

GENERATION TREND OF MEGA HYDRO PROJECTS: A CASE STUDY OF WARSAK DAM

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Abstract

With the passage of time, the generation patterns of a mega hydro plant changes due to some commonly known reasons. These reasons could be environmental, infrastructural, or mechanical. However, when this pattern changes abnormally, pinpointing of the issues is the only way forward. Warsak dam is currently facing the same abnormal generation pattern. It was having total generation of about 242.96 MW just after commissioning in 1981; currently it is generating about 193 MW. This plant is facing still a lag of 50 MW. The purpose of this research paper is to address those issues, which are meant to reduce the generation capacity of this dam, and specifically mentioning the common reasons like sedimentation, siltation, infrastructure deformation and climatic conditions and to devise a most suitable method to mitigate the issues.

Keywords: Mega hydro power plant, Warsak dam, sedimentation, problems of hydro projects.

1. INTRODUCTION

Hydroelectric Power Generation is the most affordable source of energy and it is often cost-competitive with the current market energy prices. Though, its initial investment is relatively high, but it has a long shelf life with a very small operations and maintenance costs. Average price of electric power for hydroelectric projects may be as low as 3 to 5 US cents per kWh (in 2005) [12]. Moreover, hydropower has best conversion efficiencies about 90% as compared to other resources.

Furthermore, Energy reserves were reported to be of strategic importance, however international organizations are forcing to do the utilization of renewable energy resources. Considering the worldwide demands and inadequate hydrocarbons for the support of fast-growing industries and for developmental growth, hydropower is the most economically sustainable and environmentally friendly way of overcoming energy shortage in emerging countries like Pakistan. Pakistan faced record energy crisis in the last few years. Recently during a peak crisis, there were power outage of about 10-12 hours daily [29].

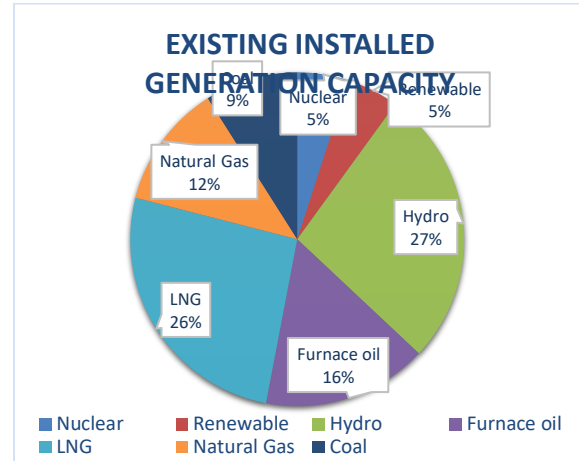


Figure 1.1: Energy mix of Pakistan

However, In Pakistan electrical energy is being generated through various resources, 9% of energy has generated by coal, 12% by Natural Gas, 26% by LNG, 16% by furnace oil, 27% by hydro, 5% by nuclear, 5% by other resources (solar, wind) as shown in figure 1.1. Pakistan has huge capacity for hydropower due to glacier in colder areas, regular rain of the monsoon and local landscape. However, estimated potential of hydel power in Pakistan is more than 59,000MW [29], although only less than 17 percent of the hydropotential is utilized. However, the total installed capacity of electricity in Pakistan is 38.7GW. Multipurpose reservoirs were constructed in Pakistan for the purpose of irrigation and to generate electric power, total installed capacity from hydro is 6,516MW, the generation from these hydel resources is 30,900GWh [29].

Table 1.1: Hydropower potential in Pakistan [29]

S. No	Rivers in Pakistan	Power (MW)
1	Hydroelectric Power projects above 50 MW	56943
2	Hydroelectric power projects below 50 MW	2265
	Total hydro power potential	59208

Table1: hydropower potential in Pakistan

Warsak dam is one of the oldest dams of Pakistan. This hydroelectric project is accomplished in two phases. The first phase was finalized in 1960, at that time its installed capacity was 160MW, four generating units were installed each of 40MW. In second phase, two more generating units were added each of 41.48MW in 1981 resulting in total installed capacity of 242.96MW. The initial gross storage capacity of warsak dam was 5,920 million cubic feet, including a live storage of 1,090 million cubic feet [29]. The reservoir is silted up to the top of the spillways after 5 years since commissioning. The annual flow of kabul river is 109 times higher than the initial capacity of the reservoir [29].

Nowadays, the Warsak dam generation capability has been reduced to 193MW, which is 50MW less than its installed capacity. This research will provide important advices for significantly reducing the damage to the environment for upcoming hydroelectric dams. Electricity remains the main factor to improve life of millions of impoverished people across the emerging world. In several countries, hydroelectric dams are considered as a renewable source to provide electricity in future as well [18].

2. LITERATURE REVIEW

It is important to consider that the generation pattern of all mega hydroelectric projects is not identical, though it changes with the passage of time due to some common issues.

2.1. Water Quality

In this case two hydroelectric dams are compared one is Pehuenche Hydroelectric Project located in Chile, it covers 400 hectares of area and generate 500 MW. At the same time as the Dam name Brokopondo in Suriname flooded about 160,000 hectares of land which is biologically valuable rainforest near the equator, while offering comparatively less generation of electricity only 30 MW [18]. This comparison shows that water quality also has effect on electricity generation.

2.2. Siltation /Sedimentation

Though, hydropower performs a very important role in the energy sector in Pakistan. But the unexpected siltation in hydroelectric power plants have a considerable impact on the power output. Thus, as countries that are seeking to increase its hydro power capacity, it is essential to find policies to enhance productivity of current power plants.

Most of the hydro projects reached its 100 percent of its trap efficiency, the reservoir is filled with sediments and silt and they are behaving as run-off river [4]. The rate of accumulation of sediment varies considerably depending upon the quality of water. The Main reservoirs in the US loses its storage capacity by an average of around

0.2 per cent annually, Though, In China large reservoirs lose its capacity to store at an average rate of 2.3 per cent per year [4]. Tarbela Reservoir is the largest earth filled dam of Pakistan. In 1992, it lost 12 percent of its storage capacity after 18 years of operation. [4].

Apart from rapidly filling of the reservoirs, the river which contain sediments create problems for the operators of the powerhouse due to abrasions and erosion of turbine parts and its other components. The efficiency of the turbine is highly dependent on the blade's hydraulic properties, in the same way as an Aeroplane is dependent on aerodynamic characteristics of their wings [4]. Due to sand and silt in the water causes eroding and cracking in the edges of the blades of turbine blade, which significantly reduces their power generation efficiency [4]. An Additional harmful phenomenon from the accumulation of sedimentary materials in the reservoir is the reduction of the stability of dams [28].

Mangla Dam is the second largest dam of Pakistan, its installed capacity is 1000MW. Different techniques were proposed to reduce the silt/sediments problem [16]. A watershed management program has been started by WAPDA since 1960, to effectively control land erosion and reduce the proportion of sediment. 55 years has been passed in these years they planted 133 million trees, they did construction of stone and earthen structures covering 122 million cubic feet by constructing retaining walls and check dams. They did construction of engineering structures by constructing stone masonry, an

improvement in the 8400 acres of farmland and giving training to farmers [16]. As a result, the sediment load decreases from 42,000 acre-feet/annum to 27,747 acres-feet/annum [16].

The original storage capacity of Mangla dam was 5.88 MAF, as the time passed its storage capacity was reduced to 4.67MAF due to sedimentation and silting phenomena. another project was started in July 2014 for up-raising of Mangla dam [16]. In this project Mangla dam height was raised about 30 feet, and its storage capacity was extended to 7.48MAF, total increase in its storage capacity was 2.81 MAF [16]. Furthermore, by construction of debris dams at the Mangla reservoir, which has helped in draining/filtering water.

2.3. Climatic Changes

Change in climate showed increase in temperature, past 40 years of temperature were being observed, the maximum increase that has been noted is an average of 0.058°C/year whereas the minimum temperature that increased is 0.014°C/year [21]. Snow is expected to drop considerably as the temperature increases, melt from glaciers are about to increase to mid-century and then will start decreasing afterwards. River systems depends on the seasonal rain and climate change will affect the dynamics of monsoon that are needed for the river systems. The effects on water due to climate change is not predictable which is the most worrying and disturbing factor. Climatic change will vary the river discharge, which affects water availability, regular flow of

water and hydropower generation [22]. Furthermore, Climate-change makes the world warmer, which results in frequent and severe flooding.

2.4. Useful Life of Reservoir

Useful life of reservoir is the period in which reservoir has some capacity of storing water when sedimentations gathered in reservoir, it decreases its water storage capacity and its power generation capacity [18]. Some reservoir has useful life not more than ten years, prior to its dead storage capacity has been covered (for example Paute Dam at the Ecuador) while other has potential of thousands of years [18]. Generally, those reservoirs have longest useful life which are comparatively situated on rivers with low sediment loads and are having deep reservoir.

Mangla Dam useful life was proposed to be 50 years at the time of designing. Its capacity of water storage dropped to 4.67 MAF with passage of time due to silting/sedimentation, but laterally some improvements and different management program were implemented to increase its useful life. By implementing watershed management program and construction of debris dam results in reduction in accumulation of silt in the reservoir and resultantly its useful life was increased to 100 years.

2.5. Modification in runner design

Improvements and development in mechanical design has also improved the performance of the hydroelectric turbines. Henceforth some

examples are discussed by considering improvement in runner designs.

Example of Outardes-3 project [15]

Outrade-3 power station is on Outarde's river, in Canada. This power plant has started its commercial operation 1969. Rehabilitation of the four turbines has been done in 2016 [15]. They designed the new turbines which operates at 180 r.p.m and these turbines generate a maximum of 260MW with the same net head, the maximum opening angle of the wicket gates and water discharge area were increased, which enhanced 30% of its power output [15].

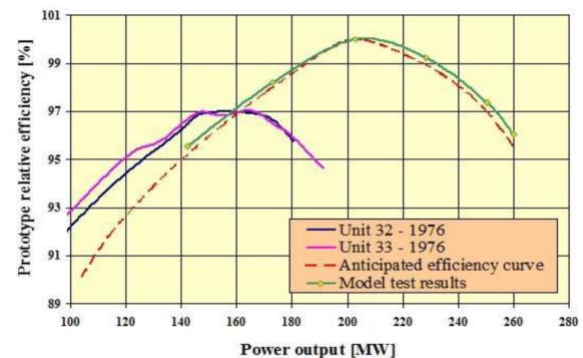


Figure 2. 1: Efficiencies of the model tested, guaranteed and original design [15]

Case study of Shasta project [15]

This hydel station, which is situated on the Sacramento river near California, USA. This power plant was operational in 1944, Unit No 3 to 5 were required to be rehabilitated [15]. The power output of the original design was 133 MW having 145m head while the challenge was to design a new runner to obtain 144 MW of power under 129.5m head [15]. The required increase in the maximum power factor according to the new

head was 28 % [15].

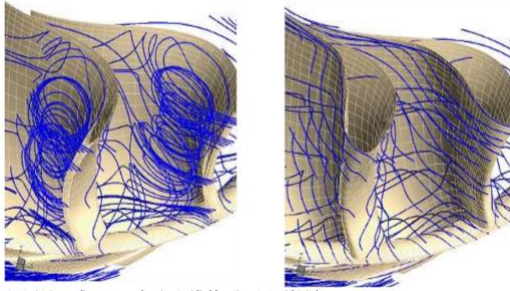


Figure 2. 2: high nED flow pattern for classical (left) and optimized (right) runner [15]

The design of the runner blade shape was amended having greater blade thickness at the leading edge with much optimum flow patterns at low head as shown in the right of Figure 2.2.

Calculations of the Model test showed that the results of the viscous calculations have better performance on the thicker runner as can be seen in figure 2.3.

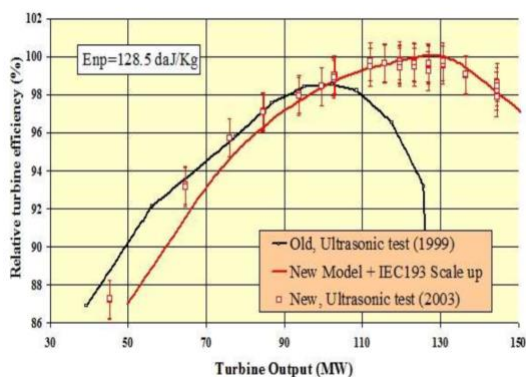


Figure 2. 3: New model was tested with increasing load [15].

3. WARSAK DAM CURRENT SCENARIO

However, the power generating capacity of

Warsak hydro power plant has been reduced to 193 MW. It is due the following reasons mentioned below.

3.1. Siltation/sedimentation

The major problem of Warsak hydro station is silt/sediment, which results in greater loss in generation. There is no proper method of removing silt from the reservoir. The useful life of the reservoir has decreased due to great quantity of silt/sediment and other trashes flowing in Kabul river.

This water when passes through turbines causes great degree of wear and tear in under water parts which results in loss in generation.

3.1.1. Run-off-river.

Approximately after 5-years of commissioning of the project, the basin of the dam silted up to the crest of the spillways, there is no proper technique of flushing it out.

The average annual flow of the kabul river at Warsak Dam is 650,000 million cubic feet which is about 109 times higher than the initial capacity of the reservoir[29]. At present The warsak dam is now considered as run-of river type.



Figure 3. 1: Loess: accumulation of silt forming

plain surface.

3.1.2. Choking effect

The intake to the powerhouse is heavily silted, that creates the issue of deterioration in the moving parts of the turbines and the valves. There are four trash racks in each section and each trash rack is 11ft, they do not allow trashes greater than 5-inch. Cleaning of trash rack is a great problem in Warsak Dam. Currently three of the trash racks of each section are chocked/blocked with trashes and sediments, only one trash rack of each section which is 11ft allows water to the turbines, due to which the water flow is less as compared to requirement for the turbine specially in summer season when all the turbine are operational, sucking of water is more than supply which results in choking (an air gap/vacuum is formed), which is hazardous for the power tunnel, blasting of tunnel is possible when vacuum is created due to less inflow of water. Due to this choking effect, the turbines should be turned off for the safety of powerhouse at peak water season while the inflow is abundant, this is a great loss that we are capable to generate but due to formation of air gap(choking) we reduce the generation or turn off some turbines.

3.1.3. Erosion Effect

Hence, the concentration of silt and sediment is very high, results in very bad quality of water. The concentration of silt and sediment in river flow also affects the mechanical parts of the turbines; erosion of the underwater parts occurs, which reduces the lifetime of the mechanical parts also its efficiency.



Due to high concentration of silt in river flow wear-and-tear usually occur in following components of the turbine, in runner, bottom ring, head cover, wicket gates, Wicket gates levers, Servomotor bearings, butterfly & spherical valves, Wearing rings of turbines, Shaft Seal, spiral case and other mechanical parts of the turbine.



Figure: Erosion in underwater mechanical parts

3.2. Structure Deformation

After some years of commissioning of the four units in 1960, the powerhouse has exposed signs of differential settlement in the form of opening of building joints and cracks that showed up in the floor and walls in parallel with the problem of unbalanced arrangement and change in clearance of the turbines.

However, WAPDA had started the process of investigating cracks. A Canadian consultant were hired from 1984 to 1986 who also installed additional instruments. They concluded that the cracks and distortions in the powerhouse have been the result of Alkali-aggregate reaction [8]. The changes in the building structure and movement are still in progress even though at a very slow rate. AAR has changed the alignment of the trunnions and guides [8].

3.3. Head Loss

Generally, turbines of Warsak powerhouse are designed for the head of 144ft to generate electricity to its rated capacity. In Warsak powerhouse head loss occurs due to two reasons:

- Tail race level increases
- Due to choking effect

3.3.1. Tail-race level

When all the turbines are under operation the outflow from the turbines and the excess water from spillway gates met at same place which results to the rise in level of the water at the tailrace max up to 11.7ft in flood season. When tail race level increases, the net head reduces, which has great impact on generation.

$$\text{Net head} = \text{head-race level} - \text{tail-race level}$$

This is major problem which significantly reduces the generation.

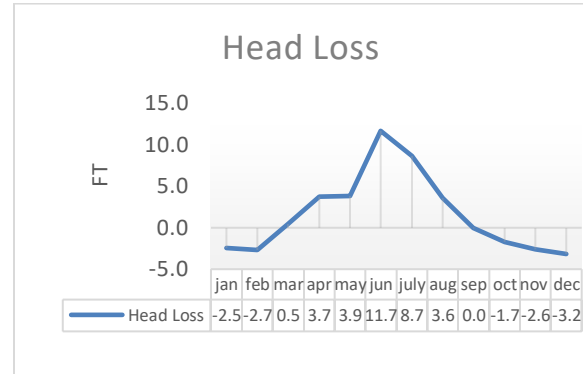


Figure 3. 2: Head loss graph monthly wise due to increase in tail race level.

3.4. Stator/Armature Winding of Machine

The stator or armature winding should be capable of withstanding higher electrical and mechanical stresses and has better thermal conductivity.

3.4.2. Winding used in Warsak.

Two types of windings were installed at Warsak power station. The windings of unit 1-4 were installed in 1960, they were capable of carry load of 40MW (2100Amps) at unity power factor. While the windings of Unit5-6 were installed in 1980, they were designed to carry load of 41.42MW at 0.85pf (2500Amps). the lifetime of these windings has also completed. As most of the load are inductive in nature, the windings are needed to be replaced because when the voltage is depressed the current requirement is more and the existing winding are not capable to supply the required current in accordance with the rated power.

4. MITAGATE THE EFFECT

Though, with properly implementation of the mitigation measures, most of the adverse

environmental and social impacts of hydroelectric project can be reduced to a very acceptable level.

4.1. Reservoir sedimentation

Warsak reservoir has been ultimately completely silted up to the peak of the spillways. Studies carried out by WAPDA pointed out that more than 80% of bed sediment load passes through the intake structure [8], results in erosion of turbine components. Currently, Warsak does not have the facility to remove the sediment deposited in the reservoir. Sediment has blocked its intake passage up to 75%.

Based on the review of previous sedimentation studies of the Warsak reservoir as well as from studies of work in other power stations, the following options are considered:

- i The consultant proposed dredging technique for sedimentation/siltation load in Warsak, it is very expensive method.
- ii Since 1976, WAPDA has introduced a reservoir flushing method. It is done only for few hours one in year, in an attempt not to reduce the generation. Its effect on silt omission is limited and does not last over the whole year.
- iii Various possible alternatives have been studied that include lowering of one or more gates of the spillway so that low level flushing outlet has been available.
- iv Making the diversion tunnel lower than the spillway gates was also considered so that the

path will be provided for flushing out of silt and sediment load.

- v Installation of a new trash rack cleaning machine to serve the existing trash racks [29]
- vi Implementation of new sediment flushing structures hoppers type to reduce sediment flow and deposition into the area located between the skimming wall and the trash racks [29].
- vii Build a new flushing structure in front of the intake and tunnels to transport the sediments downstream of the spillway [29].
- viii Regular draw down of the water through spillway gates can flush out the silt of the reservoir up to a great extent. However, timely loss of generation can be sacrificed but that it can be compensated through silt free water to the turbines. Thus, the expenditure on the heavy mechanical parts would be reduced and the equipment's will be having a long life and better generation in the long run.
- ix To implement Water shed management program as implemented in Mangla to control soil erosion. However, in Pakistan a watershed management program implemented by WAPDA in Mangla reservoir has reduced sediment load to 27,747 acres feet/annum from 42,000-acre feet/annum [16].

4.2. Water Quality Improvement

As the soil erosion is more the sediment load will be more in water it also fills the reservoir (loses its storage capacity). Thus, to reduce

sedimentation first we have to improve the quality of water using different techniques.

- i Adoption of soil and water conservation measures will reduce the average soil erosion rate.
- ii Converting all lands in steep areas with gradient more than 60% to forests will result in decline in soil erosion rate.
- iii Converting of agriculture lands to forests will contribute in reduction of soil erosion rate.
- iv Protected areas are sometimes established in upper catchments to reduce sediment flows into reservoirs, as with the Fortuna Dam in Panama and the proposed Rio Amoya (Colombia) and Nam Theun II (Laos) projects [18].
- v If effectively watershed management is implemented, it can minimize sedimentation rate and hence water quality will improve. In Mangla, watershed program was implemented and 93% of the sediment load was reduced.

4.3. Head loss Issue

The generation is also affected by head loss, by solving the head loss challenge due to tail race, the generation will be improved by 23%, as the water is abundant in flood season but the power generation in that months is less as compared to less water flow months as can be seen in the figure 5.1 the discharge rate of water is higher but the generation is not as much as according to available discharge.

Reason for this is the head loss problem is because of the rise tail race level. As in Tarbela and Mangla the spillway gates and the discharge from turbines flow through different paths so it does not affect the generation.

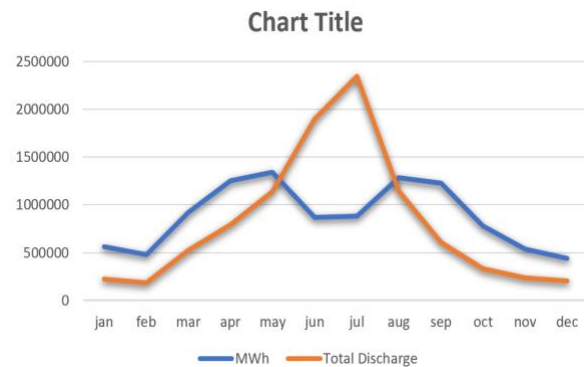


Figure 4.1: Month wise discharge vs power generation

- i Making the diversion tunnel lower than the spillway gates was also considered, so that the path will be provided for flushing out of silt and sediment load and the outflow from the tunnel would be at the distant from the outflow of the turbines so the head loss will be reduced.
- ii Sediment problem will be solved using different techniques, with which choking effect can be eliminated, so the effect on the generation due to head loss will be removed.
- iii By making different path for the flow of excess water through spillways (as in

Mangla and Tarbela) is also an option so that it will not influence the water at the tail race.

4.4. Winding Improvement/Replacement

The windings of the first four generator turbines were installed in 1960. However, the Useful life of these stator windings are 40 years [29]. These windings have completed its useful life and needed to be replaced. Presently these windings are not capable of carrying full load due to its useful life is completed and some other factors (air gap reduced or disturbed, insulation weakens) they usually trip in summer (reaches to its temperature limit) before attaining its maximum generation point, due to which it is not capable to carry load or generate up to its installed capacity. They are needed to be replaced with windings capable of carry more load and having good insulation property. Thus, the windings would be capable of carrying maximum load or generate up to its installed capacity. In this way the generation of the turbines can be improved.

Replacement of the stator windings in the generator will be more beneficial, it will increase the installed capacity of the generating units. It will also recover the cost of the windings within few years. The cost of

new stator windings is Pkr 300 million according to General Electric company (GE), which will be having the capability to improves the generating capacity up to 6MW, which in turn will generate additional 6000 unit/hour. Thus, it will generate 52,560,000 units annually. The per unit price decided by NEPRA for Wapda Hydrel is Rs 2 /- therefore it will add Rs 105,120,000 per year in the national treasure. And within three years, it will recover its cost, hence its benefit to cost ratio is 14.

4.5. Improvement In Runner Design

The turbines installed at Warsak power station are old-fashioned (59 years old), upgradation is required for improving the electricity generation. As improvement in runner design as well as in other mechanical parts will enhance the electricity generation. As examples mentioned above in rehabilitation of outrade-3 and shasta projects, improvement in runner design has improved its efficiency by almost 30%.

4.6. Useful lifespan of reservoir of Warsak Dam

i The useful life has been increased by flushing down all the sediments from the reservoir.

- ii By constructing a debris also increase the lifespan of the reservoir as built in Mangla Dam, which increases its useful life from 50 years to 100 years.
- iii By making some path for the sediments to flow out of the reservoir will increase its useful life for unlimited time, as sediments will be removed on regular basis, so the reservoir is not going to fill up with sediments.

5. CONCLUSION AND RECOMMENDATIONS

Just after few years of commissioning of the Warsak dam project, the plant's generation was drastically reduced to the lowest of 150 MW; that is of worst ever efficiency of 60% [30]. When investigated, it was found that the plant is highly sedimented, have high siltation, and have structural deformation. So, WAPDA hydel carried out a rehabilitation project which boosted its efficiency to 90% i.e., 220 MW. A second rehabilitation project is in the pipeline to further enhance its efficiency and generation capability.

This paper concludes that generation is affected because sedimentation, siltation, structure deformation and climatic condition. By removing sedimentation, it will be capable of storing water in flood season and

that can be utilized at peak and demanding hours. More dams should be constructed on such river which has less siltation, or some proper method should be adopted to clean the reservoir to avoid the generation losses. Silt/Sedimentation will be minimized using following techniques by opening diversion tunnel which is at the riverbed level (1128ft), it will flush out sediments from the bottom of the reservoir. Installing hopper system for flushing of silt. By Head loss issue will be reduced by opening diversion tunnel in flood season so the extra water will move through it and the tail race level will not raise, generation loss will minimize. Installing advanced runners will enhance the generation capacity of the turbines. Replacement of windings with advanced will also improve its generation capability. Reservoir developments help the world to fulfill the food and fiber Requirements. It also has an essential role in accomplishing the irrigation demands of the nation as well because they can be used in flood control measures. They can also be used for generation of power from hydro, which is also the cheapest source of the energy in the world due to huge social and economic benefits of the reservoir, new reservoirs are constructing in the world.

5.1. Policy recommendations for improving water quality.

Some different strategies are discussed below to reduce soil erosion and minimize the problem of siltation which is the major problem faced by Warsak hydro project and to enhance the electricity generation. The siltation has increased the mechanical maintenance cost and has reduced the useful life of the parts of generators.

- By implementing soil and water conservation action will minimize the erosion rate of a soil by 23 percent [20].
- By converting slope cropland into grass/forest and terraced field will reduce soil erosion up to 16% [20].
- There will 11 percent of reduction in soil erosion if 1/10th of the agriculture land is converted into forest [20]
- In 2006-2010 policy is invented to reduce soil erosion, it has been reduced by 20 percent on rain-fed cropland and the total decrease in soil loss was 32 percent over local evaluations [31].

If the above strategies can be followed properly the sediment and the erosion rate will be reduced to minimum and it will contribute in the economic benefit to its maximum value and electricity generation will be improved.

The very most important mitigation measure for hydro projects is selection of good site and to ensure that the dam which is planned is harmless and the benefit from this hydro-project will be great in future. It is important to consider and measure all the negative environmental components before construction of a dam, and most of the negative effects can be either eliminated or reduced by selecting a good site for the project [18].

5.2. Strategies to be followed in the upcoming projects.

By considering this issue the following measures should be considered before construction of large dams.

1. Sedimentation/siltation is the major problem faced by Warsak Dam. Proper survey should be done on water quality and quantity of silt in rivers on which dams would be constructed.
2. Construction of large dams are costly, Proper techniques should be applied to reduce silt/sediment quantity (water shed management program) otherwise construction of large dams (reservoirs) is useless on such rivers because it will lose its useful life in few years and will not serve its purpose properly.
3. Hydro project construction on rivers which are heavily silted will have high maintenance

cost which will resultantly increases the cost of electricity.

4. Proper flushing techniques for silt/sediments should be implemented at the time of construction so the problem of losing reservoir useful life will be resolved.
5. Tunnel should be constructed at the base of the reservoir for flushing of silt.
6. Proper survey should be done so that dams should be constructed on such rivers which has less siltation.
7. Debris dam should be constructed to control or reduce sediment level up to some extent.
8. Tailrace and spillway gates should be constructed at different location so that the outflow from the spillway gates will not increase the water level at the tail race. Hence head loss that occurs due to increase in TRL (i-e Warsak power station) will be eliminated.

Tail race and spillways	Waving wall needs to be extended. In future power plants, spillway and tailrace must not be constructed together to avoid head losses.
Choking due to trashes	Log boom installation
Structural deformation	Further research work is required.

Table 2.1: Possible solutions of the problems of Warsak hydro project.

Complications in Warsak	Possible solution
Sedimentation	Dredging techniques Debris Dam Water Shed Management Diversion tunnel Hopper Structure
Useful life of reservoir	Sediment reduce/flush out
Runner design modification	Blade profile amendment Increase in discharge through Runner Blades
Heating of armature windings	Replacement of Stator Winding

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