WP-2010-019

Econometric Approach to Water Use Estimation in Power Plants

PERINI PRAVEENA SRI

Indira Gandhi Institute of Development Research, Mumbai
September 2010
http://www.igidr.ac.in/pdf/publication/WP-2010-019.pdf

Econometric Approach to Water Use Estimation in Power Plants

PERINI PRAVEENA SRI

Indira Gandhi Institute of Development Research (IGIDR)
General Arun Kumar Vaidya Marg
Goregaon (E), Mumbai- 400065, INDIA
Email (corresponding author): praveena@igidr.ac.in

Abstract

The purpose of this paper is to examine water use estimation in hydel and thermal electric power plants in selected regions i.e. Coastal, Rayalaseema and Telangana regions of Andhra Pradesh. The study primarily focuses on the realistic fundamental premise that thermal electric and hydro electric energy generation is responsible for the largest monthly volume of water withdrawals in four seasons (i.e. summer, rainy, winter and post monsoon season) of a year. These enormous water withdrawals by these hydel and thermal power plants can have significant influence on local surface water resources. However there are very few studies of determinants of water use in hydel and thermal electric generation. Analysis of hydel and thermal electric water use data in the existing power plants clearly indicates that there is wide variability in unitary hydel and thermal electric water use within the system. The multivariate regression procedures were used to identify the significant determinants of thermal and hydel water withdrawals in various power plants i.e. five hydel and four thermal power plants. The estimated regression coefficients indicate that the best explanatory variables for the total quantity of hydel water withdrawals are storage capacity, tail water level and actual generation and thermal water withdrawals are condenser cooling and ash disposal. The unit variability of unit water usage indicates that there is significant potential for water conservation in existing power plants. Apart from this as water is no longer available as a free good; it calculates the real value of water in selected power plants using Water Valuation Techniques such as Residual Value and Opportunity costs.

Keywords:

Thermal water withdrawals, hydel water withdrawals, storage capacity, tail water level, actual generation, condenser cooling and ash disposal.

JEL Code:

C 50, C 51, C 53

Acknowledgements:

I express my sincere thanks to friend, Mrs. Jaya Shree (Research Associate, National Institute of Rural Development) for helping me with regression analysis.

Econometric Approach to Water Use Estimation in Power Plants

1.0 Introduction

Water has become a growing source of tension especially in power sector in many parts of the World. For India hydro and thermal power projects are vital to fill in the serious electric energy shortfalls that crimp its economy. About 40 percent of India's population is off the power grid and due to this the welfare of the economy was badly affected. The main stumbling block for this kind of worse situation are a genuine water shortage problem in India and the country's inability to properly manage large quantities of water during rainy season has made matters worse, exposing it to any small variation in rainfall or river flow.

Though the country has invested heavily on nuclear power to generate 30,000 MW and $ 19 billion to produce factories of major thermal, hydro and nuclear power stations, the electric energy shortages were very much prevalent in most parts of the country. For this the first and foremost thing is to judiciously manage the vital resource "water". The country also planned for setting up of 20,000 MW solar power by 2020. The Government of India has an ambitious mission of Power for All By 2012. This would require an installed generation capacity of atleast 20,000 MW by 2012 from the present level of 144,564.97 MU. However the power requirement will double by 2020 to 400,000 MW. How India is able to meet this target with the on-going water shortage plight in Electricity Generation Industry is a matter of great concern. However the Electricity Generation Industry strategy should primarily focus on this invisible culprit "Water" causing huge generation losses through better water efficiency techniques and lay emphasis on technology up gradation and massive utilization of renewable sources of energy.

The purpose of this paper was to examine water use estimation at hydel and thermal electric power plants in selected regions i.e. Coastal, Rayalaseema and Telangana regions of Andhra Pradesh. The study primarily focuses on the realistic fundamental premise that thermal electric and hydro electric energy generation is responsible for the largest monthly volume of water withdrawals in four seasons (i.e. summer, rainy, winter and post monsoon season) of a year. These enormous water withdrawals by these hydel and thermal power plants can have significant influence on local surface water resources. Water use at the power station level (by fuel type) can be estimated indirectly by using multiple regression analysis. In regression models, water use relationships are expressed in the form of mathematical equations, showing water use as a mathematical function of one or more independent (explanatory) variables. The mathematical form (eg. Linear, multiplicative and exponential) and the selection of the Right hand side (RHS) or independent variables depend on the category and on aggregation of water demand represented by Left Hand side (LHS) or dependent variable.

The first section deals with back ground on thermo electric water use in power generation, objectives and provides a model specification. The second section lays emphasis on important findings of water use studies for various uses of the economy. The third section describes the data sources and analytical methods used to estimate water use in hydel and thermal power plants. The fourth section describes the estimation and interpretation of model specifications. The fifth section analyzes the application of Water Valuation Techniques in selected hydel and thermal power plants. The conclusions of the study and its important insights results might influence further research in Electric Energy Water Policy.

I

The detailed survey of my paper titled "Electric Energy-Water Nexus: Managing the Seasonal Linkages of Fresh Water Use in Energy Sector for Sustainable Future" revealed interesting facts about voracious appetite of water withdrawals for hydel and thermal power plants supported with empirical evidences. Taking cue of this, this paper lays emphasis explicitly on how to determine the significant determinants of thermal and hydel power plants empirically.

Let us examine the over all picture of industry wise water withdrawals in India. The Centre for science and Environment (2001) estimated the annual consumption of water for eight core industries and found that nearly 87 percent

Table 1: Water Use in Water Intensive Industries in India

Type of Industry	Annual Waste Water Discharge (million cubic meters)	Annual Consumption (million cubic meters)	Proportion of water consumed in the Industry
Thermal power plants	27000.9	35157.4	87.87
Engineering	1551.3	2019.9	5.05
Pulp and paper	695.7	905.8	2.26
Textiles	637.3	829.8	2.07
Steel	396.8	516.6	1.29
Sugar	149.7	194.9	0.49
Fertiliser	56.4	73.5	0.18
Others	241.3	314.2	0.78
Total	30729.2	40012.0	100.0

Source: Estimated by Centre for Science and Environment based on the wastewater discharged data published by CPCB in "Water quality in India (Status and trends) 1990 - 2001".

of water has been consumed by thermal power plants. (Table 1) This proportion was very high in comparison with other water intensive industries such as Engineering, textiles, pulp & paper, iron &steel, sugar, Fertilizer where as chlor-alkali, cement, copper, zinc and plastics require little water. By looking in to the high intensity nature of thermal power plants it was rightly remarked by the World Bank, 2001 (Table 2) that Indian power plants consume on average 80 cubic meters of water and water consumption for modern thermal power plants is only 10 cubic meters. In terms of value also, India stands first for very poor representation, $ 7.5 /cubic meter (i.e. in terms of ratio of its water consumption and economic value creation in Indian Industry) in comparison with other countries like Argentina, Brazil, Korea, Norway, Sweden, Thailand and United Kingdom.

Table 2: Economic Value of Water

Country	Industrial water use (billion cubic metres)	Industrial productivity (million US $)	Industrial water productivity (US $ / cubic metre)
Argentina	2.6	77171.0	30.0
Brazil	9.9	231442.0	23.4
India	15.0	113041.0	7.5
Korea, Rep.	2.6	249268.0	95.6
Norway	1.4	47599.0	35.0
Sweden	0.8	74703.0	92.2
Thailand	1.3	64800.0	48.9
United Kingdom	0.7	330097.0	443.7

Source: World Bank, 2001

The thermal power plant guzzling of enormous amount of water (with its atrocious figure) makes us rethink once again about its sustainability due to rampant usage of water, which is an inexhaustible natural resource in power plants. This important resource “water” indeed decides the growth and development of Indian Electricity Generation Industry in the future. In view of all these factors, the sustenance of this precious resource “water” is a pressing need of the hour and it is quite feasible today for an Indian Electricity Generation Industry to sort out ways to substantially reduce its water consumption by putting efficient systems in to practice.

The objective is to determine if multiple regression models of unit hydel and thermo electric water use have the potential

- To identify significant determinants of total hydel and thermo electric water withdrawals across selected region wise power plants in AP using aggregated category wise water use estimates.
- To estimate the future water withdrawals for hydel and thermal electricity generation plants expressed as cubic meters per second. (Cumecs) and cubic meters using the growth rate phenomenon.

The type of data used for estimation are monthly water withdrawals data (For surface fresh water resources)

Region level models for hydro and thermo electric water withdrawals

- The potential dependent and independent variables for water withdrawals are identified for estimation purpose. Regional level data for thermal and hydel water withdrawals are more accurate data. The underlying reason being water withdrawals are usually metered.
- Dependent Variable: Total Hydel Water Withdrawals

Total Thermal Water Withdrawals

Independent Variables of Hydel Power Plant:

(a) Reservoir levels
(b) Inflows
(c) Storage capacity
(d) Evaporation losses
(e) Tail water level
(f) Gross Head

Independent Variables of Thermal Power Plant:

(a) Demineralized water
(b) Boiler Feed back
(c) Condenser Cooling
(d) Ash disposal
(e) Others include colony domestic, drinking, sanitation, fire fighting, back wash filter
(f) Installed generation capacity
(g) Actual electric energy production
(h) Total no. of cooling towers
(i) Water temperatures in summer, rainy and winter.

Multiple Regression analyses were performed using the data related to category wise water use in power plant, generating facility and weather conditions from month wise 1995-96 to 2008-09 data in respective thermal and hydel power plants. The effect of variables such as quantities of water used exclusively for the production of electricity i.e. Boiler feed, Demineralized water, Condenser cooling, Ash Disposal, colony domestic (Drinking, Sanitation, Fire Fighting, Back wash filter), installed capacity generation, number of cooling towers, cooling temperature and electric energy generation on total water withdrawals of thermal power plants are explicitly analyzed. In addition to this, the effect of variables such as reservoir elevation, storage capacity, tail water level, evaporation losses, inflows, gross head, actual generation on total hydel withdrawals have also been looked in to. This paper explores the structure of power plant level aggregated water use data based on corresponding and routinely collected economic and climatic data. The purpose of this enquiry is to determine if multiple regression models have the potential to explain the temporal and climatic variability across various thermal and hydel power plants in Andhra Pradesh using aggregated water use estimates and most importantly to identify significant determinants of total water withdrawals of thermal and hydel power plants. The statistical models examined here are derived using data estimates of total water withdrawals for hydel and thermo electric power use.

Specification of Mathematical Model

$$WHE_{im} = a + \sum_j bj\, X_j$$

Where WHE_{im} = Fresh water withdrawals for Hydel Electric Energy within region wise i during particular months m in a year.

X_j is a set of explanatory variables. (Mentioned above)

$$WTE_{im} = a + \sum_j bj\, X_j$$

WTE_{im} = Fresh water withdrawals for Thermal Electric Energy within region wise i during particular months m in a year.

X_j is a set of explanatory variables. (Mentioned above)

Coefficients a and bj can be estimated using multiple regression model.

Specification of the Econometric Model:

In Linear forms, these equations can be estimated as follows

$$Y_t = B_1+B_2X_2+B_3X_3+B_4X_4+B_5X_5+B_6X_6+B_7X_7+ \mu$$

Model: 1 $WTE_{im} = B_1+B_2\, CT+B_3DB+B_4CD+B_5AS+B_6WT+B_7AG+\mu$ ……… (1)

Where, WTE_{im} = Water withdrawals for thermal electric energy in region i for particular months m.
CT = Condenser cooling (with Cooling Towers)
DB = Dimineralized water and Boiler Feed
CD = Colony Domestic
AS = Ash Slurries
WT= Water Temperature
AG= Actual generation
μ= random error term

Condenser Cooling: Water required for cooling hot turbines and condensers

Demineralized Water: Water that is, free of minerals and salts. Water runs through active resin beds to remove metallic ions and filtered through sub micron filter to remove suspended impurities.

Colony Domestic: Water that is used for the purpose of colony maintenance, drinking purpose and plantation.

Ash Slurries: As coal burns, it produces carbon –di-oxide, sulphur –di-oxide and nitrogen oxides. These gases together with lighter ash are called fly ash. The electro static precipitators remove all the fly ash and are mixed with water to make in to ash slurries.

Water temperature: Recording the temperature of water during summer, rainy and winter seasons.

Actual Generation: The generation of electricity that is actually generated apart from installed generation.

Model 2: $WHE_{im} = B_1+B_2\,RE+B_3SC+B_4\,TW+B_5GH+B_6WT+B_7AG+\mu$ ……. (2)

Where WHE_{im}= Water withdrawals for hydel electric energy in region i for particular months m.

RE = Reservoir Elevation
SC= Storage Capacity
TW= Tail water level
El= Evaporation losses
GH= Gross Head
WT= Water Temperature
AG= Actual Generation
μ= random error term

Reservoir Elevation: This is defined as the foot of the dam. i.e. the level from which the reservoir storage level and the height of the dam are measured.

Storage Capacity: This corresponds to the flood level usually designated as the upper limit of the normal operational range, above which the spill gates come in to operation

Tail water Level: Water immediately below the power plant. Tail water elevation refers to the level that water which can rise as discharges increase. It is measured in the feet above sea level.

1 foot = 0.305 meters.

Inflows: The inflow may be monsoonal rains or lakes, rivers. The average volume of incoming water, in unit period of time.

Evaporation Losses: Conversion of liquid to vapor state by latent heat. Water gets saturated in the form of vapor due to rise in water temperature.

Discharge: Volume of water released from power dam at a given time measured as cubic feet per second.

Gross Head: A dam's maximum allowed vertical distance between upper stream's surface water fore bay elevation and the down stream's surface water (tail water) elevation at the tail race for reaction wheel dams.

Actual Generation: The amount of electricity actually generated apart from installed generation.

Selected power plants in three regions of Andhra Pradesh

Power Plant by Fuel Type	**Rayalaseema Region**	**Telangana Region**	**Coastal Region**
Thermal	Rayalaseema Thermal Power Plant	.Kothagudaem Thermal Power Station O & M .Kothagudaem Thermal Power Station Stage V	Narla Tata Rao Thermal Power Plant
Hydel	Nagarjuna Sagar Main Power House Nagarjuna Sagar	Srisailam Left canal power house Srisailam right	

	Left Canal Power House Nagarjuna Sagar Right Canal Power House	Canal Power House

The collection of data includes a monthly time series data analysis during the period (1995-96 to 2008-09).

Analysis of hydel and thermal electric water use data in the existing power plants clearly indicates that there is wide variability in unitary thermal and hydel electric water use within the system. The multi- variate regression procedures were used to identify the significant determinants of thermal and hydel water withdrawals in various power plants i.e. five hydel and four thermal power plants. The unit variability of unit water usage indicates that there is significant potential for water conservation in existing hydel and thermal electric power plants.

II

2.0 Different Approaches of Water Use Estimation: Literature Review

Before highlighting the intricate details of the actual subject matter i.e. water use estimation in power plants, it is imperative to distinguish between two terms i.e. water use and water withdrawals. In broader sense, water use denotes the interaction of humans with hydrologic cycle. These include off-stream and in stream uses such as water withdrawals, delivery, consumptive use, waste water release, hydro electric power use and other uses.

The various studies relating to water demand for thermal power plants and its significant determinants are reviewed for explicit understanding of thermal electric energy water use. Cootner, Paul and George O Golf (1965) have build upon a systematic model for estimating water demand in conventional steam electric utility industry. They have regarded water as a common factor input along with fuel. Here

$TWD = f(Q_f, Cw, E_{He}, C_{WH})$

Where in TWD = Thermal water withdrawal demand

Q_f = Quantity and cost of fuel

C_w = Cost of water

E_{He} = Economics of heat exchange and recycling

C_{WH}= other costs of thermal power plant associated with the disposal of waste heat.

In other words the quantity of the fresh water withdrawals depends upon the above mentioned factors. In another study Wollman and Bonem (1971) found that the quantity of fresh water withdrawals for steam electric power generation depends upon (1) Thermal efficiency (with higher thermal efficiency less heat will be dissipated. Due to this smaller amount of cooling water are needed) (2) The extent to which sea or brackish water can substitute for fresh water (3) The rate of recirculation. Recirculation is a function of price of water availability. Young and Thompson (1973) in their study identified three factors that affect water use in thermal electric energy generation. They can be listed as water pricing, change in generation, technology, price of electricity, price of substitutes used in electricity i.e. oil and gas, population and level of general economic activity. The other factors include waste and heat discharge to water and the changes in cooling technologies.

Gleick (1993) in his study reviewed the water requirement of electric energy. Taking as base of earlier studies, he estimated the consumptive water use in Electricity Generation Industry using different technologies. The system efficiency for conventional coal combustion (Once through Cooling Towers), natural gas combustion (Once Through Cooling Towers) and nuclear generation (CTs) stood at 35 percent, 36 percent and 40 percent. The estimates specifies that with the help of Once Through Cooling Technologies, the average consumptive use ranges from 1.2 m^3/MWH in case of conventional coal, for oil and natural gas consumption the average consumption use is less by 1.1 m^3/MWH , where as with cooling towers it was 2.6 m^3/MWH. For nuclear power generation the average consumptive use of water with the aid of CTs was more that stood at 3.2 m3/MWH. There is a need for use of high efficient technology in cooling towers for water conservation. Electric Power Research Institute 2002, estimated the evaporation water loss from recirculating towers i.e., roughly 480 gal/MWH for a coal fired power plant. Mortenson, 2006 in his study have provided a technological break through i.e. small scale tests of one technology (that uses cross-currents of ambient air for condensation) as a counteracting measure for these evaporation losses. By this technology the evaporation losses can be reduced to about 60-140 gallons/MWH (that can be applied even to hotter climates). In value terms, EPRI 2004 notified that the savings from reduction of evaporation losses will be $870,000.

There are very few studies of determinants of water use in hydel and thermal electric generation. The literature available relating to water use estimations are very few. Water use experts have to opt for estimation methods for many of the water withdrawals classes i.e. domestic, agriculture and industry because of the true fact that many legal, financial and political constraints limit for getting the hard data. For instance water withdrawals in domestic and live stock water use are usually estimated by multiplying population figures by coefficient. Incase of agricultural sector, the irrigation water withdrawals are often estimated by multiplying the acreage by assumed water requirements of the crop rather than by measuring actual water pumped and applied.

Using the estimates from United States of Geological Survey 1995 Water Use Inventory and power Generation estimates from EIA (Energy Information Administration), have calculated the amount of evaporative water losses from both hydro electric and thermal electric power production. For this purpose, Torcellini et.al (2003) has developed a metric for relating water to electric energy water use. They have estimated the quantity of electricity used to crush and transport coal, excitation for generator and power machinery within the plant and distribution losses. Around 5 percent of thermo electric generation is needed out of the gross generation and in this again out of the gross generation, 9 percent was contributed by transmission and distribution losses. This type of metric was used to adjust the quantity of power production to compensate for the power loss (i.e. in brief power used for auxillary consumption). Later, their metric was used to calculate the total adjusted consumptive water use divided by the total power output. Such kind of estimates reveals that for a typical thermo electric power plant nearly 0.47 gallons of fresh water was evaporated per KWH of electricity produced. This kind of analysis that was carried out in Tennessee and Delaware found that evaporation losses were 0 gallons /KWH to 1.61 gallons/KWH in Delaware.

Snavely (1986), explicitly details the water use data collection programs and maintaining regional data base of the Great Lakes St. Lawrence River Basin States. The results are very much appealing indicating as how broad the range of estimation coefficient for water use can be within a geographic area with similar water availability. Mostly the estimated coefficients used for agriculture and domestic use vary by a factor of 10. The econometric studies relating to water use estimation in public supply use and thermo electric power use have the potential to explain temporal and geographic variability across USA. The aggregated water use estimates were provided by the National water Use Information Programme. These estimates primarily focus on measuring total water withdrawals (that includes annual extraction of fresh surface water and ground water) for the period 1980-1985 to 1990-1995 in each of 48 states of USA for public supply water withdrawals , domestic, commercial, irrigation and live stock. The saline water withdrawals were estimated for industrial, mining and thermal electric categories. The public supply water withdrawals are estimated within geographical area i during year t using a set of explanatory variables that includes air temperature, precipitation, price of water, median household income and others.

Cohn et.al (1989) and Christensen et.al (2000) have used examples of such kind by using statistical techniques. The shorter time period used has the advantage of highlighting the recent trend of declining water use since the 1980 compilation. The mean withdrawal for the period (1980-1995) clearly indicates that it was

183.7 gallons per capita per day. This average water withdrawals would decrease by 7.8 gpcd, if the state GDP per capita increased by $1000. The inclusion of this state GDP captures the effects of relative volume of non residential uses (along with their ability to pay for water). The model also indicates that US was able to withdraw 17.2 gpcd, because of its surface water rights in comparison with riparian law states. The inclusion of temperature and precipitation variables also clearly shows the effect of weather on water with drawals and can be used in normalizing water use for weather. The model indicates that average per capita demand for water in the state decreases by 2.1gallons per day per one inch increase in precipitation and vice versa i.e. water demand increases during summer months. i.e. average temperature.

Billings and Jones, 1996 employed indirect estimation of water use in urban and municipal planning using coefficient based methods. It calculates water use for commercial, residential and industrial categories. They assume constant water use rates and ignores trends i.e. changes in water use due conservation, technological change or economic forces. Mullusky et.al (1995), Wood Well and Desjardin (1995) for Washington D.C. metropolitan area have employed this water use coefficients for three categories of water users i.e. simple family homes, multiple family homes and employment water use. Another approach of estimating National Water Use in USA includes Stratified random sampling followed by Census of Agriculture. They employed various methods of collecting data such as telephone, mail survey instruments to develop detailed country level estimates of national agricultural activities. According to Hutson et.al 2004 the thermo electric power water use refers to water that is removed from the ground or diverted from surface water sources (that includes fresh water and saline water) for use in the process of generating electricity with steam driven turbine generators. In this paper the term water withdrawals is used more often precisely. The term designates the amount of water that is extracted from natural water sources. Again it is essential to demarcate between water with drawals and discharge as consumptive use. Water consumption is the quantity of water with drawn that is evaporated, transpired, incorporated in to crops, consumed by human or live stock.

At the end it can be said that different authors have notified different methods for estimation of water use for various uses of the economy. This paper employs multi variate models of water use for estimation of significant determinants of thermal and hydel water with drawals.

III

3.0 Approach and Methodology

The study includes three main components. (a) A series of site visits and interviews with power plant personnel. (b) Field surveys of selected hydel and thermal power plants of Andhra Pradesh (c) The multiple regression analysis of power generation data and other associated information.

Summary of site visits: Site visits for selected five hydel namely Nagarjuna Sagar Main Power House, Nagarjuna Sagar Left Canal Power House, Nagarjuna Sagar Right Canal Power House**,** Srisailam Left canal power house and Srisailam right Canal Power House and four thermal namely Rayalaseema Thermal Power Plant, Kothagudaem Thermal Power Station O & M, Kothagudaem Thermal Power Station Stage V and Narla Tata Rao Thermal Power Plant have been made to assess the over all performance scenario of power plants and also to examine the extent of water irregularities .

Appraisal of Power Plant Survey: The research estimates of hydel and thermal Electric Energy water withdrawals are based upon the authenticated sources of data provided by respective hydel and thermal power plants of Andhra Pradesh Generation Corporation of India Limited. In order to transparently clarify the way that power generation officials responded to this kind of field survey in practice and to solicit information from them on factors responsible for water use at power generation facilities, site visits have been taken up. At various Power plants several personal interviews with power plant officers helped to identify the types of onsite water uses, the measurement of these uses and provision of information on various types of cooling systems and water use procedures employed by hydel and thermal electric energy generation facilities.

The purpose of conducting a series of personal interviews with power plant officials can be listed as follows:

(a) Scrutinize and examine the power generation water use and water withdrawals from intake (surface water) to discharge in various types of facilities.
(b) Observing the fact that all the water with drawals (hydel and thermal) are metered.
(c) Detailed analysis about important onsite uses of water and its significant determinants
(d) To obtain feed back on the cooling system level of water use in power stations.

Multiple Regression Models of Water Use

The principal sources of data used in the multi variate analyses of thermal and hydel power plants are most accurate and provides a fairly comprehensive review of plant characteristics, power generation and water withdrawal details. The data in electronic format and in official records was available for the years 1996-97 to 2008-09. The weather data i.e. especially related to water temperatures during summer, rainy and winter was collected in order to examine the influence of it on total thermal and hydel water withdrawals.

At the end it can be concluded that the site visits and field surveys helped to identify important concerns about water measurement and use at thermal and hydel electric power plants. Added to this, these factors have received attention in the development of models to describe hydro and thermal electric water use. All the above mentioned information proved very much useful in the design of data analysis that was used to develop water use bench marks.

IV

4.0 Estimation and Interpretation of Model Specifications

Hydel based Electric Energy Power Plants

I <u>Nagarjuna Sagar Main Power House</u>
(Appendix table: A4.1)
In model 1 the estimated regression equation for total hydel water withdrawals is in the linear form as follows:

$$WHE = -146.238 - 0.080RE - \underset{(-3.96)}{0.258SC^{*}} + \underset{(3.144)}{0.350TW^{**}} + 0.133GH + \underset{(119.87)}{50.67AG^{*}}$$

N= 154, R^2 =0.99, f= 5543.05

- The estimated equation indicates that the total hydel water withdrawals are inelastic with respect to storage capacity. This kind of negative relationship indicates that the hydel water withdrawals are some what in responsive to changes in the storage capacity. The coefficients are statistically significant at 1 % level.
- The total hydel water withdrawals are elastic with tail water level and actual generation that hold a positive relationship. The coefficients are statistically significant at 5 % and 1 % level.
- The t-ratio of regression coefficients is highly significant for three independent variables namely SC, TW and AG. As the t ratio value is greater than 2.58 indicates that the relation between dependent variable and independent variables observed in the sample holds good.
- The t- ratio of regression coefficient is not at all significant for other independent variables such as reservoir elevation and gross feet, as the t-value is very small.
- The R^2 (coefficient of determination) is 0.99. It means that the independent variables tail water level, actual generation and storage capacity can explain 99 percent of variation in the dependent variable (WD) and remaining 1 percent variation is unexplained by the model. As R^2 is very high, the estimated equation is considered as an equation of very good fit.

- ➢ The over all model is statistically significant as f value is higher and more significant at 1% level. This clearly indicates that the regressors are significantly associated with dependent variable.

II <u>Nagarjuna Sagar Left Canal Power House</u>
(Appendix Table: A4.2)

```
         *                     *         *             *
WHE = 1660.770-3.516RE-21.705SC+9.653TW+491.286AG+0.130EL
       (3.314)               (4.16)    (3.84)      (15.67)
```

N= 166, R^2= 0.78, f = 116.22

- ➢ The estimated regression coefficients indicate that the best independent that have significant effect are storage capacity and actual generation with significant levels at 1 % for each of independent variables.
- ➢ The t-ratio of regression coefficients is highly significant with two independent variables namely storage capacity and actual generation. As t ratio value is greater than 2.58, it indicates that the relation between Hydel Water withdrawal and independent (SC) and (AG) observed in the sample holds good.
- ➢ The R^2 is 0.78. It means that the independent variables SC and AG can explain 78 percent variation in the dependent variable and the remaining 22 % variation is unexplained by the model. The estimated equation is considered as an equation of very good fit.
- ➢ The over all model is statistically significant as f value is higher (116.22) and more significant at 1 % level. This indicates that the regressors SC and AG are significantly associated with dependent variable.

III <u>Nagarjuna Sagar Right Canal Power House</u>
(Appendix Table: A4.3)

```
       *                   *                                   *
WHE = 6133.252+0.628 RL-58.029 SC+0.414EL+37.493TW+486.057 AG
      (7.314)            (6.063)                        (16.232)
```

N= 166, R^2= 0.78, f value = 116.22

- ➢ The estimated regression coefficients indicate that the best independent variables that have significant effect are storage capacity and actual generation with significant levels at 1 % for each of independent variables.
- ➢ The t-ratio of regression coefficients is highly significant with two independent variables namely storage capacity and actual generation. The relation between water withdrawals and Storage

capacity and actual generation in the sample holds good as the t-value is greater than 2.58.

- The t-ratio of regression coefficients is not at all significant for other independent variables such as reservoir level, storage capacity and evaporation losses.
- The R^2 is 0.78. It means that the independent variables SC and AG can explain 78 % variation in the dependent variable and remaining 22 % variation is unexplained by the model. The estimated equation is considered as the equation of very good fit.
- The over all model is statistically significant as f value is higher (116.22) and more significant at 1 % level. This indicates that the regressors are significantly associated with dependent variable (WD)

IV <u>Srisailam Left Bank Power House</u>

(Appendix Table: A4.4)

$$WHE = -2243.501 \underset{(-2.27)}{-0.766RE} + 1.195SC + \underset{(18.81)}{57.47AG^{*}} + 0.592EL + \underset{(2.69)}{4.24TW^{*}} + 0.000IF$$

N= 58 , R^2= 0.96, f value = 221.872

- The estimated regression coefficients indicate that the best independent variables that have significant effect are actual generation and tail water level with significant levels at 1 % and 10 % for independent variables.
- The t-ratio of regression coefficients is highly significant with three independent variables namely reservoir elevation, actual generation and tail water level. The t-ratio value is greater than 1.96 value for reservoir level and greater than 2.58 value for actual generation and tail water level. This indicates that the relation between WD and independent variables AG and reservoir elevation observed in the sample holds good.
- The t- ratio of regression coefficients is not at all significant for other independent variables such as evaporation losses and inflows.
- The R^2 is 0.96. It means that the independent variables reservoir level, actual generation and tail water level can explain 96 % of variation in the dependent variable and remaining 4% is unexplained by the model. Thus the estimated regression coefficient is considered as an equation of very good fit.
- The over all model is statistically significant as f value is higher (221.872) and more significant at 1 % level. This indicates that the regressors AG and TW are significantly associated with dependent variable. (WD)

V Srisailam Right Bank Power House
(Appendix Table: A4.5)

$$Y = -7630.380 - \overset{*}{1.78}RE + \overset{*}{0}SC + \overset{*}{56}AG + 0.051EL + 0.627TW + 0.289GH$$

(-4.199) (-4.3) (122.65)

N= 138 , R^2 = 0.99 and f value = 4.59

- The estimated regression coefficients indicate that the best independent variables that have a significant effect are storage capacity and actual generation with significant levels at 1 % level each of independent variable.
- The t-ratio of regression coefficients is highly significant with two independent variables namely storage capacity and actual generation. The t- ratio value is greater than 2.58 for SC and AG that indicates that the relation between WD and independent variables SC and AG holds good.
- The t- ratios of regression coefficients is not at all significant for other independent variables such as evaporation losses, tail water level and gross head.
- The R^2 is 0.99. It means that the independent variables such as storage capacity and actual generation can explain 99 % variation in the dependent variable and remaining 1 % is unexplained by the model. Thus the estimated regression coefficient is considered as an equation of very good fit.
- The over all relationship was statistically significant as f value is 4.59 and more significant at 1 % level. This indicates that the regressors SC and AG are significantly associated with WD.

Thermal based Electric Energy Power Plants

VI Kothagudaem Thermal Power Plant O &M
(Appendix Table: A4.6)

$$Y = -787978.047 + \overset{*}{1.021}CC - 2.130DB - 12.190CD + 146.699\,OT + 1.152\,AD + \overset{*}{4616.497}\,CT - 817.112AG$$

(3.259) (3.841)

N= 84, R^2 = 0.55, f value = 13.710

- The estimated regression coefficients indicate that the best explanatory (independent) variables with significant effect on quantity of water with drawals per Kilowatt hour are condenser cooling with cooling towers (Natural Draft cooling system) and ash disposal with significant levels of 5 % and 1 % level.
- The estimated equation indicates that the total thermal water withdrawals are elastic with respect to condenser cooling and ash

disposal. This kind of positive relationship indicates that the thermal water withdrawals are responsive to changes in condenser cooling and ash disposal.

- The t-ratio of regression coefficients have expected signs and is highly statistically significant for two independent variables namely condenser cooling with Natural Draft CTs and Ash Disposal. The t ratio value is greater than 2.58.
- This indicates that the importance of technological alternatives (i.e. Condenser Cooling with natural draft CTs) is the significant determinant of water withdrawals. Next ash disposal takes second place as significant determinant of total thermal water withdrawals.
- The t-ratio of regression coefficient is not at all significant for other independent variables such as DM and Boiler feed back, colony domestic, others (Drinking, Sanitation, Fire fighting, Back Wash Filter), cooling temperature and actual electric energy generation.
- The R^2 is 0.55. It means that the independent variables such as condenser cooling and ash disposal can explain 55 % of variation in the dependent variable and remaining 45 % variation is unexplained by the model. The estimated equation is considered as good fit.
- The over all model is statistically significant as f value is higher (13.710) and highly significant at 1 % level. This indicates that the regressor's condenser cooling with Natural Draft CT's and Ash Disposal are significantly associated with dependent variable WDs.

<u>VII Kothagudaem Thermal Power Station Stage V</u>
(Appendix Table: A4.7)

$$Y = 98233.879 + \underset{(20.91)}{\overset{*}{0.873}}\,CC + \underset{(15.247)}{\overset{*}{1.186}}AD + 0.111\,DB - 1688.373CT + 32.019\,AG$$

N= 83, R^2= 0.97, f value = 706.164

- The estimated regression coefficients indicate that the best independent variables with significant effect on quantity of WD per million tones are Condenser cooling and ash disposal with significant levels at 1% level each.
- The t-ratio of regression coefficients have expected signs and is highly statistically significant for two independent variables namely Condenser cooling with natural draft CT's and Actual Generation. The t- ratio value is greater than 2.58. Here the significant determinant of WD's are CC with natural draft CT's. Next comes ash disposal as second good determinant.
- The t- ratio of regression coefficient is not at all significant for other independent variables such as BF & DM, cooling temperature and Energy Generation.

- The R^2 is 0.97. It means that independent variables such as CC and AD can explain 97 % of variation in the dependent variable (Water withdrawal) and remaining 3 % variation are unexplained by the model. Thus the estimated equation is considered as an equation of very good fit.
- The over all model is statistically significant as f value is higher (706.164) and highly significant at 1 % level. This indicates that the regressors condenser cooling with NDCT's and Ash Disposal are significantly associated with Water withdrawal's (Dependent Variable)

VIII Rayalaseema Thermal Power Plant
(Appendix Table: A4.8)

$$Y = 10334.674+0.745^{*} CC+8.725 BF+0.847 AS-4.143 AG-145.408 CT$$

(2.677) (3.007)

N= 35, R^2 = 0.87 and f value = 33.145

- The estimated regression coefficients indicate that the best independent variables with significant effect on quantity of Water Withdrawal Condenser cooling with significant levels at 5%.
- The t-ratio of regression coefficients have expected signs and is highly statistically significant for one independent variables namely Condenser cooling with natural draft CT's .The t- ratio value is greater than 2.58. Here the significant determinant of WD's are CC with natural draft CT's.
- The t- ratio of regression coefficient is not at all significant for other independent variables such as BF & DM, Ash Disposal cooling temperature and Energy Generation.
- The R^2 is 0.87. It means that independent variables such as CC can explain 87 % of variation in the dependent variable (WD) and remaining 13 % variation are unexplained by the model. Thus the estimated equation is considered as an equation of very good fit.
- The over all model is statistically significant as f value is higher (33.145) and highly significant at 1 % level. This indicates that the regressors condenser cooling with NDCT's are significantly associated with WD's (Dependent Variable)

IX Narla Tata Rao Thermal Power Plant
(Appendix Table: A4.9)

$$Y = 139993.709 + 1.002^{*}CC -0.863CD + 1.031^{*} AS- 373.483 CT- 56.843 AG$$

(1277.966) (19.88)

N= R^2 = 1.00, f value = 907849.564

- The estimated regression coefficients indicate that the best explanatory (independent) variables with significant effect on quantity of water with drawals per Kilowatt hour are condenser cooling with cooling towers (Induced I Draft cooling system) and ash disposal with significant levels of 1 % and 1 % level.
- The estimated equation indicates that the total thermal water withdrawals are elastic with respect to condenser cooling and ash disposal. This kind of positive relationship indicates that the thermal water withdrawals are responsive to changes in condenser cooling and ash disposal.
- The t-ratio of regression coefficients have expected signs and is highly statistically significant for two independent variables namely condenser cooling with Induced Draft CTs and Ash Disposal. The t ratio value is greater than 2.58.
- This indicates that the importance of technological alternatives (i.e. Condenser Cooling with Induced draft CTs) is the significant determinant of water withdrawals. Next ash disposal takes second place as significant determinant of total thermal water withdrawals.
- The t-ratio of regression coefficient is not at all significant for other independent variables such as, colony domestic, cooling temperature and actual electric energy generation.
- The R^2 is 1.00. It means that the independent variables such as condenser cooling and ash disposal can explain 100 % of variation in the dependent variable. This shows that we have accounted for almost all the variability with the variables specified in the model. The estimated equation is considered as very good fit.
- The over all model is statistically significant as f value is higher (907849.564) and highly significant at 1 % level. This indicates that the regressor's condenser cooling with Induced Draft CT's and Ash Disposal are significantly associated with dependent variable WDs.

4.1 Estimation of Future Total Hydel Water Withdrawals based on (Percentage Increase of Growth): Regression Models

(1) To predict the future total hydel water withdrawals by taking in to account the growth rates of parameters. For Eg in hydel parameters such as reservoir elevation, storage capacity, inflows, Gross Head, Evaporation losses, tail water level and actual generation.

(2) To predict the future total thermal water withdrawals by taking in to account the growth rates of parameters such as condenser cooling, boiler feed, demineralized water, ash disposal, cooling water temperature, colony and domestic, others and actual generation.

Major Findings

- The estimated water withdrawals in Nagarjuna Sagar Main power house for the month of February 2009 was 139.371 cumecs.
- In Nagarjuna Sagar Left Canal power house, the estimated water withdrawals for the month of February 2009 was 38221.57 cumecs
    - The estimated water with drawals in Nagarjuna Sagar Right Canal Power house for the month of February 2009 was 7290.01 cumecs.
    - The estimated water withdrawals in Srisailam Left Canal Power House for June 2008 was -1011.405 cumecs (predominance of pump mode)
    - The estimated water withdrawal in Srisailam Right Canal Power House for June 2008 was 170.82 Cumecs.
    - The estimated water withdrawals for April 2009 in Kothagudaem O & M thermal power plant was 143918.97 cubic meters.
    - The estimated water withdrawals for October 2009 in Kothagudaem Stage V thermal power plant was 1179095.93 cubic meters
    - The estimated water withdrawal for April 2008 in Rayalaseema Thermal Power Plant was 15111.22 cubic meters.

V

5.0 APPLICATION OF WATER VALUATION TECHNIQUES IN POWER PLANTS

After basic needs of water in all stages of power station are met

- Water should be allocated its highest value uses
- Price charged by water supplier's authorities to power stations is too low, unrelated to value of water.
- Imperative to estimate or impute economic value of water.

Economic values are most reliable for water used as input to hydel and thermal power stations. In the context of poor pricing of natural resource "Water" we can say that it is leading to massive exploitation by its uneconomic use. The three components to water cost industries are:

- Water cess paid to Pollution Control Boards based on amount of waste water discharge.
- Cost of purchasing water from water suppliers like municipality or private water suppliers.

The question is whether the power industry is paying the appropriate cost of water? It is well known fact that consumption of water for industrial (for example cooling purpose) and boiler is thrice that of process water. The cost of water is fixed at the rate of 10 paise per kilo liter for cooling purpose. This cost is two or three times lower than the cost of process water. (That stands @ 0.20 to 0.30 paise per kilo litre). For example during the year 2000-2001, the cost of power generation for Indian Thermal Power plants is Rs.121860.99 crores. In this the total water cess paid by them is only Rs.323.12 crores. This example clearly shows that the total water cess as a percentage of power generation cost was very meager that is 0.265.[1] These instances are real evidences of poor pricing of natural resource "water".

In real terms, economic value is defined as the value when people are willing to pay for it, rather than go with out. But how much people (for example here power plants) are willing to pay for clean water. But often the prices charged by water suppliers are unrelated to the value of water that is too low. The major imputed Water Valuation Techniques are Residual value and Opportunity cost. These techniques are considered to be good to estimate the value of water in a single use or several closely related uses. This paper tries to examine whether the price of water paid by the selected thermal and hydel power stations do truly reflect its economic value or are they distorted?

I Residual Value (Value Marginal Product)

The easiest & most commonly applied valuation technique

$$TVP = \sum p_i q_i + p_w q_w$$

$$p_w = \frac{TVP - \sum \quad q_i}{q_w}$$

Where
TVP = Total Value of the commodity Produced
$p_i q_i$ = the opportunity costs of non-water inputs to production
p_w =price of water
q_w = the cubic meters of water used in production

Non-water inputs include:
intermediate inputs, labor, capital costs, land

---

[1] Source: Annual Report on the Working of SEBs and Electricity Departments, 2001-02, Planning Commission.

Table: A 5.1Estimation of Total Value Product of water: Thermal Power Plants

The table A5.1 displays the particulars of cost items with respect to coal, furnace oil, land cost, auxiliary power construction, steam generation, DM water, employment, repair and maintenance, factory over heads, indirect material construction, non-moving stock, clarified raw water, ash handling, cooling water system for the years 2006-07, 2007-08 and 2008-09 in selected thermal power plants i.e. KTPS O &M, KTPS V, RTPP and NTTPs. The summation of all non-water inputs provides the opportunity costs of non-water inputs that includes intermediate inputs, labor, capital and land costs (p_iq_i). The nominal price (p_w) is only charged by water supply authorities for water @ Rs 2.25 for thermal power stations such as NTPPs, KTPS O&M, KTPS V and RTPP. The Total Value Product of NTTPs is high @ 3547179062.99 for 2008-09 as the opportunity costs on non water inputs is high in comparison with other power plants. For KTPS O&M, KTPS V & RTPP the cost of non-water inputs are very low in comparison with NTTPs. Moreover the water cost is also the same for all the power plants that is @ Rs.2.25 irrespective of the quantity of the water withdrawals. This is also one of the core reasons for low total value product in all the other power stations. For instance, The TVP of RTPP is lowest @247355.5 for the year 2008-09 as the opportunity costs of non water inputs is lowest in comparison with other power plants.

Table: 5.2 Estimation of Total Value Product of water in Hydel Power Plants

The table A 5.2 also displays the particulars of raw water cost, auxillary power consumption cost, employee cost, repair and maintenance cost, factory over heads, indirect material construction cost, turbine conversion cost for the years 2006-07, 2007-08 and 2008-09 in selected hydel power stations of Srisailam left bank power house, Nagarjuna Sagar, Lower sileru and upper sileru. The summation of all the non water inputs provides the opportunity costs of water (p_iq_i). The nominal price of water charged for all the hydel power stations was @ Rs.2.25. The total value product calculated is lowest for Nagarjuna Sagar Hydel power station for the year 2008-09 @ the value of 316867.8 in comparison with other hydel power station where as the highest TVP was recorded for Srisailam Right canal power house @ the value of 956186.1 for the year 2006-07. For the remaining hydel power stations the TVP was less in comparison with Srisailam Right Canal Power house.

Opportunity Costs

OC is defined as the difference between production cost of hydro power and cost of next alternative thermal based power plant. Based on differences in cost of production it is a good technique to estimate the value of water.

$Rent = (C_T – C_H) QE_H$ Where

CT = cost of production per unit of electricity for Thermal power plants

C_H = cost of production per unit of electricity for hydropower plants

QE_H = quantity of electricity produced by hydropower plants

Table: A 5.3 Opportunity Costs of Thermal Vs Hydel

The table depicts the six scenarios of Thermal Vs Hydel namely VTPS Vs NAGMAIN, VTPS Vs SLB, KTPS O &M Vs SLB, KTPS O &M Vs SRB, KTPS Stage V Vs SRB, KTPS Stage V Vs UP Sileru, RTPP Vs UP Sileru, RTPP Vs Lower Sileru, VTPS Vs Lower Sileru and VTPS Vs UP Sileru. Out of 6 scenarios relating to Thermal Vs Hydel power combination, the maximum rent was obtained by replacing hydro with coal for VTPS Vs NAGMAIN. The highest rent was accrued for the year 2006-07 that stood at 218618792. The negative figures were notified for the year 2008-09 for other power plants (i.e. RTPP Vs Upper Sileru, RTPP Vs Lower Sileru and VTPS Vs lower Sileru that stood at -74.34,-170.97 and -170.97.This means that the rent obtained by replacing hydro with coal based power plants is absolutely nil. The underlying reason is the thermal power plants sustenance is very much under stake due to major reason of fresh water shortages in power generation.

Important Insight conclusions

- Pertinent conclusion of this study is there may be significant potential for water conservation after having identified the significant determinants of total thermal water withdrawals i.e. condenser cooling and ash disposal.
- The choice of explanatory variable for eg: Induced draft and natural draft technological innovation was able to address the significant changes of water withdrawals.
- The quantity of water withdrawn in any given year depends on weather conditions. Water withdrawals for most purposes increase during periods of hot and dry weather and decrease during periods of cool and wet weather and decrease in water withdrawals due to flood conditions.
- This dependence of withdrawals on weather conditions can be determined by including weather-related variables in the set of explanatory variables.
- The study aims at looking the responses of climate anomalies (irregularities) in the power plants by fuel type at aggregate level on production of electricity and cost, in three regions namely Coastal Andhra, Rayalaseema and Telangana region of Andhra Pradesh.
- The regression model by taking in to account cooling temperature in all four seasons of year failed to capture the seasonal changes.

- ❖ How ever inclusion of more weather related variables and other hydro climatic changes, marginal price of water etc as additional explanatory variables can provide better results.
- ❖ On going research on water use models provides a pragmatic basis for pursuing improvements in the efficiency of water use in power plant and cooling systems that exceed the standard values.

Appendix Tables

Table: A4.1: Nagarjuna Sagar Main Power House

Variables Entered/Removed

Model	Variables Entered	Variables Removed	Method
1	acutal_generation, tail_water_level, Reser_elevation, Gross_feet, Storage_capacity[a]	.	Enter

a. All requested variables entered.

b. Dependent Variable: water_discharge_cums

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.997[a]	.995	.995	512.92868

a. Predictors: (Constant), acutal_generation, tail_water_level, Reser_elevation, Gross_feet, Storage capacity

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	7291771208.745	5	1458354241.749	5543.053	.000[a]
	Residual	38675087.446	147	263095.833		
	Total	7330446296.191	152			

a. Predictors: (Constant), acutal_generation, tail_water_level, Reser_elevation, Gross_feet, Storage capacity

b. Dependent Variable: water_discharge_cums

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-146.238	1555.816		-.094	.925
	Reser_elevation	-.080	.093	-.012	-.865	.389
	Storage capacity	-.258	.065	-.091	-3.966	.000
	tail_water_level	.350	.111	.031	3.144	.002
	Gross_feet	.133	.094	.026	1.419	.158
	acutal_generation	50.669	.423	1.041	119.869	.000

a. Dependent Variable: water_discharge_cums

Table: A 4.2 Nagarjuna Sagar Left Canal Power House

Variables Entered/Removed[b]

Model	Variables Entered	Variables Removed	Method
1	evaporation, energe_bus, twl_ft, storage capacity, reservior_level[a]	.	Enter

a. All requested variables entered.

b. Dependent Variable: water_drawals

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.864[a]	.747	.739	2350.84646

a. Predictors: (Constant), evaporation, energe_bus, twl_ft, storage capacity, reservior_level

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	2626964399.664	5	525392879.933	95.068	.000[a]
	Residual	889763133.646	161	5526479.091		
	Total	3516727533.310	166			

a. Predictors: (Constant), evaporation, energy bus, twl_ft, storage capacity, reservior_level

b. Dependent Variable: water_drawals

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	1660.770	501.102		3.314	.001
	reservior_level	-3.516	3.411	-.157	-1.031	.304
	storage capacity	-21.705	5.219	-.538	-4.159	.000
	twl_ft	9.653	2.510	.394	3.846	.000
	energy bus	491.286	30.765	.987	15.969	.000
	evaporation	.130	.508	.015	.255	.799

a. Dependent Variable: water_drawals

Table: A4.3 Nagarjuna Sagar Right Canal Power House

Model	Variables Entered		
1	generation bus, reservior_level, evaporation, storage capacity, tailwaterlevel[a]		

b. Dependent Variable: water_drawals

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.885[a]	.784	.777	3767.05581

a. Predictors: (Constant), generation bus, reservior_level, evaporation, storage capacity, tailwaterlevel

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	8246365913.182	5	1649273182.636	116.222	.00
	Residual	2270513515.133	160	14190709.470		
	Total	10516879428.315	165			

a. Predictors: (Constant), generation bus, reservior_level, evaporation, storage capacity, tailwaterlevel

b. Dependent Variable: water_drawals

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	6133.252	838.604		7.314	.000
	reservior_level	.628	7.571	.016	.083	.934

	storage capacity	-58.029	9.570	-.832	-6.063	.000
	evaporation	.414	.810	.027	.511	.610
	tailwaterlevel	37.493	21.598	.263	1.736	.084
	generation bus	486.057	29.945	1.045	16.232	.000

a. Dependent Variable: water_drawals

Table: A4.4 Srisailam Left Canal Power House

Variables Entered/Removed[b]

Model	Variables Entered	Variables Removed	Method
1	inflow, Reservoir, evaporat, Actual generation, Tail water, storage_capacity[a]	.	Enter

a. All requested variables entered.

b. Dependent Variable: water_withdra

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.981[a]	.963	.959	1454.18057

a. Predictors: (Constant), inflow, Reservoir, evaporat, Actual generation, Tail water, storage capacity

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	2815082375.894	6	4.692E8	221.872	.000[a]
	Residual	107846697.597	51	2114641.129		

	Total	2922929073.491	57			

a. Predictors: (Constant), inflow, Reservoir, evaporat, Actual generation, Tail water, storage capacity

b. Dependent Variable: water_withdra

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-2243.501	2527.275		-.888	.379
	Reservoir	-.766	.337	-.239	-2.272	.027
	storage capacity	1.195E-6	.000	.000	.004	.997
	Actual generation	57.476	3.055	.953	18.814	.000
	evaporat	.592	.939	.081	.631	.531
	Tail water	4.237	1.572	.248	2.695	.010
	inflow	.000	.002	-.017	-.339	.736

a. Dependent Variable: water_withdra

Table: A4.5 Srisailam Right Canal Power House

Model	Variables Entered	Variables Removed	Method
1	Gross head, Tailwaterlevel, actual generation, Evaporation, storage, Reservoir	.	Enter

Model	Variables Entered	Variables Removed	Method
1	Gross head, Tailwaterlevel, actual generation, Evaporation, storage, Reservoir	.	Enter

a. All requested variables entered.

b. Dependent Variable: water withdrawals

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.998[a]	.995	.995	631.39218

a. Predictors: (Constant), Gross head, Tailwaterlevel, actual generation, Evaporation, storage, Reservoir

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1.099E10	6	1.832E9	4.596E3	.000[a]
	Residual	5.222E7	131	398656.090		
	Total	1.105E10	137			

a. Predictors: (Constant), Gross head, Tailwaterlevel, actual generation, Evaporation, storage, Reservoir

b. Dependent Variable: water withdrawals

Coefficients[a]

	Unstandardized Coefficients		Standardized Coefficients		
Model	B	Std. Error	Beta	t	Sig.

1	(Constant)	-7630.380	1817.341		-4.199	.000
	Reservoir	-.178	.322	-.027	-.553	.581
	storage	.000	.000	-.068	-4.288	.000
	actual generation	56.314	.459	1.022	122.651	.000
	Evaporation	.051	.139	.005	.365	.716
	Tailwaterlevel	.627	.334	.059	1.874	.063
	Gross head	.289	.320	.036	.904	.368

a. Dependent Variable: water withdrawals

Table: A4.6 Kothagudaem Thermal Power Plant O &M

Variables Entered/Removed[b]

Model	Variables Entered	Variables Removed	Method
1	energy generation , cooling temp, DM Water & Boiler Feed back , Ash Disposal , Condenser Cooling , Colony domestic , (Drin, Sani, Firefigh, Backwarhfiler) [a]	.	Enter

a. All requested variables entered.

b. Dependent Variable: Total water consumption

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate

1	.747[a]	.558	.517	289298.132

a. Predictors: (Constant), energy generation , cooling temp, DM Water & Boiler Feed back , Ash Disposal , Condenser Cooling , Colony domestic , (Drin, Sani, Firefigh, Backwarhfiler)

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	8.032E12	7	1.147E12	13.710	.000[a]
	Residual	6.361E12	76	8.369E10		
	Total	1.439E13	83			

a. Predictors: (Constant), energy generation , cooling temp, DM Water & Boiler Feed back , Ash Disposal , Condenser Cooling , Colony domestic , (Drin, Sani, Firefigh, Backwarhfiler)

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-787978.047	1.334E6		-.591	.557
	Condenser Cooling	1.021	.313	.551	3.259	.002
	DM Water & Boiler Feed back	-2.130	5.717	-.038	-.373	.710
	Colony domestic	-12.190	15.642	-.250	-.779	.438
	(Drin, Sani, Firefigh, Backwarhfiler)	146.699	201.477	.467	.728	.469
	Ash Disposal	1.152	.300	.409	3.841	.000
	cooling temp	4616.497	10000.955	.039	.462	.646
	energy generation	-817.112	1096.318	-.295	-.745	.458

a. Dependent Variable: Total water consumption

Table: A4.7 Kothagudaem Thermal Power Plant Stage V

Variables Entered/Removed[b]

Model	Variables Entered	Variables Removed	Method
1	Energy Generation, ASH DIS-POSAL (MT), Cooling Temperature , Boiled Feed and DM plant Regeneration, COOLING TOWER MAKEUP (MT)[a]	.	Enter

a. All requested variables entered.

b. Dependent Variable: TOTAL CONS. (MT)

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.989[a]	.979	.977	64726.513

a. Predictors: (Constant), Energy Generation, ASH DIS-POSAL (MT), Cooling Temperature , Boiled Feed and DM plant Regeneration, COOLING TOWER MAKEUP (MT)

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	14792454121098.932	5	2958490824219.786	706.164	.000[a]
	Residual	322593153570.889	77	4189521474.947		
	Total	15115047274669.820	82			

a. Predictors: (Constant), Energy Generation, ASH DIS-POSAL (MT), Cooling Temperature , Boiled Feed and DM plant Regeneration, COOLING TOWER MAKEUP (MT)

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	14792454121098.932	5	2958490824219.786	706.164	.000[a]
	Residual	322593153570.889	77	4189521474.947		
	Total	15115047274669.820	82			

a. Predictors: (Constant), Energy Generation, ASH DIS-POSAL (MT), Cooling Temperature , Boiled Feed and DM plant Regeneration, COOLING TOWER MAKEUP (MT)

b. Dependent Variable: TOTAL CONS. (MT)

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	98233.879	76676.230		1.281	.204
	COOLING TOWER MAKEUP (MT)	.873	.042	.577	20.912	.000
	ASH DIS-POSAL (MT)	1.186	.078	.484	15.247	.000
	Boiled Feed and DM plant Regeneration	.111	.978	.003	.114	.910
	Cooling Temperature	-1688.373	2158.260	-.014	-.782	.436
	Energy Generation	32.019	115.619	.005	.277	.783

a. Dependent Variable: TOTAL CONS. (MT)

Table: A 4.8 Rayalaseema Thermal Power Plant

Variables Entered/Removed[b]

Model	Variables Entered	Variables Removed	Method
1	Cooling Temp, Ash slurry, Actual Generation, Power Generation, Boiler feed, Condenser cooling, BCW[a]	.	Enter

a. All requested variables entered.

b. Dependent Variable: Water consumption

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.934[a]	.873	.846	1324.085

a. Predictors: (Constant), Cooling Temp, Ash slurry, Actual Generation, Power Generation, Boiler feed, Condenser cooling, BCW

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	3.487E8	6	5.811E7	33.145	.000[a]
	Residual	5.084E7	29	1753200.788		
	Total	3.995E8	35			

a. Predictors: (Constant), Cooling Temp, Ash slurry, Actual Generation, Power Generation, Boiler feed, Condenser cooling, BCW

Coefficients[a]

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
1	(Constant)	10334.674	3861.078		2.677	.012
	Condenser cooling, BCW	.745	.248	.432	3.007	.005
	Boiler feed	8.725	4.628	.244	1.885	.069
	Ash slurry	.847	.501	.230	1.692	.101
	Power Generation	-.595	.388	-.138	-1.532	.136
	Actual Generation	-4.143	5.478	-.077	-.756	.456
	Cooling Temp	-145.408	94.141	-.109	-1.545	.133

a. Dependent Variable: Water consumption

Table : A 4.9 Narla Tata Rao Thermal Power Plant

Variables Entered/Removed[b]

Model	Variables Entered	Variables Removed	Method
1	Energy Generation, Condenser cooling & BCW (KL), Cooling Temperature , Ash slurry water (KL), Colony Domestic (KL)[a]	.	Enter

a. All requested variables entered.

Variables Entered/Removed[b]

Model	Variables Entered	Variables Removed	Method
1	Energy Generation, Condenser cooling & BCW (KL), Cooling Temperature , Ash slurry water (KL), Colony Domestic (KL)[a]	.	Enter

b. Dependent Variable: Totalwaterconsumption

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	1.000[a]	1.000	1.000	50290.302

a. Predictors: (Constant), Energy Generation, Condenser cooling & BCW (KL), Cooling Temperature , Ash slurry water (KL), Colony Domestic (KL)

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	11480277367590772.000	5	2296055473518154.000	907849.564	.000[a]
	Residual	42994946072.977	17	2529114474.881		
	Total	11480320362536844.000	22			

a. Predictors: (Constant), Energy Generation, Condenser cooling & BCW (KL), Cooling Temperature , Ash slurry water (KL), Colony Domestic (KL)

b. Dependent Variable: Totalwaterconsumption

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	139993.709	137540.088		1.018	.323
	Condenser cooling & BCW (KL)	1.002	.001	.987	1277.966	.000
	Colony Domestic (KL)	-.863	.584	-.001	-1.476	.158
	Ash slurry water (KL)	1.031	.052	.018	19.879	.000
	Cooling Temperature	-373.483	3763.081	.000	-.099	.922
	Energy Generation	-56.843	138.469	.000	-.411	.687

a. Dependent Variable: Totalwaterconsumption

Table: A 5.1 Total Value Product of Selected Thermal Power plants

	2008-09	2007-08	2006-07	2008-09	2007-08	2006-07	2008-09	2007-08	2006-07
Particulars	**VTPS**			**KTPS-O & M**			**KTPS-STAG: V**		
(a) Coal	150071	104246	100052	47911	42258	37679	33684	29954	24921
(b) Furnace Oil	759	506	495	2550	816	1111	1339	307	275
(c) HSD/LD Oil	140	135	128	393	277	294	34	14	3
Landed Cost of Coal	2069	1463	1450	1207	1025	1011	1122	1022	946
Landed Cost of F.Oil	29679	21236	20715	34254	20928	20851	35909	21635	21547
Landed Cost of LD/HSD Oil	34701	33344	32283	35815	33727	33355	35440	30198	5448
	217419	160930	155123	122130	99031	94301	107528	83130	53140
Para 7									
Auxiliary Power Cons. Cost	17365	12959	12889	7379	5934	5927	6433	5441	4880
Steam Generation Cost	178384	128797	124634	67529	58167	54643	54692	49392	43839
DM Water Cost	931	715	954	583	597	623	443	332	186
Auxiliary Power Cons.	1.87	1.45	1.42	1.77	1.36	1.37	1.71	1.43	1.42
Steam Generation Cost	559.71	431.27	407.71	445.43	344.7	344.26	495.73	413.46	397.02
DM Water	151.33	98.1	112.54	90.89	83.57	87.35	191.39	146.9	83.04
	197392.91	143001.8	138998.67	76029.09	65127.63	61625.98	62256.83	55726.79	49386.48
Para 8									
Employment Cost	8324.98	7718.15	7280.96	7799.38	7742.87	8565.65	2596.59	1956.071	2678.63
Employes Cost (Including E.L provision)	8324.98	7718.15	8598.72	7799.38	7742.87	10193.38	2596.59	1956.071	3210.79
Employes Cost	8.05	7.9	8.64	17.48	15.39	21.29	7.9	5.45	9.62
	16658.01	15444.2	15888.32	15616.24	15501.13	18780.32	5201.08	3917.592	5899.04
Para 9									
Repairs & Maintenance	2202.95	2488.46	2652.28	3811.13	1780.05	3060.03	2618.39	2414.89	3077.89
Repairs & Maintenance	2.34	2.55	2.66	8.54	3.54	6.39	7.96	6.73	8.36
	2205.29	2491.01	2654.94	3819.67	1783.59	3066.42	2626.35	2421.62	3086.25
Para 12									
Factory Overheads	4726	3983	4418	2193	2210	2048	2015	2183	2332
Facy. Overheads per KWH	4.57	4.08	4.44	4.92	4.39	4.28	5.5	5.5	6.33
Head Office Overheads	477	250	866	163	24	623	140	17	595

HO Overheads per KWH	0.46	0.26	0.87	0.37	0.05	1.3	0.38	0.04	1.62
	5208.03	4237.34	5289.31	2361.29	2238.44	2676.58	2160.88	2205.54	2934.95
Para 18 (A)									
Indirect Material Cons .	2911	3511	2417	2467	2525	2029	1724	1450	2090
Indirect Mat. Cosg stock	11583	11159	12706	8684	8664	7919	5004	4173	2391
Non- Moving Stock	1467	1372	1253	1843	1842	2031	678	500	423
	15961	16042	16376	12994	13031	11979	7406	6123	4904
Cost Statement									
Raw Water Cost	0.04	0.02	0.02	0.32	0.3	0.34	0.79	0.86	1.2
Clarified Raw Water	15.21	11.96	10.85	3.03	1.63	2.08	1.86	1.99	2.15
DM Water	151.33	98.1	112.54	90.89	83.57	87.35	191.39	146.9	83.04
Cooling water System	0.22	0.17	0.2	9.12	5.99	6.76	23.89	18.05	20.43
Ash Handling Plant	35.29	21.44	35.55	64.91	49.63	75.17	112.89	80.08	87.66
Coal Handling Plant Conversion Cost	89.21	82.83	44.43	85.42	72.82	89.53	77.82	75.08	97.72
Boiler Conversion Cost	41.94	37.69	44.18	60.59	48.68	55.15	139.18	127.53	132.08
Turbine Conv. Cost	0.14	0.12	0.17	0.22	0.21	0.23	0.21	0.18	0.23
Total cost	1.87	1.44	1.42	1.78	1.36	1.41	1.7	1.41	1.42
	335.25	253.77	249.36	316.28	264.19	318.02	549.73	452.08	425.93
Non -water inputs	455179.49	342400.1	334579.6	233266.6	196976.98	192747.32	187728.87	153976.622	119776.65
Water used in production	1576321726	3310532	1454501919	12605110	33913540	31663856	18124620	18848979	17750361
value of water	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25
	3546723884	7448697	3272629318	28361497	76305466.08	71243676.09	40780394.68	42410202.75	39938312.25
Total Value Product (TVP)	3547179063	7791097	3272963897	28594764	76502443.06	71436423.41	18312348.73	19002955.62	17870137.65

Cont …..Table A 5.1

2008-09	2007-08	2006-07
	RTPP	
58801	40600	41306
658	384	351
136	24	15
2512	1827	1856
37581	23241	21774
42648	29366	28810
142336	95442	94112
8723	6945	7199
77366	59303	62242
168	185	259
2.48	2.06	2.1
753.6	623.44	603
80.31	84.32	117.38
87093.39	67142.82	70422.48
3797.75	3124.58	3078.84
3797.75	3124.58	3731.86
5.63	7.73	11.33
7601.13	6256.89	6822.03
2475.94	1195.77	943.08
3.67	3.79	2.86
2479.61	1199.56	945.94
1667	1123	891
4.97	3.57	2.65

108	22	544
0.32	0.07	1.65
1780.29	1148.64	1439.3
1991	1007	889
3514	3256	3327
154	154	154
5659	4417	4370
0.86	1.09	2.48
3.06	4.18	8.15
80.31	84.32	117.38
13.57	16.28	19.09
148.43	105.61	95.89
53.61	63.89	68.48
103.61	123.06	222.13
0.17	0.16	0.21
2.48	2.06	2.1
406.1	400.65	535.91
247355.5	176007.6	178647.7
0	192325	120520
2.25	2.25	2.25
0	432731.3	271170
247355.5	368332.6	299167.7

Table A 5.2 Total Value Product of Selected Hydel Power plants

	2008-09	2007-08	2006-07		2008-09	2007-08	2006-07		2008-09	2007-08	2006-07
	Srisalam Left (SLBHES)				Srisalam Right (SRBHES)				Nagarjuna sagar		
Para 5											
Raw Water (Royalty Cost)	93434	90598	93432		415911	359525	416867		93433	93433	97653
Para 7											
Auxiliary Power Cons.	30.57	24.12	22.87		56.97	31.31	26.54		10.2	56.84	44.73
Auciliary Power Cons.	0.77	0.54	0.56		0.32	0.26	0.33		0.41	0.24	0.27
Para 8											
Employes Cost	3.68	2.45	3.01		4.59	3.46	5.44		7.98	4.58	6.02
Para 9											
Repairs & Maintenance	1.56	0.51	0.45		1.05	0.66	0.76		1.15	0.65	0.38
Para 12											
Factory Overheads	406.95	433.9	486.36		360.92	344.82	361.33		515.59	523.29	416.04
Head Office Overheads	176.09	118.66	381.56		119.63	101.29	176.04		149.14	127.07	224.52
Para 18 A											
Indirect Material Cons.	71.6	36.91	115.15		74.77	93.67	109.01		59.22	70.5	59.57
Indirect Mat. Closg. Stock	421.33	275.4	261.09		304.52	378.41	1077.08		137.53	108.93	79.33
Non- Moving Stock	43	0	0		38.22	58.91	61.28		13	22.16	13.47
Raw Water Cost	659565	452111	476742		476422	402613	494569		113253	108001	114101
Turbine Conv. Cost	0.66	0.46	0.48		0.24	0.19	0.24		0.38	0.22	0.24
Total value	754155.21	543601.95	571445.53		893294.23	763150.98	913254.05		207580.6	202348.48	212598.57
value of water	2.25	2.25	2.25		2.25	2.25	2.25		2.25	2.25	2.25
Water used in production	60240.2	164052.31	141753.14			15560.57	19080.91		48572.1	102802.7	89391
	135540.45	369117.7	318944.565			35011.2825	42932.048		109287.23	231306.08	201129.75
Total Value Product (TVP)	889695.66	912719.65	890390.095		893294.23	798162.2625	956186.1		316867.83	433654.56	413728.32

	2008-09	**2007-08**	**2006-07**		**2008-09**	**2007-08**	**2006-07**
	Sileru-Upper				**Sileru-Lower**		
Para 5							
Raw Water (Royalty Cost)	93516	93516	93433		93516	93516	93516
Para 7							
Auxiliary Power Cons.	62.43	77.32	68.76		36.67	17.77	27.76
Auciliary Power Cons.	0.34	0.4	0.37		0.19	0.19	0.19
Para 8							
Employes Cost	11.94	14.26	17.21		7.47	7.5	8.71
Para 9							
Repairs & Maintenance	2.55	3	2.91		2.89	2.74	2.47
Para 12							
Factory Overheads	322.3	331.39	424.48		465.41	399.91	620.85
Head Office Overheads	39.25	31.59	73.51		70.07	60.52	100.21
Para 18 A							
Indirect Material Cons.	66.14	138.22	72.41		170.53	112.02	140.98
Indirect Mat. Closg. Stock	0	0	0		389.34	366.49	246.66
Non- Moving Stock	0	0	0		19.28	19.11	0.13
Raw Water Cost	29.325	335699	284598		453483	427508	434847
Turbine Conv. Cost	0.3	0.35	0.32		0.15	0.15	0.15
Total cost	94050.575	429811.53	378690.97		548161	522010.4	529511.11
value of water	2.25	2.25	2.25		2.25	2.25	2.25
Water used in production	49.56	57.26	42.09		113.98	113.68	126.47
Total Value Product (TVP)	111.51	128.835	94.7025	0	256.455	255.78	284.5575
TVP	94162.085	429940.37	378785.6725	0	548417.455	522266.18	529795.67

Table A 5.3 Opportunity Costs: Thermal Vs Hydel

Particulars	2008-09	2007-08	2006-07	2008-09	2007-08	2006-07
		VTPS			**KTPS-O & M**	
Water used in production		1208344113	1454501919	12605110	33913540	31663856
	2008-09	2007-08	2006-07	2008-09	2007-08	2006-07
		NAG-MAIN		**SRISAILAM LEFT BANK**		
Water used production	48572.1	102802.7	89391	60240.2	164052.31	141753.14
Hydro per year	1.5	1.5	1.5	1.5	1.5	1.5
	VTPS VS NAGMAIN -2007-08		**VTPS VS NAGMAIN**	**KTPS-O&M VS SLB**	**KTPS-O&M VS SLB**	**KTPS-O&M VS SLB**
Opportunity cost	70842.9 Exclu.Feb and Mar	1812361965	2181618792	18817304.37	50624232.26	47283154.35
	VTPS VS SLB -2007-08		**VTPS VS SLB -2008-09**	**KTPS O & M SRB**	**KTPS O & M SRB**	**KTPS O & M SRB**
Opportunity cost	-90360.3	1812270091	2181540249	18907664.67	50846969.87	47467162.7

Cont…. Table A 5.3

2008-09	2007-08	2006-07	2008-09	2007-08	2006-07	2008-09	2007-08	2006-07
KTPS-STAG: V			RTPP			VTPS		
18124620	18848979	17750361	0	192325	120520	0	1208344113	1454501919
2008-09	2007-08	2006-07	2008-09	2007-08	2006-07	2008-09	2007-08	2006-07
SRISAILAM RIGHT BANK			**Upper sileru**			**Lower sileru**		
	15560.57	19080.91	49.56	57.26	42.09	113.98	113.68	126.47
1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
KTPSSTAGV VSSRB	**KTPSSTAGV VSSRB**	**KTPSSTAGV VSSRB**	**RTPP VS UP SILERU**			**VTPS VS LOWERSILERU**		
27186929.78	28250127.65	26596920.14	-74.34	288401.61	180716.865	-170.97	1812515999	2181752689
KTSPSTAGEV VS UPSILE	**KTPSSTAGV VSSRB**	**KTPSSTAGV VSSRB**	**RTPP VS LOWERSILERU**			**VTPS VS UPSILERU**		
27186855.44	28273382.61	26625478.37	-170.97	288316.98	180590.295	-74.34	1812516084	2181752815

REFERENCES

1. Benedy Kt Dziegielewski, Thomas Bik (August 2006), " Water Use Bench Marks for Thermo Electric Power Generation" Project report, Southern Illinois University, United States Geological Survey, 2004, USGS National Competitive Grants Program.

2. Gbadebo Oladosu, Stan Hadley, Vogt D.P. and Wilbanks J.J. (September, 2006), "Electricity Generation and Water Related Constraints: An Empirical Analysis of Four South Eastern States", Oak Ridge National Laboratory, Oak Ridge Tennessee.

3. Sitanon Jesdapipat and Siriporon Kiratikarnkul, " Surrogate pricing of water: The Case of micro Hydro –Electricity Co-operatives in Northern Thailand".

4. Xiaoying Yang & Benedy Kt Dziegielewski (February,2007), " Water Use by Thermo Electric power plants in the United states" Journal of the American Water Resources Association, Vol 43, No.1.

5. "Estimating Water Use in United States: A new Paradigm for National Use WaterUseInformationProgramme"(2002), http://books.nap.edu/openbook.php?record_id=10484&page=95

6. Water Price Review, (2008), draft Decision Vol II, East Gipps land water.

7. http://www.powermag.com

Data Sources

Annual Report on the Working of SEBs and Electricity Departments, Planning Commission, Various Issues

Administrative Reports of Andhra Pradesh Generation Corporation of India Limited (APGENCO), Various Issues.

Field Level data of selected thermal and hydel power stations authenticated by APGENCO.

Central Electricity Authority, (2010), Ministry of power, Government of India, New Delhi.