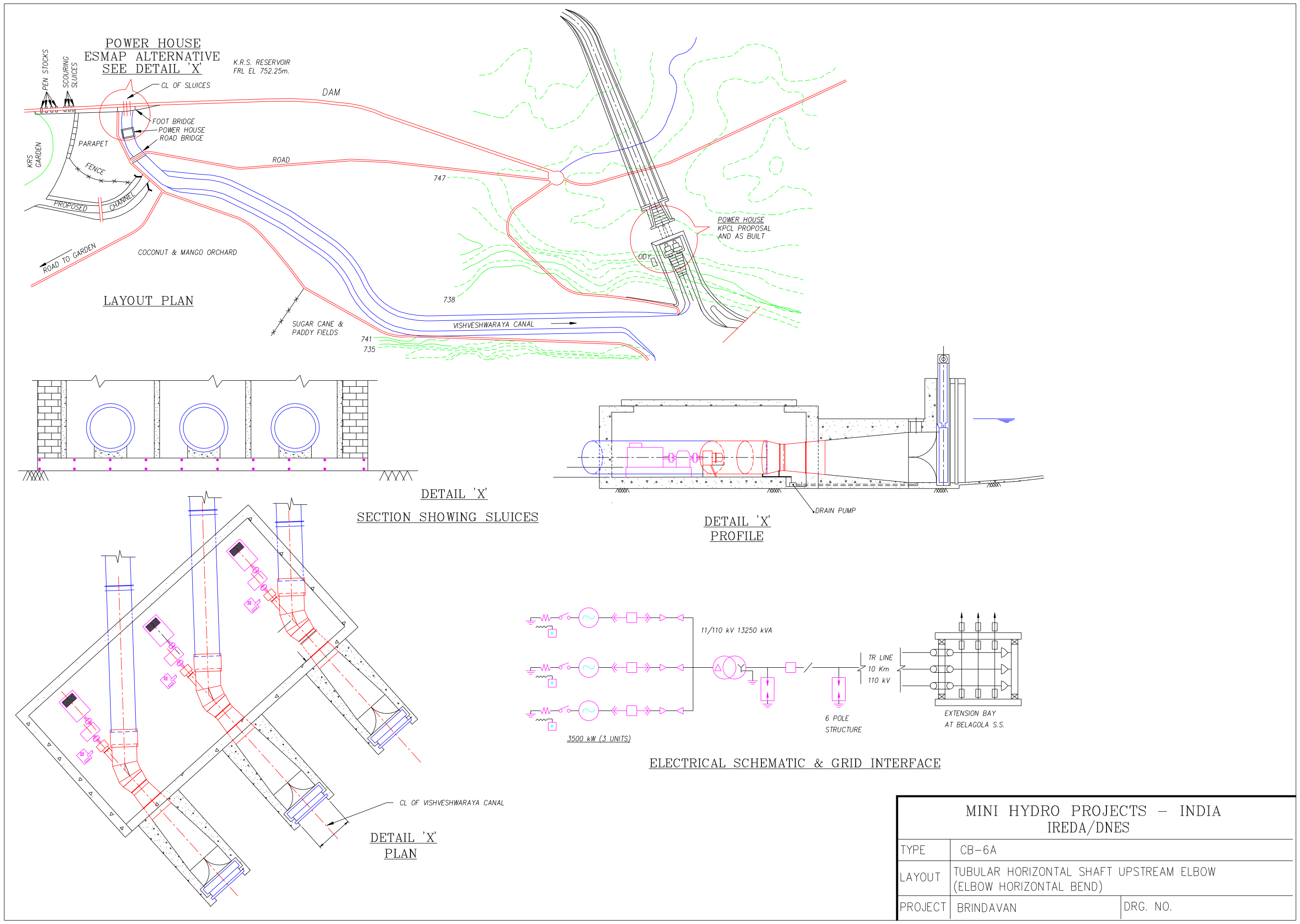


Figure 9-5 Brindavan Small Hydro Project

The above drawing shows the Brindavan project as proposed in the pre-investment report utilizing existing sluices for the powerhouse. The upstream elbow turbine with horizontal bend resulting in a compact powerhouse is shown. Project as constructed is shown on the left bank with large excavation for power canal and powerhouse.

Section 10 Optimization Analysis

The following section illustrates the method to fix the optimum installed capacity based on economic considerations for a typical case. The flow records are used to carry out the power generation studies. For an incremental increase in plant discharge, the annual energy is computed. The resulting average year energy output versus plant installed capacity is plotted to give the energy curve as in Graph C. The following values of energy output are obtained.

Table 10-1 Installed capacity and mean year annual energy vs. plant flow

SL	MEAN PLANT FLOW (cum/s)	INSTALLED CAPACITY (kW)	MEAN CONTINUOUS POWER (kW)	ENERGY OUTPUT (GWh/yr)	PLANT LOAD FACTOR (%)	INC ENERGY (GWh/yr)	INC E/MW (GWh/yr)
1	12.6	500	361	3.171	72.40%	2.021	4.042
2	25.2	1000	590	5.192	59.27%	3.415	3.415
3	50.5	2000	978	8.608	49.13%	2.892	2.892
4	75.7	3000	1305	11.500	43.76%	2.376	2.376
5	101.0	4000	1573	13.876	39.60%	1.912	1.912
6	126.2	5000	1789	15.788	36.05%	1.434	1.434
7	151.5	6000	1950	17.221	32.77%	1.102	1.102
8	176.7	7000	2074	18.323	29.88%	0.695	0.695
9	202.0	8000	2152	19.019	27.14%	0.143	0.143
10	227.2	9000	2152	19.162	24.30%		

The determination of the installed capacity takes into consideration benefit-cost analysis of the project. The value of the annual benefits is compared with the annual costs for variation in the installed capacity to arrive at an optimum value.

The installed capacity is varied from nil to 9000kW in steps. For each installed capacity, the costs associated with fixed components, civil works, electro-mechanical equipment, and hydro-mechanical equipment were evaluated separately to arrive at the total capital cost shown in the table below.

The capital cost of the project for various installed capacities is determined by deriving its components which are fixed costs, civil works, electro-mechanical works, hydro-mechanical works, transmission, and IDC. For each installed capacity, the runner diameter of the turbine is determined and used to derive the basic dimensions of the powerhouse from which the major quantities of civil works (excavation, concrete and steel) are determined and multipied by unit rates to obtain the civil works component.

The cost of the electro-mechanical equipment is obtained by seeking budgetary prices from the manufacturer. It is usual to obtain the quote for two or three unit sizes and to interpolate for other capacities.

The cost of the hydro-mechanical equipment is computed by determining the size of the various gates and valves which in turn depend on the runner diameter. To arrive at the cost, formulae are used which give the weight of gates and valves for various dimensions to determine the weights, which are multiplied by the fabrication rates specified in the schedule of rates available.

Transmission costs are determined selecting voltage, and obtaining the cost of the power transformer, and required conductor size for various capacities.

Table 10-2: Variation in capital cost with installed capacity

SL	INSTALLED CAPACITY (kW)	CIVIL COST M.Rs	E&M COST M.Rs	H&M COST M.Rs	T&D COST M.Rs	IDC M.Rs	TOTAL COST M.Rs
1	500	35.500	9.00	24.19	13.97	16.53	99.19
2	1000	37.700	18.00	26.83	14.53	19.41	116.47
3	2000	39.900	36.00	32.12	15.65	24.74	148.41
4	3000	42.100	54.00	37.42	16.77	30.06	180.35
5	4000	44.300	72.00	42.71	17.89	35.38	212.28
6	5000	46.500	90.00	48.00	19.02	40.70	244.22
7	6000	48.700	108.00	53.29	20.14	46.03	276.16
8	7000	50.900	126.00	58.58	21.26	51.35	308.09
9	8000	53.100	144.00	63.88	22.38	56.67	340.03
10	9000	55.300	162.00	69.17	23.50	61.99	371.96

For each installed capacity, the annual energy production is calculated and the annual benefit derived by using the purchase price of Rs.2.80/kWh without considering CDM benefits. Similarly, the annual costs associated with the capital cost are calculated using 12.5% interest rate, 3.5% depreciation and 0.5% O&M expenses[21]. For each installed capacity, the incremental benefit-cost ratio and first year generation cost are determined as shown in the table below.

Table 10-3 Incremental benefit-cost analysis for determining installed capacity

SL	IC (kW)	E GWh/yr	INC ENERGY GWh/yr	INC E/MW GWh/yr	CAPITAL COST M.Rs	INC ANNUAL COST M.Rs	INC ANNUAL BENEFIT M.Rs	INC B/C	GEN COST Rs/kWh
	500	3.171	2.021	4.042	99.186	2.766	5.659	2.05	5.32
1	1000	5.192	3.415	3.415	116.474	5.110	9.563	1.87	3.81
2	2000	8.608	2.892	2.892	148.410	5.110	8.099	1.58	2.93
3	3000	11.500	2.376	2.376	180.347	5.110	6.653	1.30	2.67
4	4000	13.876	1.912	1.912	212.283	5.110	5.353	1.05	2.60
5	5000	15.788	1.434	1.434	244.219	5.110	4.014	0.79	2.63
6	6000	17.221	1.102	1.102	276.156	5.110	3.086	0.60	2.73
7	7000	18.323	0.695	0.695	308.092	5.110	1.946	0.38	2.86
8	8000	19.019	0.143	0.143	340.028	5.110	0.401	0.08	3.04
9	9000	19.162	0.000	0.000	371.964	0.000	0.000	0.00	3.30

It can be seen that beyond 6000 kW, the incremental energy is less than 1.0 GWh per MW increase in installed capacity.

The above results are used to perform the optimization analysis given below, in which the annual benefit, profit, benefit-cost ratio are computed.

[21] At the planning and feasibility stage, the goal is to decide the installed capacity given the present hydrological and economic conditions. Hence inflation is not included in the calculations. If the proposed project is to be constructed at a date well into the future, then inflation to account for changes in the economy would be required. The revenue is computed for a typical average year.

Table 10-4 Optimization Analysis

SL	INSTALLED CAPACITY (kW)	ENERGY OUTPUT (GWh/yr)	CAPITAL COST (M.Rs)	ANNUAL COST (M.Rs)	ANNUAL BENEFIT (M.Rs)	B/C RATIO	PROFIT (M.Rs)
	500	3.171	99.19	15.87	8.88	0.559	-6.991
1	1000	5.192	116.47	18.64	14.54	0.780	-4.097
2	2000	8.608	148.41	23.75	24.10	1.015	0.356
3	3000	11.500	180.35	28.86	32.20	1.116	3.344
4	4000	13.876	212.28	33.97	38.85	1.144	4.887
5	5000	15.788	244.22	39.08	44.21	1.131	5.131
6	6000	17.221	276.16	44.18	48.22	1.091	4.035
7	7000	18.323	308.09	49.29	51.31	1.041	2.011
8	8000	19.019	340.03	54.40	53.25	0.979	-1.153
9	9000	19.162	371.96	59.51	53.65	0.902	-5.861

From the analysis, it is seen that the incremental benefit-cost ratio drops below 1.1 for an installed capacity more than 5000kW.

Below, a series of graphs are constructed showing the variation of the following with installed capacity:

A) Installed capacity in kW vs plant flow in cumecs
B) Maximum power output vs. installed capacity in kW
C) Annual energy production in GWh vs. installed capacity in kW
D) Annual plant load factor vs. installed capacity in kW
E) Annual energy generation per MW vs. installed capacity in kW
F) Mean continuous power output in kW vs. installed capacity in kW
G) Annual cost vs. installed capacity
H) Annual benefit vs. installed capacity
I) Annual profit vs. installed capacity
J) Benefit-cost ratio vs. installed capacity
K) Incremental benefit-cost ratio vs. installed capacity
L) Generation cost in Rs/kWh vs installed capacity

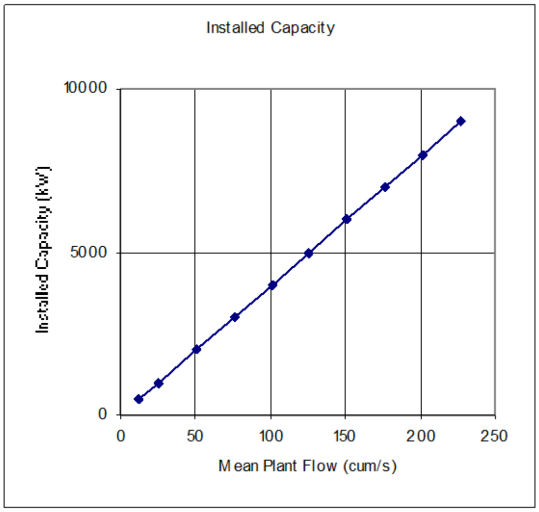
From Graph C, it is seen that incremental energy production drops with increase in installed capacity.

From Graph D, it is seen that the Plant Load Factor drops below 35% for installed capacity beyond 5000kW.

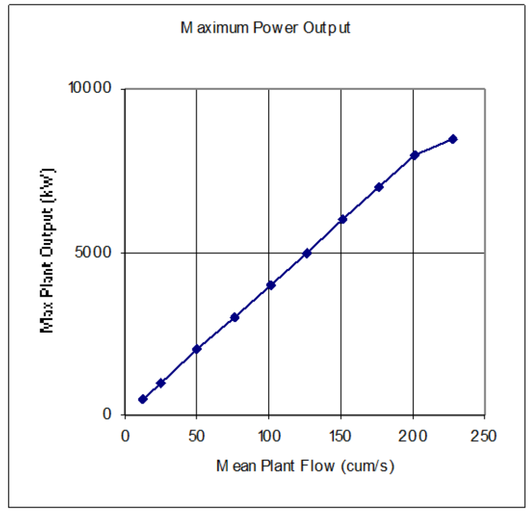
From Graph E, it is seen that incremental energy production drops below 1.5 GWh /MW beyond 5000kW.

From Graph I, it is seen that annual profit is maximum at about 5000kW.

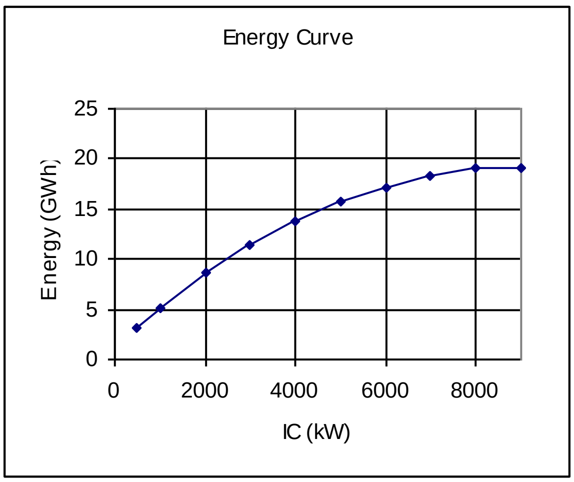
From Graph L that plots generation cost versus installed capacity, it is seen that generation cost drops as installed capacity is increased. Around 5000kW the cost of generation is minimum and thereafter starts rising again. This is the optimum installed capacity.



GRAPH-A



GRAPH-B



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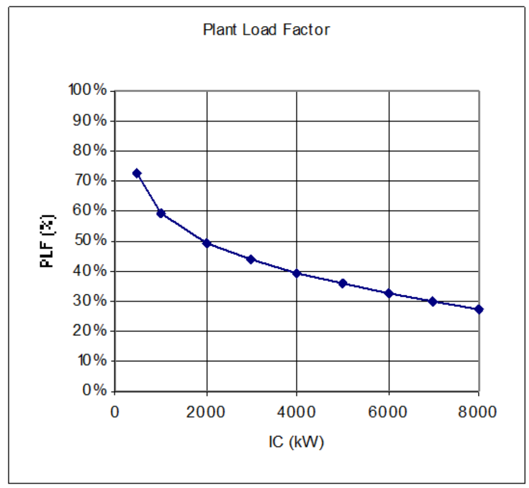

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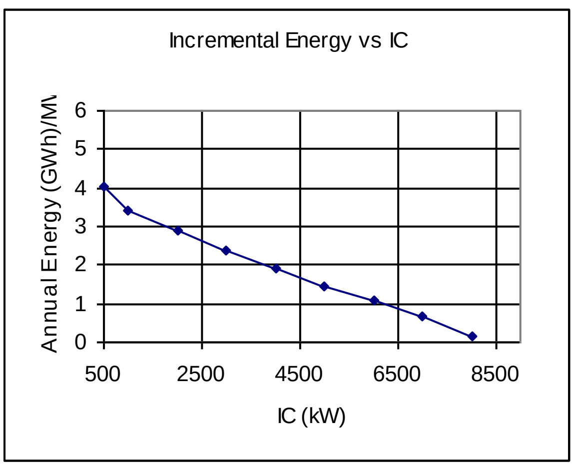

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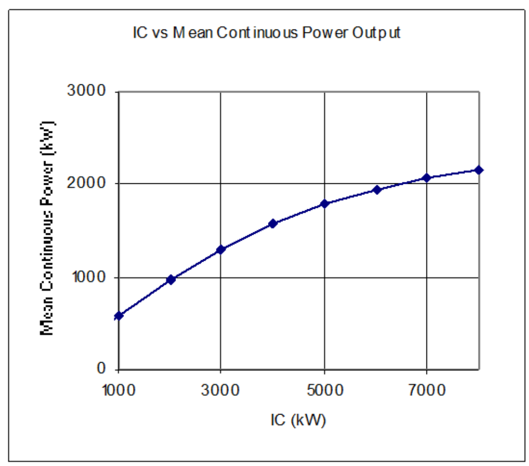
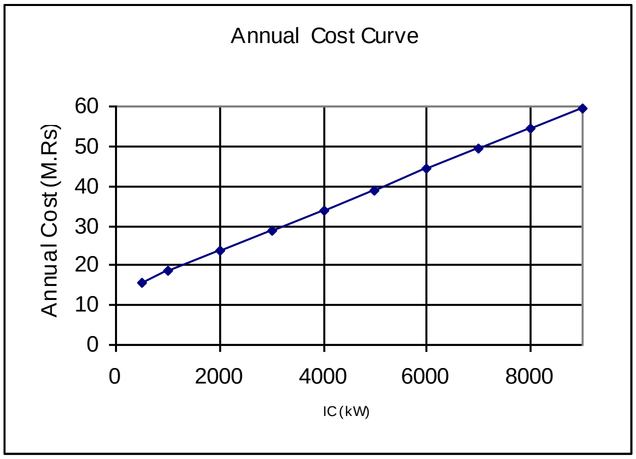
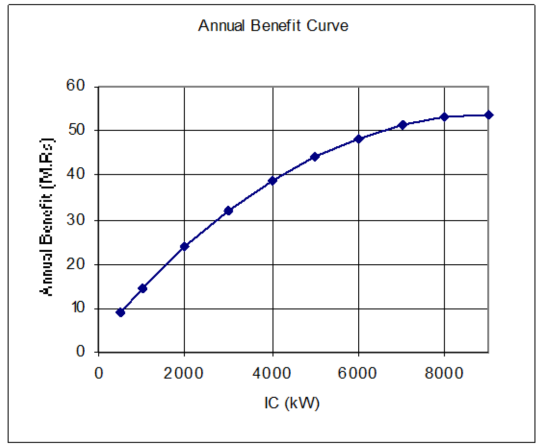


GRAPH-F

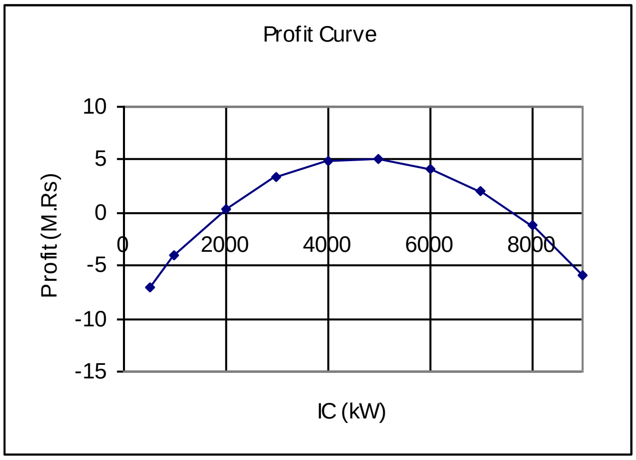
Figure 10-1 Capacity Optimization Curves 1 to 6



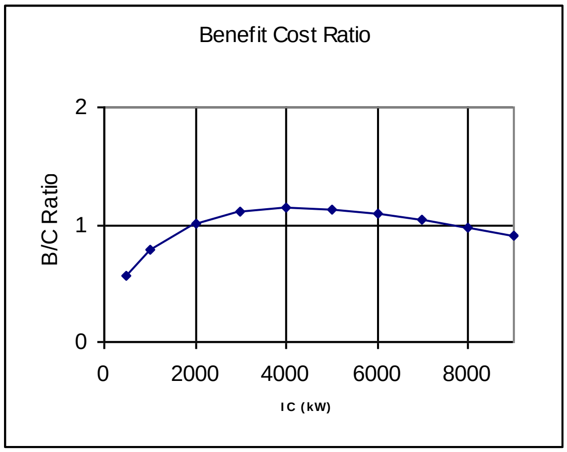
GRAPH-G



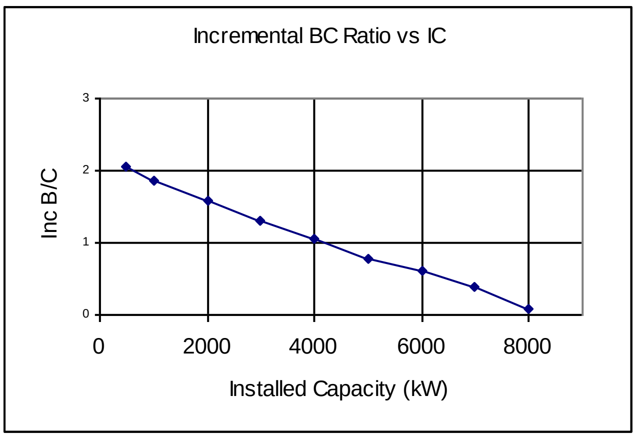
GRAPH-H



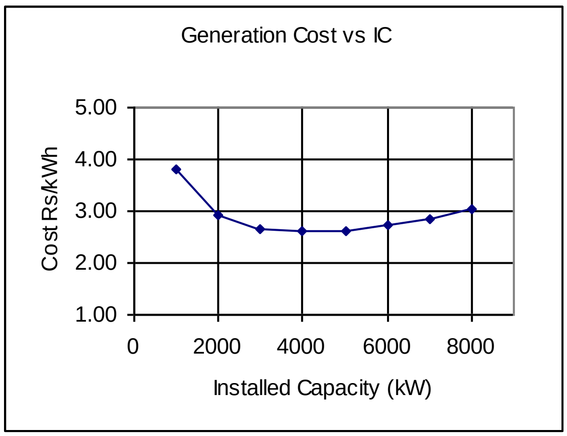
GRAPH-I



GRAPH-J



GRAPH-K



GRAPH-L

Figure 10-2 Capacity Optimization Curves 7 to 12

Section 11 Economic and Financial Analysis

This section illustrates the economic and financial analysis of the mini-hydro plants on Guntur Branch Canal developed by KCP limited. The company developed the five mini-hydro projects as BOOT schemes in 1999 for wheeling the energy to its cement plant located close by. Detailed description of the energy requirement and generation from the hydropower plants is given in the review report prepared for the project.

Part 11 .1 Economic Analysis

The economic analysis requires the determination of the economic value of energy produced by the hydropower plant. Since the analysis covers the thirty year BOOT period, the economic value of the energy produced by hydropower is determined annually from 1990 to 2010 using the procedure below.

The cement plant has a diesel generator, which is operated during times when there is no generation from renewable sources and when there is grid failure due to outage or load shedding. An analysis presented below derives the cost of energy as Rs.14.25 per kWh from a diesel plant of capacity 2500 kW operating at a 35% load factor. For larger installed capacity, multiple units of 2500kW are considered in an identical generation cost. The table also shows the cost of generation from a diesel plant of 8250kW which is equal to the capacity of the five mini-hydro projects producing energy equal to the annual average output of the mini-hydros. The variation in diesel energy cost with the load factor is given in Figure 11-2.

Table 11-1 Derivation of Energy Cost from Diesel

Description	2500kW plant @35% PLF	8250kW plant	units
Capital cost of diesel plant per kW	14,000	14,000	Rs
Diesel required per kWh	0.3	0.3	Liters
Cost of diesel per liter	42.83	42.83	Rs
Annual energy to be produced	7,665,000	27,214,331	kWh
Fuel required	2,299,500	8,164,299	liters
Cost of diesel plant	35	115.5	M Rs
Annual interest at 12.5%	4.375	14.375	M Rs
Annual cost of fuel	98.48	349.67	M Rs
Lubricating oil cost at 6%	5.90	20.98	M Rs
Annual maintenance costs at 1.5%	0.525	1.732	M Rs
Total annual costs	109.28	386.75	M Rs
Cost per kWh	14.25	14.21	Rs

To obtain the variation in energy cost for the years 1990 to 2010, the main inputs required are the capital cost of the diesel generator, prices of diesel, and annual O&M expenses. Historical values are used for the prices, whereas the O&M expenses are escalated at the historical inflation rates. In the calculations for the period 2011 to 2029, the price of diesel is increased at 5% per annum from current prices and O&M expenses at current inflation rates. The historical diesel prices and inflation rates[22] are given in Figure 11-1.

[22] The inflation rate in India was last reported at 9.82 percent in September of 2010. From 1969 until 2010, the average inflation rate in India was 7.99 percent reaching a historical high of 34.68 percent in September of 1974 and a record low of -11.31 percent in May of 1976. During the period of 1994 to 1999, inflation fell from about 10% to 8%.The period 1999 to 2005 witnessed further continuous drop in inflation with a value of 2% in 2001 and was at 4% in 2005. Thereafter inflation rose steadily and is currently just under ten percent. The projects on Guntur Branch canal were commissioned during 1999 to 2000. Average inflation during the ten year period was 5.6%.

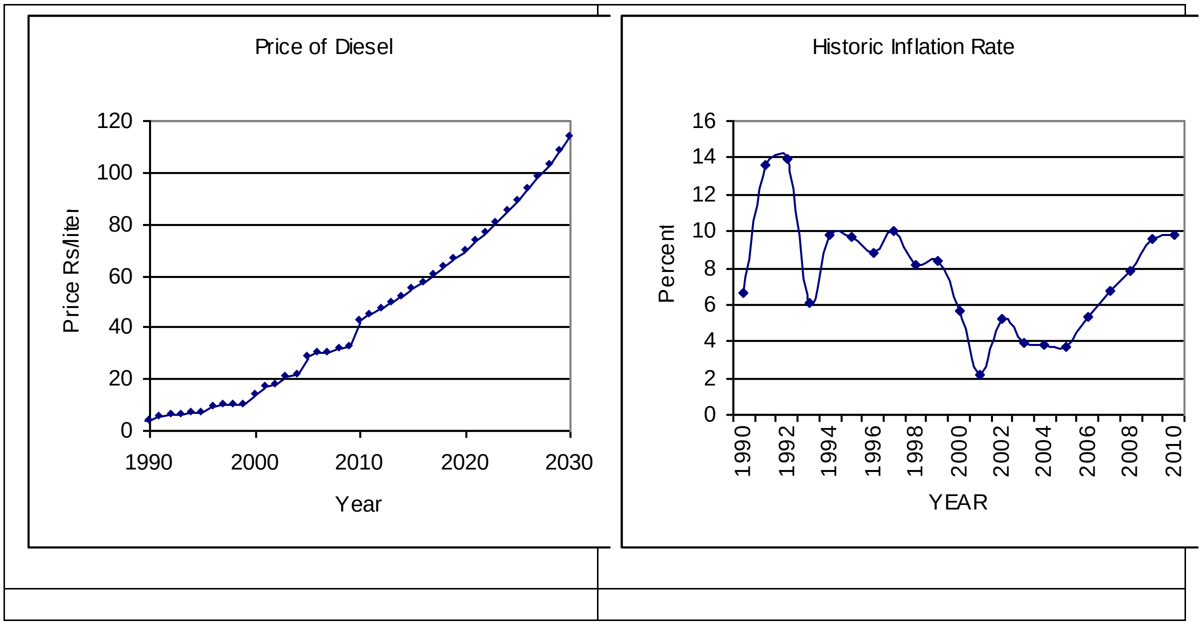


Figure 11-1 Historical Diesel Price and Inflation

The present price of grid energy is Rs.4.19 per kWh. The company purchased 18.60GWh energy from the grid in 2009, and generated 0.66 GWh from diesel which is about 3.6% of energy purchased from the grid. Thus the weighted cost of energy is (0.036*14.25 + 0.964*14.25) Rs.4.55 per kWh which is the economic value of the energy produced by hydropower. The economic value of energy as a ratio of grid to diesel energy consumption is plotted in Figure 11-4 below. The value varies from Rs. 14.25 per kWh for condition where grid is not present and diesel energy is the only alternative source to Rs.4.19 for reliable grid energy. At 50:50 ratio, the value is Rs.9.22 per kWh.

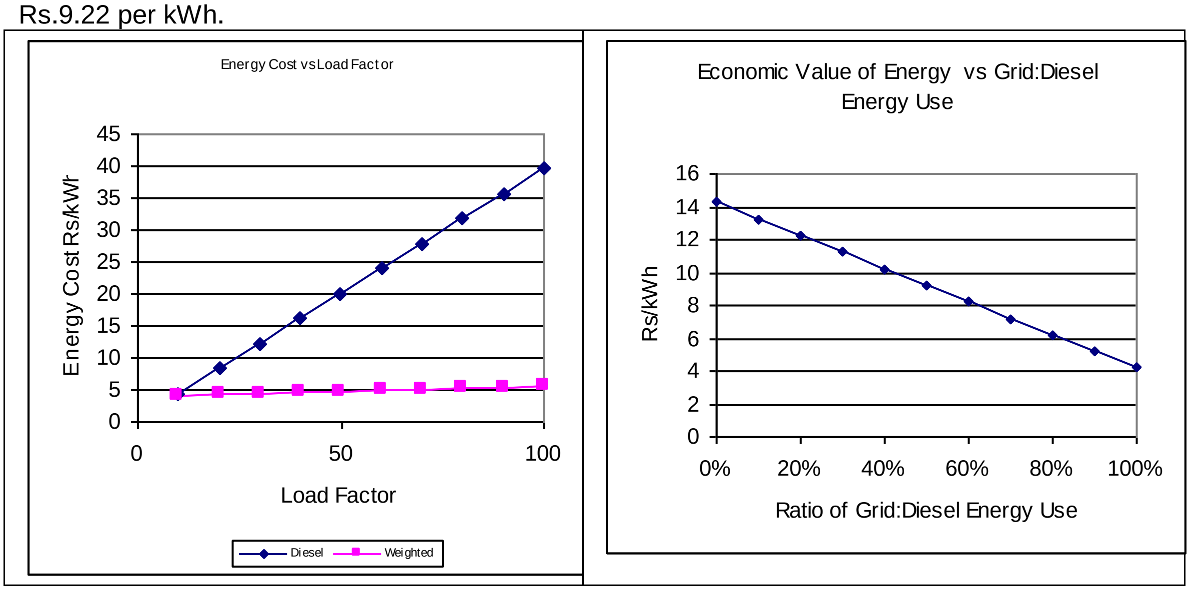


Figure 11-2 Economic Value of Hydropower versus Load Factor and Ratio of Grid: Diesel Energy Use

The historical variation till 2010 and projected energy costs are given in the Figure 11-5 for diesel and grid energy and the tariff paid by the SEB for energy from hydropower based on a 20% increase once in five years as per past trends.

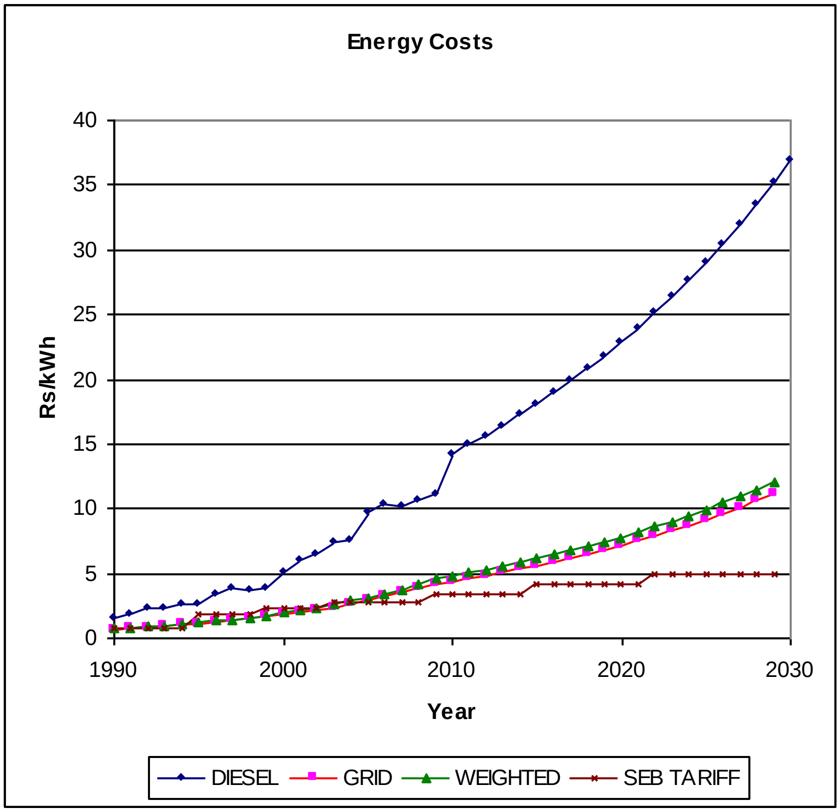


Figure 11-3 Historical and Projected Variation in Energy Costs and Tariffs

With the above data, a life-cycle analysis of costs and benefits is carried out with the following conditions on a consolidated basis that is combining the capital cost and energy production of all the five schemes.

The following are the input parameters:

- Capital cost of the plants is Rs.372.8 million
- Economic life is 30 years
- Energy outputs produced by the plants are historical values for the period 1999 to 2009. For the period 2010 to 2029, the pattern is repeated assuming a ten-year hydrological cycle.
- Economic value of the energy produced is as per computation in the previous section
- Operation and maintenance expenses for the hydropower plant are 1% of the capital cost in base year 1999 with escalation as per historical inflation rates.
- Discount rate[23] is 11%.

Based on the above, the project life-cycle costs and benefits have been computed and are given in Table 11-2 below.

[23] The WACC is computed as interest rate x (1 – corporate tax rate) x debt percentage + (required rate of return on equity x equity percentage). The IPPs consider a 15% rate of return on equity to be acceptable for investments in hydropower. With interest rate 12.5%, corporate tax rate 30%, and debt equity ratio 70:30, the WACC is 10.625%. Discount rate of 11% has been adopted.

Table 11-2 Results of Economic Analysis

Present worth of total life cycle benefits	Rs. 848.17 M
Present worth of life cycle costs	Rs. 596.52 M
Benefit-cost ratio for energy value Rs.4.19	1.928
Net present value	Rs. 408.18 M

A sensitivity study on the economic analysis is carried out for the following cases. The values of each dependent variable from the “Parameter” column can be found from the graphs that follow.

Table 11-3 Cases for Sensitivity Analysis

CASE	PARAMETERS	VARIATION IN INDEPENDENT PARAMETER	VARIATION IN DEPENDENT PARAMETER
A	B/C vs Discount Rate	0 to 25%	3.5 to 0.67
B	B/C vs Economic Value	Rs.1/kWh to Rs.6/kWh	0.62 To 3.71
C	NPV, Discounted Life Cycle Costs and Benefits vs Discount Rate	0% to 25%	NPV 1380 to –126 M.Rs
D	B/C vs annual energy production	5GWh to 40GWh per annum	0.35 to 2.80

Case A: The B/C is more than unity for discount rates below 18.75%

Case B: The annual energy output is equal to the actual generation from the projects. The B/C is more than unity provided the economic value of hydropower is more than Rs.1.63 per kWh.

Case C: The NPV reduces to zero for a discount rate of 18.75%.

Case D: In this case, the annual energy output is kept constant for thirty years whereas the economic value varies from year to year. The graph shows that a minimum energy production of 14 GWh per annum is required for a B/C of unity.

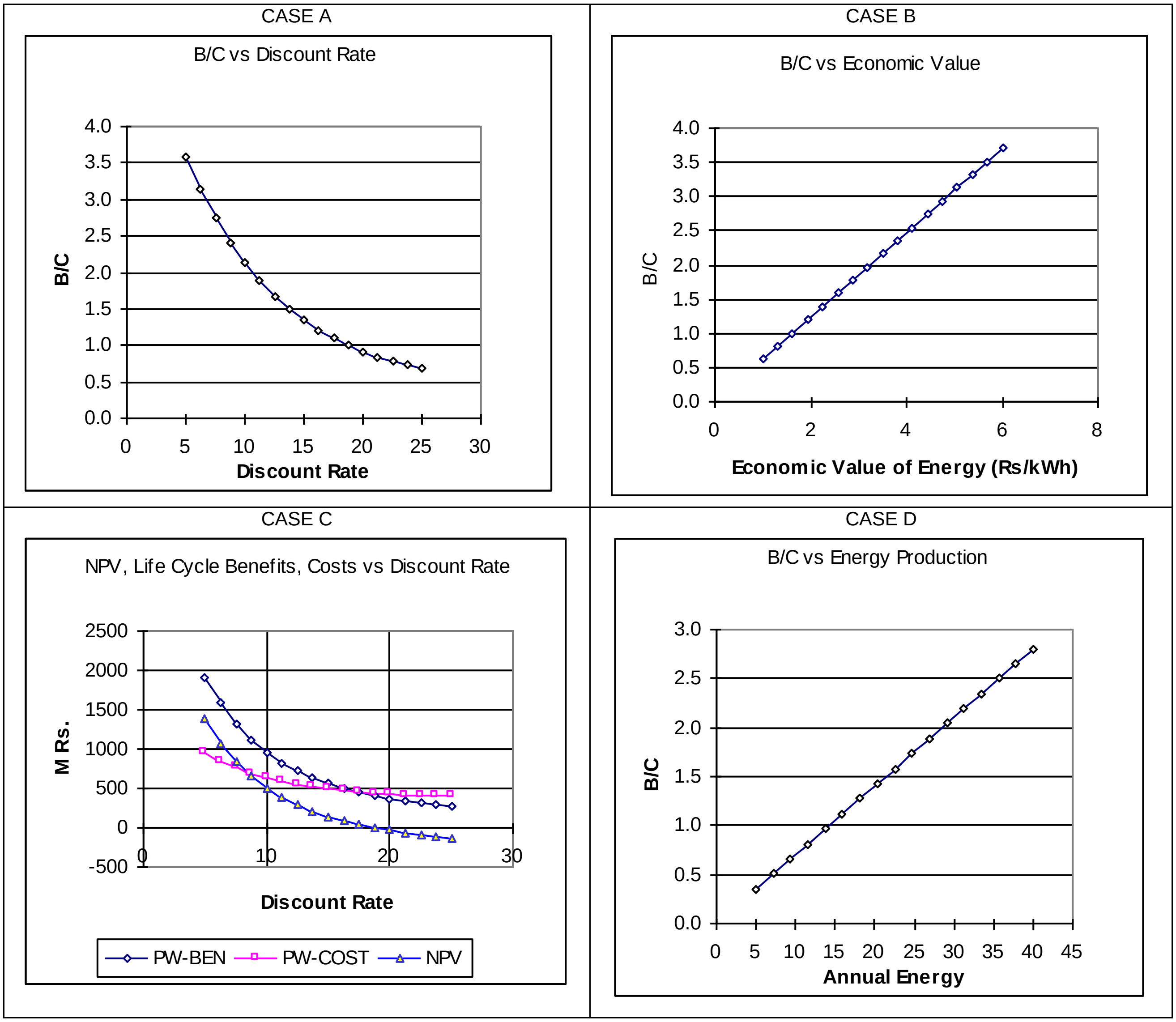


Figure 11-4 Economic Analysis Cases A to D

Part 11 .2 Financial Analysis

The financial analysis is performed for conditions given below for the five projects in the cluster, which have capacities of 1 x 2.25MW and 4 x 1.5 MW. The analysis covers the thirty year BOOT period from 1999 to 2029. The parameters used in the analysis are:

- The capital cost of the projects is Rs.372 million and IDC Rs. 47.3 million,
- The loan interest rate is 12.5%, with a repayment period of 7 years,
- The 1999 (base year) purchase price of electricity is Rs.2.25/kWh, with 2% escalation. This will cover increase in tariff for the period 2011 to 2029.
- The annual operation and maintenance expenses are 1% of capital cost in the base year 1999. The inflation rate used for computing the annual O&M expenses during the period 1999-2009 are the historical values, and kept constant at current rate of 9.82% for the period 2010 to 2029.

- The economic life of the project is 30 years and the discount rate adopted is 11%.[24]
- The energy generation series for the period 1999 to 2009 is identical to the actual annual energy produced. For the period of 2010 to 2029, the values achieved during the ten year period since commissioning are repeated assuming a ten-year hydrological cycle.

Table 11-4 Results of Financial Analysis

Present worth of total life cycle benefits	Rs. 611.57 M
Present worth of life cycle costs	Rs. 499.68 M
IRR	15.6%
Net Present Value	Rs. 111.88 M

Examination of the cash flow statement in Table 11-6 and the graphs in Figure 11-8 shows sudden increase in production cost during fourth and fifth years due to reduction in flows. Once the debt has been repaid, production cost is minimal and the energy is produced at negligible cost.

[24] The discount rate of 11% is adopted based on the computed WACC of 10.62%. The IPPs consider a return on equity of 15% to be satisfactory.

Sensitivity analysis was performed on the cash flow calculations as per variation in a particular parameter as given in the table below. The values of each dependent variable from the "Parameter" column can be found from the graphs that follow.

Table 11-5 Cases for Sensitivity Analyses

CASE	PARAMETER	COST Rs. M	LOAN PERIOD	INTEREST	PURCHASE PRICE Rs/kWh	DISCOUNT RATE
1	IRR	373	7	5% to 15%	2.25	12%
2	ENERGY COST	373	7	5% to 15%	2.25	12%
3	IRR	373	7	12.5%	2.00 to 4.50	12%
4	ENERGY COST	373	5 to 10	12.5%	2.25	12%
5	ENERGY COST	300 to 500	7	12.5%	2.25	12%
6	IRR	300 to 500	7	12.5 %	2.25	12%
7	B/C RATIO	373	7	12.5 %	2.25	5% to 15%
8	NPV	373	7	12.5%	2.25	5% to 15%
9	LIFE CYCLE ENERGY COST	373	7	12.5%	2.25	5% to 15%
10	BENEFITS AND COSTS	373	7	12.5%	2.25	5% to 15%
11	NPV	373	7	5% to 15%	2.25	5% to 15%
12	B/C RATIO	373	7	5% to 15%	2.25	5% to 15%
13	ENERGY COST vs ENERGY	373	7	12.5%	2.25	12%
14	IRR vs. ENERGY & GROWTH	373	7	12.5%	2.25	12%

The following observations can be made on each of the cases above.

Case 1: Even for an interest rate of 15% the project IRR does not fall below 14%.

Case 2: Even for an interest rate of 15%, the energy cost in the first year does not exceed Rs 2.15 per kWh i.e. the purchase price

Case 3: Even if the purchase price per kWh falls to Rs.2.00, the IRR is 12.8%.

Case 4: Even for a short loan payback period of 6 years, the first year energy cost is Rs.2.28 per kWh which is acceptable.

Case 5: Even if the capital cost increases by 20%, energy cost does not exceed Rs.2.35 per kWh.

Case 6: If the capital cost increases to Rs.460 million then the IRR becomes 10.6%.

Case 7: The financial benefit-cost ratio exceeds 1.0 as long as the discount rate is below 13.75%.

Case 8: For a discount rate of 15% the NPV is positive.

Case 9: The life-cycle energy cost in present value is only Rs 0.60 per kWh.

Case 10: The plot of benefits and costs versus discount rate intersect at a discount rate of 15.2%. The FIRR is hence taken to be 15.0%.

Case 11: Since the energy production in the first year of project operation can vary depending on the actual flow conditions, first year energy production cost is computed for various outputs. To ensure that the production cost is at least equal to the purchase price, at least 30GWh should be produced in the first year.

Case12: This case brings out the FIRR for different values of first year energy production with annual increase at rates of 1.5% to 5% per year in energy production. This case is useful for analyzing the case in which the power station supplies an isolated grid in which the energy demand steadily increases. At a low growth rate of 1% in energy demand, a minimum of 18 GWh per year must be sold to ensure that the FIRR is greater than the WACC.

Case13: Combined plot of NPV versus discount and interest rate shows that NPV is positive for all combinations of interest up to 15% with loan repayment period of 7 years at discount rate up to 17%.

Case 14: Combined plot of B/C ratio versus discount and interest rate shows that B/C ratio is greater than one for all combinations of interest up to 15% and discount rate up to 13%.

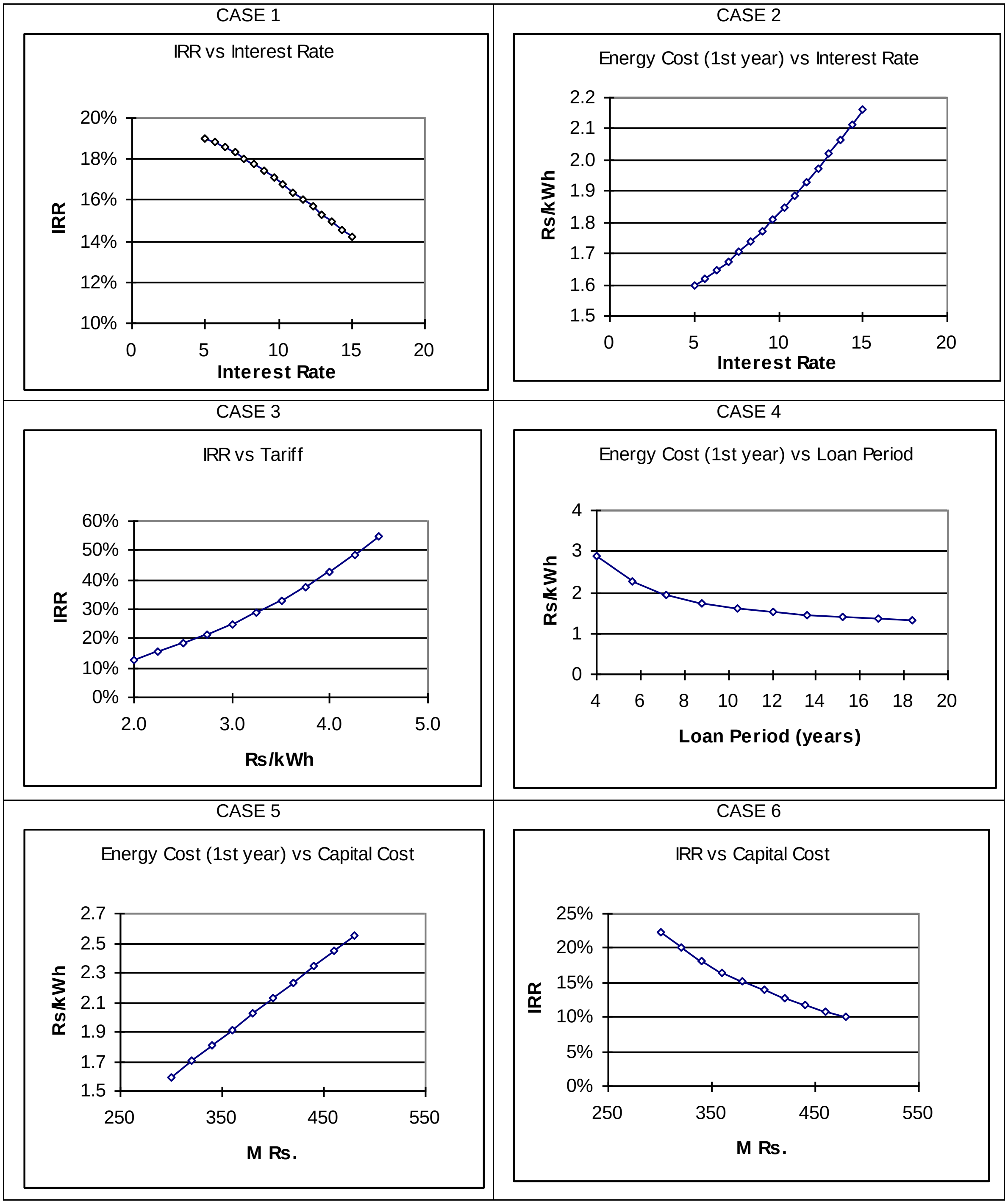


Figure 11-5 Financial Analysis for Cases 1 to 6

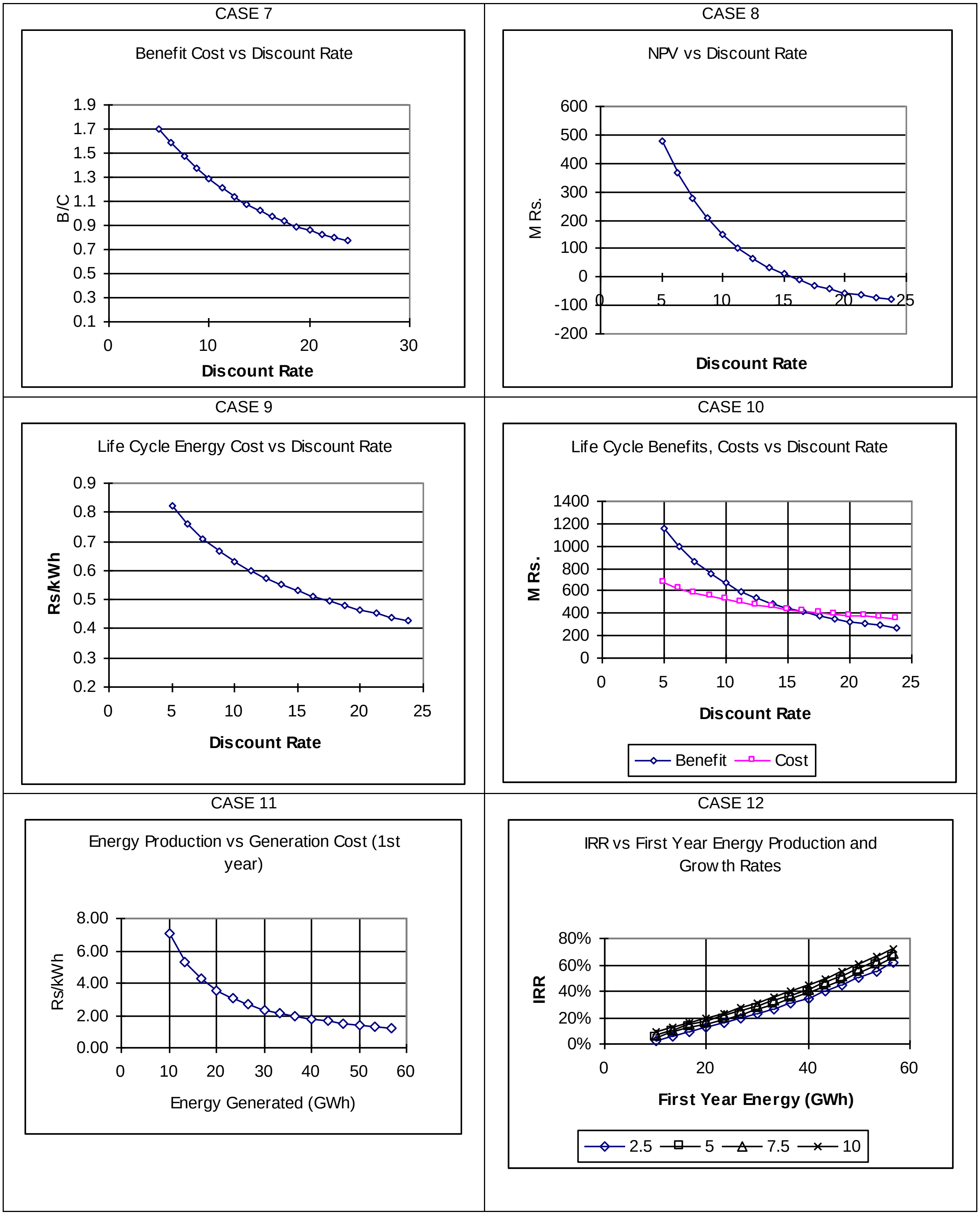
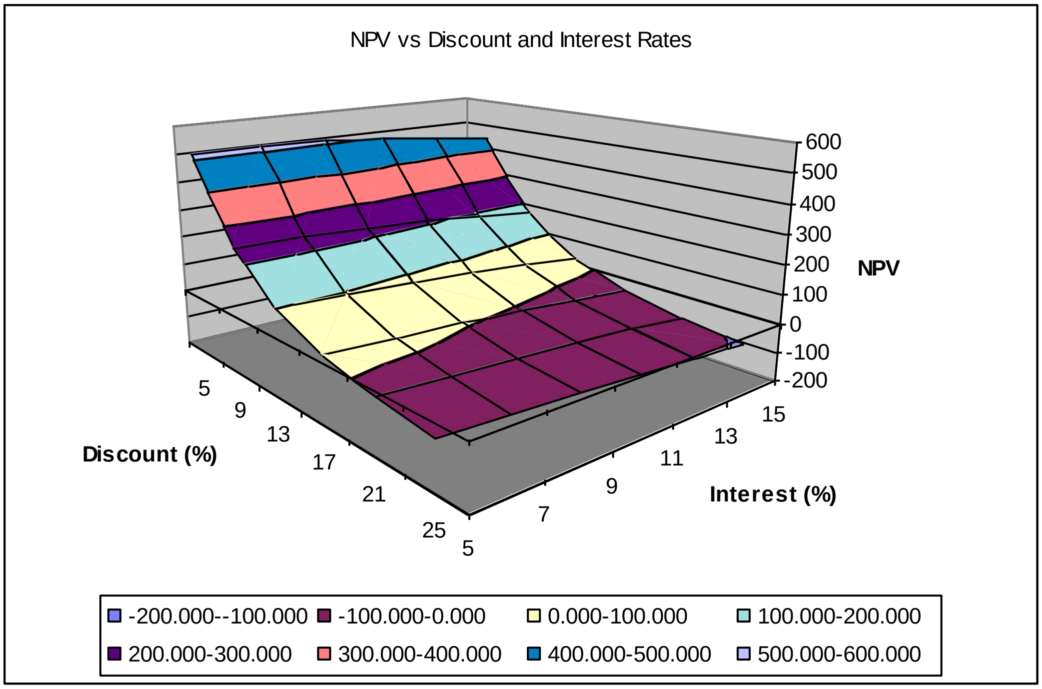


Figure 11-6 Financial Analysis for Cases 7 to 12

CASE 13



CASE 14

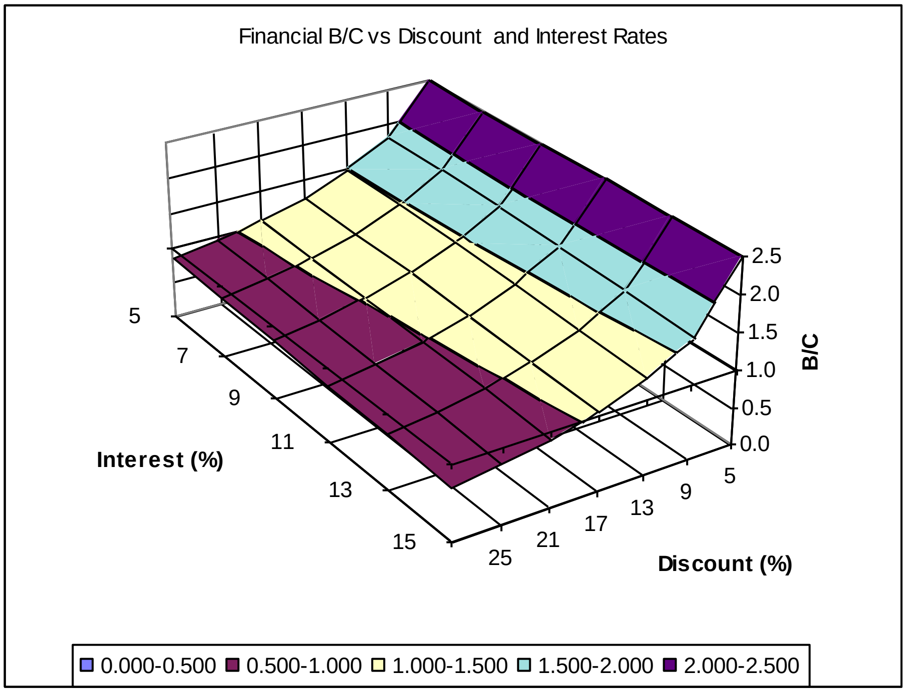
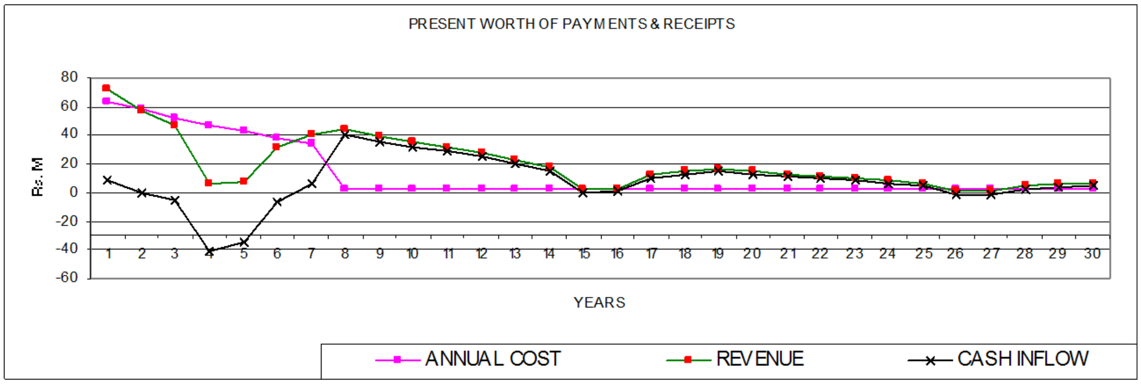
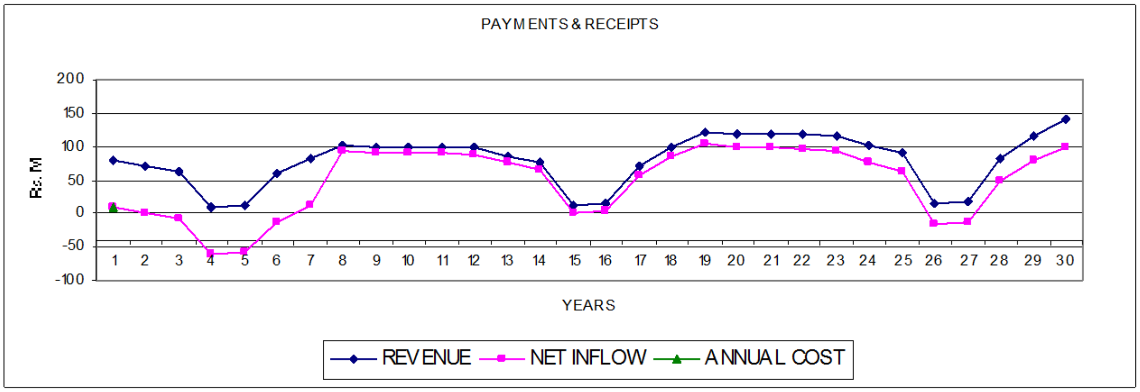
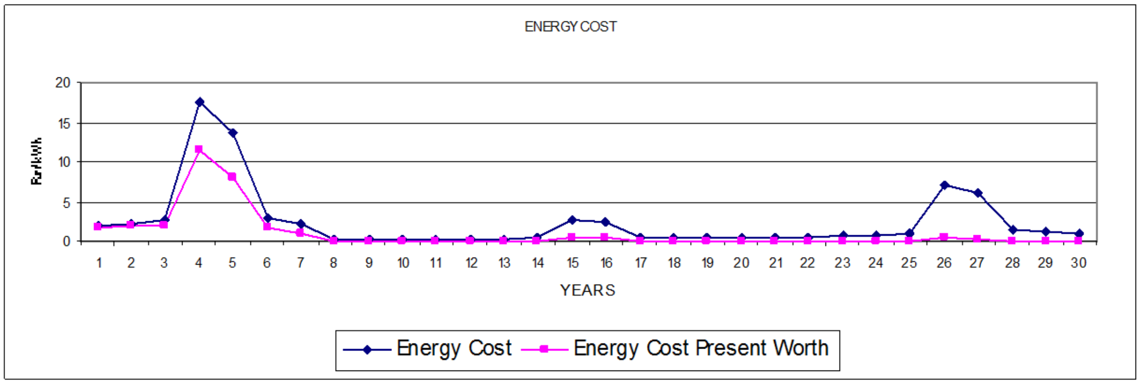


Figure 11-7 Financial Analysis for Cases 13 and 14


PRESENT WORTH OF PAYMENTS & RECEIPTS
Rs. M
YEARS
ANNUAL COST
REVENUE
CASH INFLOW


PAYMENTS & RECEIPTS
Rs. M
YEARS
REVENUE
NET INFLOW
ANNUAL COST


ENERGY COST
YEARS
Energy Cost
Energy Cost Present Worth

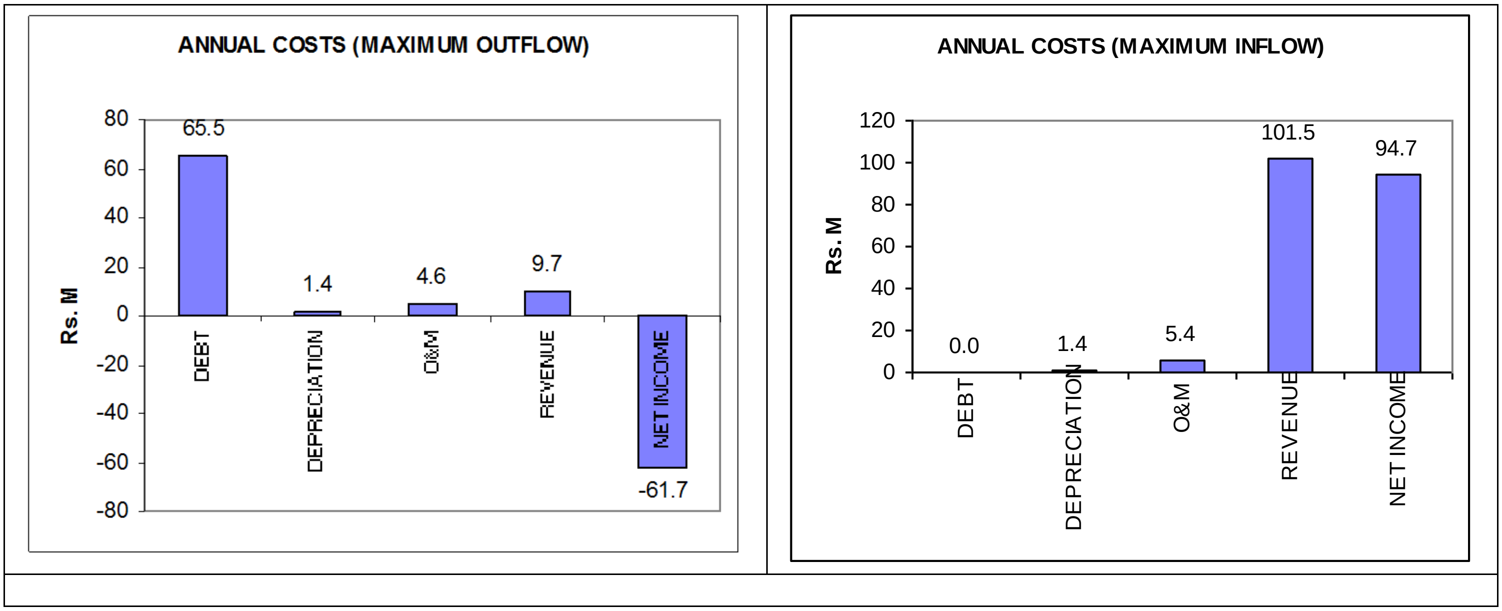


Figure 11-8 Cash Flows

Table 11-6 Economic and Financial Analysis Statement 1999 to 2029 with Cash Receipts and Expenses

															PRESENT WORTH				
SI YEAR	% CC	Investment M Rs. 1	Total Debt	IDC M Rs. 2	Debt Service M Rs. 3	Depre-ciation M Rs. 4	O & M M Rs. 5	Energy Sold GWh 6	Gen Cost Rs/kWh 7	Eco Value Rs/kWh 8	REVENUE M Rs. 9	BENEFIT 10	NET INCOME M Rs. 11	PWF 12	ANNUAL COSTS M Rs. 13	ENERGY COST Rs/kWh 14	BENEFIT M Rs. 15	REVENUE M Rs. 16	CASH FLOW M Rs. 17
-2	40	149.120	104.384	13.048															
-1	60	223.680	260.960	34.251															
													(9)-		(12)x				
													(3+4+5)		(3+4+5)	7x12	6x8x12	(8)x(6)	(16-13)
							3.73					-372.80	-111.84						-111.84
1999		0.00		0.00	65.46	1.40	4.04	35.73	1.98	1.57	80.39	56.06	9.49	0.90	63.88	1.79	50.51	72.42	8.55
2000		0.00		0.00	65.46	1.40	4.27	30.82	2.31	1.76	70.74	54.11	-0.39	0.81	57.73	1.87	43.92	57.41	-0.32
2001		0.00		0.00	65.46	1.40	4.36	27.20	2.62	1.95	63.65	53.01	-7.57	0.73	52.08	1.91	38.76	46.54	-5.54
2002		0.00		0.00	65.46	1.40	4.58	4.09	17.48	2.13	9.75	8.72	-61.70	0.66	47.06	11.52	5.74	6.42	-40.64
2003		0.00		0.00	65.46	1.40	4.77	5.26	13.61	2.36	12.79	12.42	-58.84	0.59	42.51	8.08	7.37	7.59	-34.92
2004		0.00		0.00	65.46	1.40	4.95	23.71	3.03	2.57	58.68	61.00	-13.13	0.53	38.39	1.62	32.61	31.37	-7.02
2005		0.00		0.00	65.46	1.40	5.13	33.18	2.17	2.88	83.62	95.60	11.63	0.48	34.68	1.04	46.05	40.28	5.60
2006		0.00		0.00	0.00	1.40	5.40	39.59	0.17	3.16	101.55	125.01	94.75	0.43	2.95	0.07	54.25	44.07	41.11
2007		0.00		0.00	0.00	1.40	5.76	37.89	0.19	3.43	98.89	130.03	91.73	0.39	2.80	0.07	50.83	38.66	35.86
2008		0.00		0.00	0.00	1.40	6.22	37.25	0.20	3.75	98.89	139.82	91.27	0.35	2.68	0.07	49.24	34.83	32.14
2009		0.00		0.00	0.00	1.40	6.82	36.74	0.22	4.11	99.21	150.93	90.99	0.32	2.61	0.07	47.89	31.48	28.87
2010		0.00		0.00	0.00	1.40	7.49	35.73	0.25	4.56	98.08	163.02	89.19	0.29	2.54	0.07	46.60	28.03	25.49
2011		0.00		0.00	0.00	1.40	8.22	30.82	0.31	4.79	85.99	147.63	76.37	0.26	2.48	0.08	38.02	22.14	19.67
2012		0.00		0.00	0.00	1.40	9.03	27.20	0.38	5.03	77.11	136.77	66.68	0.23	2.42	0.09	31.73	17.89	15.47
2013		0.00		0.00	0.00	1.40	9.92	4.09	2.77	5.28	11.77	21.57	0.45	0.21	2.37	0.58	4.51	2.46	0.09
2014		0.00		0.00	0.00	1.40	10.89	5.26	2.34	5.54	15.39	29.17	3.10	0.19	2.31	0.44	5.49	2.90	0.58
2015		0.00		0.00	0.00	1.40	11.96	23.71	0.56	5.82	70.42	137.94	57.06	0.17	2.27	0.10	23.40	11.95	9.68
2016		0.00		0.00	0.00	1.40	13.13	33.18	0.44	6.11	100.05	202.68	85.51	0.15	2.22	0.07	30.97	15.29	13.07
2017		0.00		0.00	0.00	1.40	14.42	39.59	0.40	6.41	121.15	253.86	105.32	0.14	2.18	0.06	34.95	16.68	14.50
2018		0.00		0.00	0.00	1.40	15.84	37.89	0.46	6.73	117.65	255.07	100.41	0.12	2.14	0.06	31.64	14.59	12.45
2019		0.00		0.00	0.00	1.40	17.39	37.25	0.50	7.07	117.33	263.24	98.53	0.11	2.10	0.06	29.41	13.11	11.01
2020		0.00		0.00	0.00	1.40	19.10	36.74	0.56	7.42	117.39	272.62	96.89	0.10	2.06	0.06	27.44	11.82	9.75

Sl YEAR	% CC	Investment M Rs. 1	Total Debt	IDC M Rs. 2	Debt Service M Rs. 3	Depre- ciation M Rs. 4	O & M M Rs. 5	Energy Sold GWh 6	Gen Cost Rs/kWh 7	Eco Value Rs/kWh 8	REVENUE M Rs. 9	BENEFIT 10	NET INCOME M Rs. 11	PWF 12	PRESENT WORTH ANNUAL COSTS M Rs. 13	ENERGY COST Rs/kWh 14	BENEFIT M Rs. 15	REVENU E M Rs. 16	CASH FLOW M Rs. 17
2021		0.00		0.00	0.00	1.40	20.98	35.73	0.63	7.79	115.76	278.31	93.38	0.09	2.03	0.06	25.24	10.50	8.47
2022		0.00		0.00	0.00	1.40	23.04	30.82	0.79	8.18	101.25	252.05	76.81	0.08	2.00	0.06	20.59	8.27	6.28
2023		0.00		0.00	0.00	1.40	25.30	27.20	0.98	8.59	90.57	233.53	63.87	0.07	1.97	0.07	17.19	6.67	4.70
2024		0.00		0.00	0.00	1.40	27.79	4.09	7.14	9.01	13.79	36.83	-15.40	0.07	1.94	0.47	2.44	0.91	-1.02
2025		0.00		0.00	0.00	1.40	30.51	5.26	6.06	9.46	18.00	49.81	-13.92	0.06	1.91	0.36	2.98	1.08	-0.83
2026		0.00		0.00	0.00	1.40	33.51	23.71	1.47	9.94	82.16	235.58	47.24	0.05	1.88	0.08	12.68	4.42	2.54
2027		0.00		0.00	0.00	1.40	36.80	33.18	1.15	10.43	116.47	346.15	78.27	0.05	1.85	0.06	16.78	5.65	3.80
2028		0.00		0.00	0.00	1.40	40.42	39.59	1.06	10.95	140.74	433.59	98.93	0.04	1.83	0.05	18.94	6.15	4.32
									MEAN							MEAN			
TOTA L		372.80		47.30	458.23	42.05	432.04	822.51 27.42	0.04		2389.24		1456.92		387.85	0.02	848.18	611.57	223.72

NOTES:

Column 1 gives the sequence of investment made in the construction with 40% in first year and 60% in second year.
Column 2 gives the IDC during the construction period. The sum of the investment and IDC is the total cost of the project.
Column 3 gives the debt service with a loan repayment period of 7 years with a debt equity ratio of 70:30 and interest of 12.5%. CRR is 0.222.
Column 4 gives the depreciation
Column 5 gives the Operation and Maintenance expenses starting at 1% of capital cost in 1999 at increasing at the historic inflation rates upto 2010 and with constant current inflation rate from 2010 upto 2028.
Column 6 gives the actual energy production values from 1999 to 2010. The above production series is repeated from 2011 to 2028 assuming a ten year hydrological cycle.
Column 7 gives the generation cost computed by dividing total annual costs (Debt service + Depreciation + O&M) by the energy produced.
Column 8 gives the economic value of the energy produced which is the weighted cost of energy from grid and diesel generator.
Column 9 gives the revenue from the energy sold at base year price of Rs.2.25 per kWh with 2% annual increase in tariff.
Column 10 gives the economic beneift from the energy produced which is energy produced x economic value of energy
Column 11 gives net income (Revenue – Debt Service – Depreciation – O&M)
Column 12 gives the Present Worth Factor computed with a discount rate of 11%
Columns 13 to 17 give the present worths of annual costs, energy cost, benefits, revenue and cash flow.
The sum of the figures in each column are given in the last row, from which economic B/C is Total of Column 15/(Capital Cost + ΣPWF*O&M), financial B/C is Total of Column 16/(Total of column 13 + debt) , IRR is computed based on revenue stream in column 11, NPV is Total of Column 15 – (Total of column 13 + debt)

Section 12 Annex and References

Part 12 .1 Tables

Following tables 12-1 to 12-5 give design parameters of the projects as recommended in the pre-investment report and as constructed.

Table 12-1 Parameters of the Projects as per Pre-Investment Report

	PROJECT NAME	TYPE	ESMAP PRE INVESTMENT RECOMMENDATION								
			HEAD (m)	UNIT FLOW (cum/s)	No.	PLANT FLOW (cum/s)	UNIT RATING (kW)	IC (kW)	ENERGY (GWh)	PLF (%)	TYPE
	KARNATAKA										
1	Attehala	DAM	7	7.5	1	7.5	350	350	2.8	91.32%	
2	Brindavan Scheme 1	DAM	13	30	3	90	3500	10500	62	67.41%	RAD
3	Brindavan Scheme 2	DAM	-	-	-		-	-	-	-	-
4	Deverebelekere	DAM	13	12	1	12	1000	1000	4.8	54.79%	
5	Harangi Scheme 1	DAM	15	12	3	36	1500	4500	14.52	36.83%	RAD
6	Harangi Scheme 2	DAM	-	-	-		-	-	-	-	
7	Kabini Canal	DAM	10	12	3	36	650	1950	6.25	36.59%	RAD
8	Kabini Dam	DAM	-	-	-		-	-	-	-	-
9	Maddur Scheme 1	CANAL	4.63	20	1	20	750	750	3.75	57.08%	
10	Maddur Scheme 2	CANAL	13	7.5	2	15	1000	2000	8.3	47.37%	VSK
11	Malaprabha	DAM									
12	Nugu Scheme 1	DAM	13	12	2	24	1000	2000	6.15	35.10%	RAD
13	Nugu Scheme 2	DAM	-	-	-		-	-	-	-	-
14	Shahapur 1	CANAL	7	7.5	3	22.5	350	1050	5.1	55.45%	RAD
15	Shahapur 2	CANAL	7	7.5	3	22.5	350	1050	3.9	42.40%	RAD
16	Shahapur 3	CANAL	7	7.5	3	22.5	350	1050	3.65	39.68%	RAD
17	Shahapur 4	CANAL	7	7.5	3	22.5	350	1050	4.15	45.12%	RAD
18	Shahapur 5	CANAL	10	7.5	2	15	650	1300	4.88	42.85%	RAD
								28550 TOTAL	130.25 TOTAL	50.15% MEAN	
	TAMILNADU										
19	Amaravathy	DAM	21	12	2	24	2000	4000	10.58	30.19%	
20	Lower Bhawani Dam PH	DAM									
21	Lower Bhawani Canal PH	DAM	15	30	2	60	3500	7000	24.25	39.55%	
22	Pechiparai	DAM	10	12	2	24	650	1300	5.95	52.25%	
23	Perunchani	DAM	15	7.5	2	15	650	1300	5.1	44.78%	
24	Sathanur	DAM	30	12	2	24	2500	5000	21.82	49.82%	
25	Thirumurthy	DAM	13	7.5	3	22.5	650	1950	7.73	45.25%	
								20550 TOTAL	75.43 TOTAL	43.64% MEAN	
	ANDHRA PRADESH										
26	Adanki BC PH 1	CANAL	4.25	22.5	2	45	650	1300	3.64	31.96%	
27	Adanki BC PH 2	CANAL	10	22.5	2	45	1250	2500	6.8	31.05%	
28	Adanki BC PH 3	CANAL									
29	Guntur BC 1	CANAL	7	22.5	3	67.5	1250	3750	17	51.75%	RAD
30	Guntur BC 2	CANAL	10	22.5	3	67.5	1250	3750	19.8	60.27%	RAD
31	Guntur BC 3	CANAL	4.25	22.5	2	45	650	1300	6.4	56.20%	RAD
32	Guntur BC 4	CANAL	7	22.5	2	45	1250	2500	10.5	47.95%	RAD
33	Guntur BC 5	CANAL									RAD
34	Guntur BC 6	CANAL									RAD
35	Guntur BC 7	CANAL									RAD
36	Lock in Sula	CANAL	10	22.5	2	45	1500	3000	16.48	62.71%	RAD
37	Lower Manair	CANAL	7	22.5	2	45	1500	3000	16	60.88%	RAD

								21100 TOTAL	96.62 TOTAL	50.35% MEAN	
	KERALA										
38	Kuttiyadi PH 1	DAM	15	12	2	24	1500	3000	17.1	65.07%	
39	Maniyar	DAM	15	22.5	6	135	2500	15000	57.1	43.46%	
40	Peechi 1 (CBU)	DAM	21	10	1	10	1500	1500	10	76.10%	
								19500 TOTAL	84.2 TOTAL	61.54% MEAN	

Table 12-2 Parameters of the Projects as Implemented

	PROJECT NAME	DATE OF ALLOTMENT	DATE OF COMPLETION	TIME PERIOD (YEARS)	IPP	AS CONSTRUCTED HEAD (m)	UNIT FLOW (cum/s)	No	PLANT FLOW (cum/s)	UNIT RATING (kW)	IC (kW)	ENERGY (GWh)	PLF (%)
	KARNATAKA												
1	Attehala	1992	1998	6	YIL	4.5	9	1	9	350	350	0.09	2.94%
2	Brindavan Scheme 1	1999	2006	7	APC	12	52.5	2	105	6000	12000	50.57	48.11%
3	Brindavan Scheme 2	2002	2009	7	APC	18	14	2	28	2000	4000	19.00	54.22%
4	Deverebelekere												
5	Harangi Scheme 1	1992	1999	7	EDCL	20	26.2	2	52.4	4500	9000	23.84	30.24%
6	Harangi Scheme 2	2006	2011	5	EDCL	14.3	54.32	1	54.32	6000	6000	6.15	11.70%
7	Kabini Canal	1999	2003	4	MPG	6.5		2	0	1500	3000	6.00	22.83%
8	Kabini Dam	1994	2003	9	SKP	18	77	2	154	10000	20000	48.89	27.91%
9	Maddur Scheme 1	2004	2007	3	VGP	4.63	20	1	20	750	750	3.50	53.27%
10	Maddur Scheme 2	1990	2010	20	LKP	13	10	2	20	1000	2000	10.00	57.08%
11	Malaprabha							2		1000	2000		
12	Nugu Scheme 1	1992	2004	12	MPG	12	7.7	2	15.4	750	1500	3.52	26.79%
13	Nugu Scheme 2	1992	2002	10	MPG	28	3.28	2	6.56	750	1500	4.49	34.17%
14	Shahapur 1	1992	1997	5	BPC	6	25	1	25	1300	1300	4.14	36.35%
15	Shahapur 2	1992	1997	5	BPC	6	25	1	25	1300	1300	3.07	26.96%
16	Shahapur 3	1992	1997	5	BPC	5.5	25	1	25	1300	1300	2.94	25.82%
17	Shahapur 4	1992	1997	5	BPC	6.25	25	1	25	1300	1300	3.15	27.66%
18	Shahapur 5	1992	1997	5	BPC	10	25	1	25	1400	1400	3.82	31.15%
				7.2							68700 TOTAL	193.17 TOTAL	34.28% MEAN
	TAMILNADU												
19	Amaravathy	1994	2006	12	TNEB	21	12	2	24	2000	4000	8.28	23.63%
20	Lower Bhawani Dam PH	1987	1990	3	TNEB	26.8	10	4	40	2000	8000	35.40	50.51%
21	Lower Bhawani Canal PH	1994	1998	4	TNEB	18.67	27.41	2	54.82	4000	8000	18.58	26.51%
22	Pechiparai												
23	Perunchani	1994	2006	12	TNEB	15	7.5	2	15	650	1300	4.00	35.12%
24	Sathanur	1994	1999	5	TNEB	30	32.5	1	32.5	7500	7500	9.89	15.05%

25	Thirumurthy	1994	2000	6	TNEB	10	8.8	3	26.4	650	1950	3.61	21.13%
				7.0							30750	79.76	28.66%
											TOTAL	TOTAL	MEAN
	ANDHRA PRADESH												
26	Adanki BC PH 1	1994	1997	3	DCR	6	26.2	2	52.4	1070	2140	7.88	42.03%
27	Adanki BC PH 2	1994	1997	3	DCR	4.57	26.2	2	52.4	794	1588	6.11	43.92%
28	Adanki BC PH 3	1994	1997	3	DCR	7	26.2	2	52.4	1235	2470	9.61	44.41%
29	Guntur BC 1	1994	1999	5	DCL	6.89	25.51	3	76.53	1250	3750	16.10	49.01%
30	Guntur BC 2	1995	1997	2	SCL	10	30	2	60	2150	4300	17.71	47.02%
31	Guntur BC 3	1994	1999	5	KCP	4.5	20.75	3	62.25	750	2250	10.67	54.13%
32	Guntur BC 4	1994	1998	4	KCP	4.5	39.6	2	79.2	750	1500	4.36	33.18%
33	Guntur BC 5	1994	1998	4	KCP	4.5	39.6	2	79.2	750	1500	4.36	33.18%
34	Guntur BC 6	1994	1999	5	KCP	4.5	39.6	2	79.2	750	1500	4.36	33.18%
	Guntur BC 7	1994	1999	5	KCP	4.5	39.6	2	79.2	750	1500	4.36	33.18%
35	Lock in Sula	1994	1998	4	SPL	12	19.82	2	39.64	2000	4000	5.36	15.29%
36	Lower Manair	1999	2001	2	SPL	6.5	28.5	2	57	1500	3000	7.87	29.95%
				3.75							29498	98.75	36.51%
											TOTAL	TOTAL	MEAN
	KERALA												
37	Kuttiyadi PH 1	1991	2011	20	KSEB			3	0	1250	3750	17.10	52.05%
38	Maniyar	1991	1994	3	CUL	14.5	33	3	99	4000	12000	31.50	29.97%
39	Peechi 1 (CBU)	1991	2012	21									
				11.5							15750	48.60	41.01%
											TOTAL	TOTAL	MEAN

Table 12-3 Economic and Financial Analysis of the Projects

						ECONOMICS										ENERGY COST				
SL	PROJECT NAME	ENERGY (GWh) (1)	DATA LENGTH (YEARS) (2)	TARIFF (Rs/ kWh) (3)	COST (Rs.M) (4)	Cost/ kW (Rs.) (5)	Cost/ kWh (Rs.) (6)	Cost/ kW 1991 (Rs.) (7)	Cost/ kWh 1991 (Rs.) (8)	E/kW (kWh/ kW /Rs. 100) (9)	FIRR (%) (10)	PAY BACK PERIOD (YEARS) (11)	BC (12)	NPV Rs.M (13)	NPV/ kW Rs. (14)	1st YEAR Rs/kWh (15)	IN LOAN PERIOD Rs/kWh (16)	11th YEAR Rs/kWh (17)	AVE Rs/kWh (18)	AVE 1991 Rs/kWh (19)
	KARNATAKA																			
1	Attehalla	0.09	9	2.80	20.00	57143	35.56	31565	19.64	0.81	-3.00%	79	0.143	-21	-60842	20.19	25.16	4.12	7.78	4.30
2	Brindavan Scheme 1	50.57	1	2.80	603.00	50250	1.91	17991	0.68	23.42	29.48%	4	3.365	533	44401	2.23	1.52	0.35	0.55	0.20
3	Brindavan Scheme 2	19	1	2.80	276.00	69000	2.32	18000	0.61	26.39	24.78%	5	3.527	187	46815	2.45	1.68	0.41	0.61	0.16
4	Harangi Scheme 1	23.84	11	2.80	445.00	49444	2.99	25010	1.51	10.59	10.51%	7	1.546	-13	-1463	6.33	2.57	0.31	0.75	0.00
5	Harangi Scheme 2	6.15	0	2.80	154.70	25783	4.02	6726	1.05	15.24	12.93%	9	2.225	16	2611	4.25	2.91	0.71	1.05	0.38
6	Kabini Canal	6	3	2.80	131.00	43667	3.49	18264	1.46	10.95	12.45%	8	1.751	10	3474	3.67	2.49	0.49	0.88	0.27
7	Kabini Dam	48.89	5	2.80	1060.00	53000	3.47	22168	1.45	11.03	11.70%	8	1.735	45	2226	8.80	3.39	0.36	0.87	0.37
8	Maddur Scheme 1	3.5	2	2.80	43.57	58093	1.99	19628	0.67	23.78	28.47%	4	3.493	37	49557	1.79	1.37	0.44	0.55	0.37
9	Maddur Scheme 2	10	0	2.80	110.00	55000	1.76	14348	0.46	34.85	34.97%	4	4.498	121	60319	1.60	1.22	0.41	0.50	0.19
10	Nugu Scheme 1	3.52	4	2.80	100.60	67067	4.57	27013	1.84	8.69	7.53%	10	1.253	-19	-12875	16.87	5.72	0.92	1.30	0.13
11	Nugu Scheme 2	4.49	6	2.80	64.35	42900	2.29	18569	0.99	16.12	23.55%	5	2.128	47	31530	4.48	2.25	0.25	0.68	0.00
12	Shahapur 1	4.14	6	2.25	51.40	39538	1.99	23164	1.16	13.75	22.34%	6	2.039	32	24389	2.30	1.47	0.21	0.49	0.52
13	Shahapur 2	3.07	6	2.25	51.40	39538	2.68	23164	1.57	10.19	14.31%	7	1.558	10	7502	3.01	1.92	0.27	0.65	0.29
14	Shahapur 3	2.94	6	2.25	51.40	39538	2.80	23164	1.64	9.76	12.89%	8	1.462	6	4264	3.19	2.03	0.29	0.69	0.29
15	Shahapur 4	3.15	6	2.25	51.40	39538	2.61	23164	1.53	10.46	15.89%	7	1.658	14	11008	2.82	1.81	0.25	0.61	0.38
16	Shahapur 5	3.82	6	2.25	51.40	36714	2.15	21509	1.26	12.69	20.75%	6	1.950	28	19723	2.40	1.54	0.21	0.52	0.40
		193.17 TOTAL				47888 MEAN	4.79 MEAN	20840 MEAN	2.35 MEAN	14.92 MEAN	17.47% MEAN	11.1 MEAN	2.146 MEAN		14540 MEAN	5.40 MEAN	3.69 MEAN	0.62 MEAN	0.71 MEAN	0.52 MEAN

SL	PROJECT NAME	ENERGY (GWh) (1)	DATA LENGTH (YEARS) (2)	TARIFF (Rs/kWh) (3)	COST (Rs.M) (4)	ECONOMICS Cost/kW (Rs.) (5)	Cost/kWh (Rs.) (6)	Cost/kW 1991 (Rs.) (7)	Cost/kWh 1991 (Rs.) (8)	E/kW (kWh/kW/Rs. 100) (9)	FIRR (%) (10)	PAY BACK PERIOD (YEARS) (11)	BC (12)	NPV Rs.M (13)	NPV/kW Rs. (14)	ENERGY COST 1st YEAR Rs/kWh (15)	IN LOAN PERIOD Rs/kWh (16)	11th YEAR Rs/kWh (17)	AVE Rs/kWh (18)	AVE 1991 Rs/kWh (19)
	TAMILNADU																			
17	Amaravathy	8.28	3	2.80	224.60	56150	4.34	20103	1.55	10.30	7.05%	10	1.638	-47	-11646	5.01	3.19	0.74	1.12	0.40
18	Lower Bhawani Dam PH	35.4	19	0.80	207.50	25938	0.94	28032	1.01	15.79	23.01%	7	2.363	217	27149	1.66	0.75	0.18	0.24	0.26
19	Lower Bhawani Canal PH	18.58	12	2.80	404.30	50538	3.48	27916	1.92	8.32	36.05%	8	4.226	199	24930	23.42	9.97	0.05	0.26	0.14
20	Perunchani	4	2	2.80	84.80	65231	3.39	23354	1.21	13.18	12.65%	8	2.102	7	5720	3.57	2.44	0.55	0.87	0.31
21	Sathanur	9.89	11	2.80	357.50	47667	5.78	24110	2.93	5.47	-0.06%	13	0.823	-203	-27041	20.66	37.64	0.75	1.40	0.71
22	Thirumurthy	3.61	8	2.80	99.00	50769	4.39	23811	2.06	7.77	3.51%	10	1.104	-43	-22244	12.19	4.85	0.92	1.12	0.53
		79.76 TOTAL				49382 MEAN	3.72 MEAN	24554 MEAN	1.78 MEAN	10.14 MEAN	13.70% MEAN	9 MEAN	2.043 MEAN		-522 MEAN	11.09 MEAN	9.81 MEAN	0.53 MEAN	0.84 MEAN	0.39 MEAN
	ANDHRA PRADESH																			
23	Adanki BC PH 1	7.88	13	2.25	100.00	46729	2.03	27377	1.19	13.45	18.38%	6	1.894	45	20845	4.25	4.32	0.18	0.52	0.31
24	Adanki BC PH 2	6.11	13	2.25	100.00	62972	2.62	36893	1.53	10.43	12.09%	7	1.458	7	4270	6.40	5.37	0.24	0.68	0.40
25	Adanki BC PH 3	9.61	13	2.25	100.00	40486	1.66	23719	0.98	16.40	27.80%	5	2.370	88	35616	2.56	3.54	0.16	0.42	0.24
26	Guntur BC 1	16.1	8	2.25	190.00	50667	1.89	25628	0.96	16.75	21.76%	5	2.416	119	31826	1.72	3.00	1.29	0.48	0.24
27	Guntur BC 2	17.71	13	2.25	178.40	41488	1.61	24306	0.94	16.94	25.84%	4	2.330	150	34921	3.88	2.09	0.15	0.43	0.25
28	Guntur BC 3	10.67	10	2.25	100.00	44444	1.50	22481	0.76	21.09	37.04%	4	2.893	118	52375	1.27	2.27	0.14	0.38	0.19
29	Guntur BC 4	4.36	10	2.25	80.00	53333	2.94	29460	1.62	9.87	10.68%	8	1.443	-2	-1006	2.41	5.72	0.27	0.75	0.42
30	Guntur BC 5	4.36	10	2.25	80.00	53333	2.94	29460	1.62	9.87	9.89%	8	1.385	-5	-3505	2.51	5.96	0.28	0.55	0.30
31	Guntur BC 6	4.36	10	2.25	80.00	53333	2.94	26977	1.48	10.77	9.90%	8	1.494	-5	-3478	2.51	5.95	0.28	0.78	0.40
32	Guntur BC 7	4.36	10	2.25	80.00	53333	2.94	26977	1.48	10.77	9.50%	8	1.356	-7	-4754	2.56	6.09	0.29	0.80	0.40
33	Lock in Sula	5.358	6	2.25	170.00	42500	5.08	23476	2.80	5.71	-0.14%	14	0.773	-105	-26157	7.80	4.57	0.68	1.41	0.78
34	Lower Manair	7.87	6	2.25	140.00	46667	2.85	21036	1.28	12.47	11.59%	8	1.841	5	1595	3.10	2.10	0.38	0.73	0.33
		TOTAL				49107 MEAN	2.58 MEAN	26482 MEAN	1.39 MEAN	12.88 MEAN	16.19% MEAN	7.2 MEAN	1.805 MEAN		11879 MEAN	3.41 MEAN	4.25 MEAN	0.36 MEAN	0.66 MEAN	0.36 MEAN

						ECONOMICS										ENERGY COST				
SL	PROJECT NAME	ENERGY (GWh)	DATA LENGTH (YEARS)	TARIFF (Rs/ kWh)	COST (Rs.M)	Cost/ kW (Rs.)	Cost/ kWh (Rs.)	Cost/ kW 1991 (Rs.)	Cost/ kWh 1991 (Rs.)	E/kW (kWh/ kW /Rs. 100)	FIRR (%)	PAY BACK PERIOD (YEARS)	BC	NPV Rs.M	NPV/ kW Rs.	1st YEAR Rs/kWh	IN LOAN PERIOD Rs/kWh	11th YEAR Rs/kWh	AVE Rs/kWh	AVE 1991 Rs/kWh
		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)
	KERALA																			
35	Kuttiyadi PH 1	17.1	0	2.80	149.10	39760	1.40	10372	0.36	43.96	33.51%	3	4.173	217	57809	2.07	1.42	0.35	0.51	0.13
36	Maniyar	31.5	6	2.25	210.00	17500	1.07	12957	0.79	20.26	35.90%	3	2.987	250	20869	1.16	0.81	0.13	0.27	0.20
						35642	2.02	11665	0.58	32.11	26.09%				39339	1.62	1.12	0.24	0.39	0.17
		TOTAL				MEAN	MEAN	MEAN		MEAN	MEAN	MEAN	MEAN		MEAN	MEAN	MEAN	MEAN	MEAN	MEAN

NOTES:

Column 1 gives the average annual energy output in GWh for the project computed from the data obtained from the IPP/SEB

Column 2 gives the period in years for which energy production data was available.
Column 3 gives the base year tariff which was used to carry out the economic and financial analysis.
Column 4 gives the cost of the project with IDC.
Column 5 gives the cost per kilowatt of the project calculated in nominal terms
Column 6 gives the energy production cost during the first year of project operation computed using annual cost of 16% of capital cost (interest 12.5%, Depreciation 2.5% and O&M 1%).
Column 7 gives the cost per kilowatt of the project in 1991 constant prices obtained by using the price index given in the annex.
Column 8 gives the cost of energy produced during the first year in 1991 constant prices.
Column 9 gives the energy productivity which is energy produced per kilowatt per Rs.100 invested for the plant in 1991 prices.
Column 10 gives the FIRR of the project.
Column 11 gives the pay back period for the debt.
Column 12 gives the economic B/C for the project computed using the economic value of energy computed as given in the chapter 11.
Column 13 gives the Net Present Value of the project
Column 14 gives the Net Presetn Value of the project per kW.
Columlns 15 to 19 give the energy production costs during the first year, average production cost during the seven years after project commissioning, in the tenth year, average over the 30 year BOOT period and average reduced to 1991 constant price.

Table 12-4 Ranking Analysis of the Projects

SL	PROJECT NAME		PAYBACK PERIOD (YEARS)	RANKING								
				BC	NPV/kW	IRR	COST/kWh	PLF	COST/kW	TIME	DATA LENGTH	MEAN (%)
	KARNATAKA											
1	Attehala		79.4	0.00	0.00	0.00	0.00	0.00	0.27	0.82	0.82	23.95%
2	Brindavan Scheme 1		4.3	0.74	0.87	0.86	0.99	0.83	0.43	0.76	0.09	69.75%
3	Brindavan Scheme 2		5.2	0.78	0.89	0.73	0.98	0.95	0.00	0.76	0.09	64.80%
4	Harangi Scheme 1		6.7	0.32	0.49	0.36	0.96	0.50	0.45	0.76	1.00	60.67%
5	Harangi Scheme 2		9.0	0.48	0.52	0.42	0.92	0.16	1.00	0.88	0.00	54.86%
6	Kabini Canal		7.8	0.37	0.53	0.41	0.95	0.37	0.59	0.94	0.27	55.27%
7	Kabini Dam		7.7	0.37	0.52	0.39	0.95	0.46	0.37	0.65	0.45	51.93%
8	Maddur Scheme 1		4.4	0.77	0.91	0.83	0.99	0.93	0.25	1.00	0.18	73.31%
9	Maddur Scheme 2		3.9	1.00	1.00	1.00	1.00	1.00	0.32	0.00	0.00	66.54%
10	Nugu Scheme 1		10.2	0.25	0.40	0.28	0.89	0.44	0.04	0.47	0.36	39.21%
11	Nugu Scheme 2		5.1	0.46	0.76	0.70	0.97	0.58	0.60	0.59	0.55	65.08%
12	Shahapur 1		5.5	0.44	0.70	0.67	1.00	0.62	0.68	0.88	0.55	69.16%
13	Shahapur 2		7.4	0.32	0.56	0.46	0.98	0.44	0.68	0.88	0.55	60.96%
14	Shahapur 3		7.8	0.30	0.54	0.42	0.97	0.42	0.68	0.88	0.55	59.55%
15	Shahapur 4		7.3	0.35	0.59	0.50	0.98	0.46	0.68	0.88	0.55	62.36%
16	Shahapur 5		6.0	0.41	0.66	0.63	1.00	0.52	0.75	0.88	0.55	67.47%
	TAMILNADU											
17	Amaravathy		9.7	0.24	0.28	0.20	0.24	0.24	0.23	0.00	0.06	18.72%
18	Lower Bhawani Dam PH		7.3	0.45	1.00	0.64	1.00	1.00	1.00	1.00	1.00	88.64%
19	Lower Bhawani Canal PH		7.8	1.00	0.96	1.00	0.99	0.32	0.37	0.89	0.59	76.50%
20	Perunchani		7.6	0.38	0.60	0.35	0.45	0.57	0.00	0.00	0.00	29.41%

SL	PROJECT NAME		PAYBACK PERIOD (YEARS)	RANKING BC	NPV/kW	IRR	COST/kWh	PLF	COST/kW	TIME	DATA LENGTH	MEAN (%)
21	Sathanur		12.9	0.00	0.00	0.00	0.00	0.00	0.45	0.78	0.53	21.93%
22	Thirumurthy		9.8	0.08	0.09	0.10	0.24	0.17	0.37	0.67	0.35	25.89%
	ANDHRA PRADESH											
23	Adanki BC PH 1		5.6	0.53	0.60	0.50	0.86	0.69	0.72	0.67	1.00	69.52%
24	Adanki BC PH 2		7.3	0.32	0.39	0.33	0.71	0.74	0.00	0.67	1.00	51.87%
25	Adanki BC PH 3		4.6	0.75	0.79	0.75	0.96	0.75	1.00	0.67	1.00	83.35%
26	Guntur BC 1		5.2	0.77	0.74	0.59	0.90	0.87	0.55	0.00	0.29	58.75%
27	Guntur BC 2		4.5	0.73	0.78	0.70	0.95	0.82	0.96	1.00	1.00	86.62%
28	Guntur BC 3		4.2	1.00	1.00	1.00	1.00	1.00	0.82	0.00	0.57	79.94%
29	Guntur BC 4		8.2	0.32	0.32	0.29	0.63	0.46	0.43	0.33	0.57	41.95%
30	Guntur BC 5		8.2	0.29	0.29	0.27	0.83	0.46	0.43	0.33	0.57	43.39%
31	Guntur BC 6		8.2	0.34	0.29	0.27	0.60	0.46	0.43	0.00	0.57	37.05%
32	Guntur BC 7		8.2	0.28	0.27	0.26	0.59	0.46	0.43	0.00	0.57	35.70%
33	Lock in Sula		14.1	0.00	0.00	0.00	0.00	0.00	0.91	0.33	0.00	15.55%
34	Lower Manair		7.9	0.50	0.35	0.32	0.65	0.38	0.73	1.00	0.00	49.12%
	KERALA											
35	Kuttiyadi PH 1		3.1	2.570	313	2.570						
36	Maniyar		3.0	3.361	663	3.361						

Table 12-5 Technical Parameters of the Electro-Mechanical Equipment

SL	PROJECT NAME	TURBINE						GENERATOR			TRANSMISSION	
		TYPE	HEAD (m)	UNIT FLOW (cum/s)	MAKE	RUNNER DIA (mm)	SPEED (rpm)	GEN (V)	TYPE	SPEED (rpm)	VOLTAGE (kV)	LINE LENGTH (km)
	KARNATAKA											
1	Attehala	DSE	4.5	9	BOVING	1500		440	I		11	
2	Brindavan Scheme 1	DSE	12	52.5	ANDRITZ		185	11000	S	750	66	
3	Brindavan Scheme 2	DSE	18	14	KIRLOSKAR			11000	S		66	
4	Deverebelekere											
5	Harangi Scheme 1	DSE	20	26.2	SULZER	2200	300	11000	S	750	66	14.5
6	Harangi Scheme 2	DSE	14.3	54.32			300	11000	S	750	66	14.5
7	Kabini Canal	PIT	6.5		HPP		130.16		S	750	66	
8	Kabini Dam	VSK	18	77	BHEL		200		S	200		
9	Maddur Scheme 1	OFK	4.63	20		1350			S		11	
10	Maddur Scheme 2	DSE	13	10	BOVING		398	3300	S	750	11	
11	Malaprabha											
12	Nugu Scheme 1	DSE	12	7.7	KIRLOSKAR	1255	428.5	3300	S	750	66	7.4
13	Nugu Scheme 2	FRA	28	3.28	KIRLOSKAR	780	600	3300	S	600	66	7.4
14	Shahapur 1	DSE	6	25	VATECH		168	3300	S	750	11	
15	Shahapur 2	DSE	6	25	VATECH		168	3300	S	750	11	
16	Shahapur 3	DSE	5.5	25	VATECH		168	3300	S	750	33	
17	Shahapur 4	DSE	6.25	25	VATECH		168	3300	S	750	11	
18	Shahapur 5	DSE	10	25	VATECH		172.2	3300	S	750	11	
	TAMILNADU											
19	Amaravathy	VSK	21	12	NANNING	1500	375	3300	S	375	22	
20	Lower Bhawani Dam PH		26.8	10								
21	Lower Bhawani Canal PH	DSE	18.67	27.41			230	11000	S	750	110	
22	Pechiparai											
23	Perunchani	DSE	15	7.5								

24	Sathanur	VSK	30	32.5		2200	333.5	11000	S	333.5	33	
25	Thirumurthy	DSE	10	8.8	KOSSLER	1250	428.5	3300	S	428.5	22	
	ANDHRA PRADESH											
26	Adanki BC PH 1	OFV	6	26.2	HPP		160	660	S	1000	11	
27	Adanki BC PH 2	OFV	4.57	26.2	HPP		160	660	S	1000	11	
28	Adanki BC PH 3	OFV	7	26.2	HPP		160	660	S	1000	11	
29	Guntur BC 1	DSE	6.89	25.51					S			
30	Guntur BC 2	DSE	10	30	BOVING		250	6600	S	750	33	
31	Guntur BC 3	RAD	4.5	20.75	SULZER				I			
32	Guntur BC 4	RAD	4.5	39.6	SULZER				I			
33	Guntur BC 5	RAD	4.5	39.6	SULZER				I			
34	Guntur BC 6	RAD	4.5	39.6	SULZER			415	I		33	
35	Lock in Sula	DSE	12	19.82								
36	Lower Manair	DSE	6.5	28.5				3300	I		33	
	KERALA											
37	Kuttiyadi PH 1	FRA			BOVING							
38	Maniyar	DSE	14.5	33	VATECH		214.3	11000	S		110	
39	Peechi 1 (CBU)											

Part 12 .2 Loan Terms from IREDA[25]

Loans for debt portion of capital cost were initially available to IPPs from IREDA which disbursed credit received from World Bank, Asian Development Bank, KFW, DANIDA, GEF etc. In recent years, a number of banks such as SBICap in the country have also been providing loans for mini and small hydro projects, The loan terms are set by the market conditions and a number of IPPs especially industries with existing good credit records have preferred to obtain finance from the banking sector. Loans from IREDA are intended to promote development of hydropower projects by the GOI.

IREDA provides loans to:

- Public, Private limited companies, NBFCs and registered Societies.
- Individuals, Proprietary and Partnership firms (with applicable conditions)
- SEBs which are restructured or in the process of restructuring and eligible to borrow loan from REC/PFC.

The general eligibility criteria for availing loans from IREDA are

- Entity should be profit making with no accumulated losses.
- Debt Equity Ratio not more than 3:1 (5:1 in case of NBFCs)
- No default to IREDA and other financial institutions / Banks
- No erosion of paid-up capital.

Applicants who are loss making or do not meet the criteria relating to accumulated losses / debt equity ratio shall be eligible for financing if Bank Guarantee / fixed deposit receipts is provided as security for the entire loan.

The projects which are eligible for financing by IREDA should demonstrate techno commercial viability and should be

- Hydro electric projects at the existing irrigation projects of either canal based schemes or dam toe schemes
- Run-of-River schemes with maximum installed capacity of 25 MW.
- Projects above 25 MW capacity may be considered under co-financing / consortium financing arrangements.
- Refinancing of projects which are not commissioned earlier than 1 year from the date of application to IREDA.

The basic interest rate for the loan is 10.75% per annum with a maximum loan repayment period of ten years. Loans are provided to cover 70% of the total project cost with a minimum promoters contribution of 30%. The loan interest rate is revised every three years from the date of first disbursement. If the borrower opts for a fixed interest rate, then basic interest rate is 11.75% per annum. A rebate of 0.75% in the interest rate is given if the borrower furnishes security in the form of bank guarantee or fixed deposit receipt from a scheduled bank. A maximum one year grace period is allowed, subject to commissioning of project within a period of 3 years from first disbursement.

Loan applications submitted to IREDA will remain valid for a period of 6 months. Normally, IREDA sanctions a project within 90 days of registration, if complete details/ documents are submitted by the applicant and the project is found eligible from technical, financial and legal aspects. The project cost for consideration of loan should include the cost of land and site development,

[25] The terms and conditions are drawn from the booklet Small Hydropower Development Program, Guidelines for Loan Assistance by IREDA.

buildings and civil works, plant and machinery, miscellaneous fixed assets, technical assistance/consultancy, preliminary and pre-operative expenses including frontend-fee, stamp duty, margin money for bank guarantee, if provided as security. The loan sanction letters will have a validity of six months from the date of issue.

Furnishing of appropriate securities or guarantees may be stipulated depending on the type of project and legal status of the borrower.

The acceptable securities comprise:

- Mortgage of immovable properties as stipulated
- Hypothecation of movable assets
- Guarantees by promoters and/or promoter directors and and/or promoter companies
- Deposit of post dated cheques for principal loan amount and interest
- Trust & Retention Account / Special Account

The acceptable guarantees comprise:

State Government Guarantee.

- Unconditional and Irrevocable guarantee of All India Public Financial Institutions having “AAA” or equivalent rating
- Bank Guarantee from Scheduled Bank / Pledge of FDR issued by Scheduled Bank as described in RBI Act

Upon completion of documentation and execution of securities, IREDA normally disburses loan as per the disbursement guidelines in proportion to promoter’s contribution depending upon the progress of the project and satisfactory utilization of installment/s already advanced.

The borrower is required to follow a transparent and competitive bidding procedure for procurement and shall demonstrate that the procurement procedures adopted are appropriate and goods, services and works are of good quality purchased at reasonable and competitive prices. The borrower shall provide all such information and documents reasonably required in connection with the procurement of any goods, services and works to be financed by IREDA. Wherever the loan is sanctioned against international lines of credit such as the World Bank, Asian Development Bank, KfW, etc., the relevant procurement procedures stipulated for competitive bidding process will have to be followed by the borrower.

Part 12 .3 Consumer Price Index

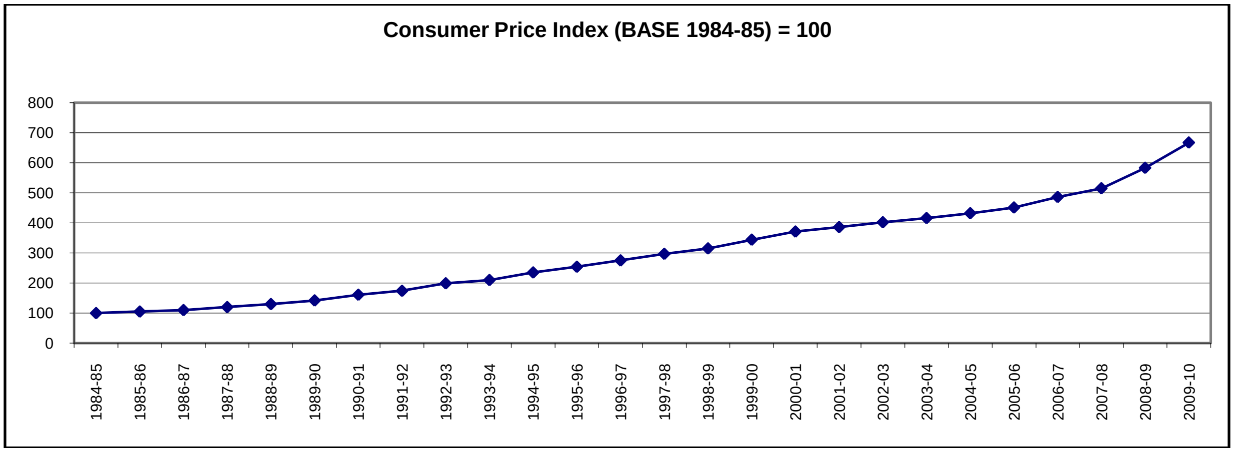


Figure 12-1 Historic Consumer Price Index 1984 to 2009

In section 4, to compare costs of projects which have been implemented during various periods, the costs have been converted to constant 1991 levels by using the Consumer Price Index for the country. The values show increase compared to the year 1984-85 with base value 100.

Part 12 .4 References

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