(ii) Identify drainage problems and opportunities;

(iii) Prepare recommendations for bringing drainage towards integrated water resource management.

3. DRAINAGE DEVELOPMENT

When the Indus Basin was developed for irrigation, the drainage needs were quite minimal. Industries were negligible and population was very less. The drainage needs, however, increased considerably over time as more and more irrigation water was supplied. Starting the late 1950's, Salinity Control and Reclamation Projects (SCARP) were implemented to address the problem of waterlogged irrigated land. Some 16,589 large deep tubewells were installed to control the table. Of these about 12,746 were fresh groundwater wells and 3,843 saline groundwater wells (Table 1). At present, drainage system has been provided in a total area of about 16.2 Ma. Subsurface pipe drainage system serves an area of 0.84 Ma (WAPDA 2005).

The extensive use of groundwater for irrigation started with the installation of the SCARP tubewells in the 1960's, soon followed by the explosive development of tubewell installation by private farmers The annual groundwater abstraction used to be in the order of 40 MAF but under the current drought conditions, the pumping has increased to 55 MAF, which compares to an estimated groundwater recharge of about 60-65 MAF. Only some 7 MAF of this recharge comes from rainfall while all the other recharge is made up by the irrigation water losses. Similarly groundwater use for domestic and industrial purposes has enormously increased.

Table 1: Existing Drainage Facilities (Upto June, 2004)

Province	Area with Drainage		Surface Drains (km)	Subsurface Drainage						
				Tubewells (Numbers)			Intercept or Drains (km)	Pipe Drainage		
	G.A (Ma)	CCA (Ma)		FGW	SGW	ScW		Length (km)	Area (Ma)	
									GA	CCA
Punjab	10.850	9.601	3883	8065	2256	-	6	2810	0.235	0.203
Sindh	6.732	5.710	9185	4190	1587	361	154	2046	0.045	0.036
NWFP	0.884	0.725	971	491	-	-	-	7756	0.658	0.527
Balochist an	0.177	0.161	322	-	-	-	-	-	-	-
Total	18.643	16.197	14361	12746	3843	361	160	12612	0.938	0.766

Source: WAPDA, 2005.

The present drainage infrastructure is, however, not sufficient to meet all drainage needs of agriculture, municipal and industrial. Considerable prolonged flooding and ponding still occurs, as the surface drainage system is not dense enough to connect all depression areas to main drains. Various types of flow blockages and poor maintenance also adversely affect the functioning of many surface drains. The provided subsurface pipe drainage needs to be extended to cover more of the waterlogged and salinised land.

4. CAUSES OF WATERLOGGING, SALINITY AND POLLUTION

Waterlogging (Figure 2) and salinity (Figure 3) are the principal threats to the sustainability of irrigated agriculture in Pakistan: 12% of the gross commanded area (GCA) is waterlogged with a pre-monsoon groundwater table depth of less than 5 ft (150 cm). About 25% of the surface soil is saline, of which 6% is moderately and 8% severely saline.

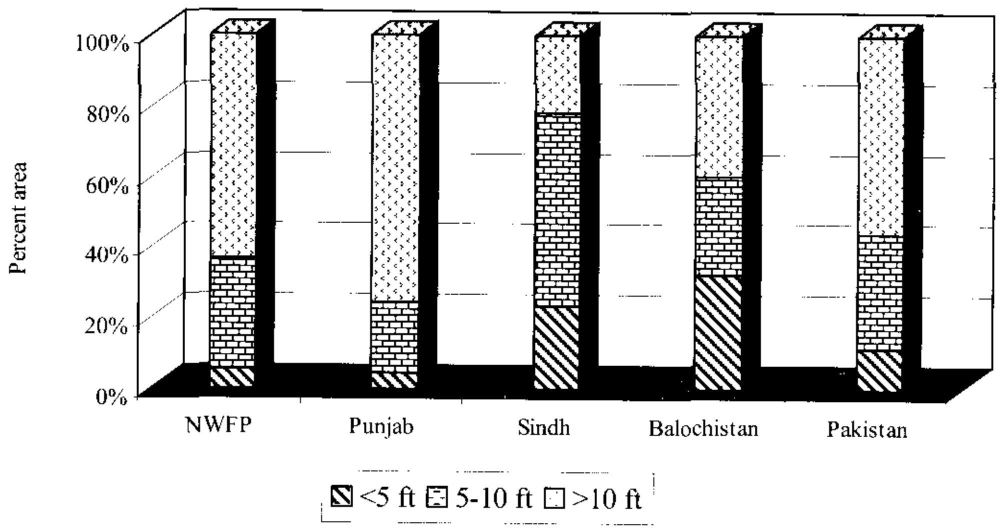

Figure 2: Groundwater table status in Pakistan (1993-2002)

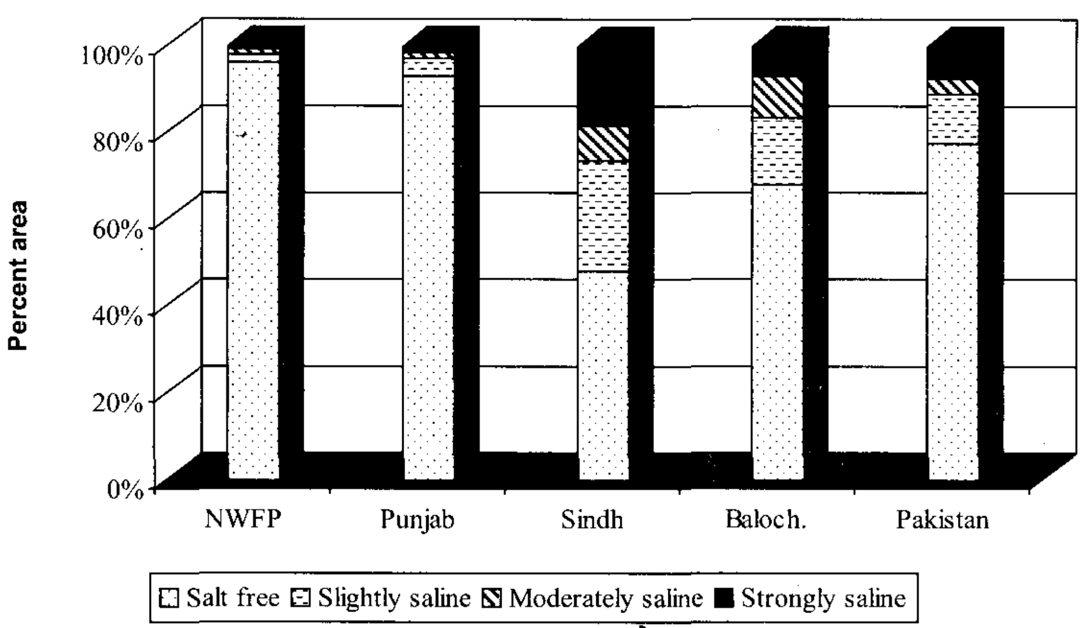

Figure 3: Surface salinity in the Indus Basin (2001 -2003)

The principal causes of waterlogging and salinity are poor water management over-irrigation, low efficiency of the irrigation systems and inadequate drainage measures. The arid to semi-arid climatic conditions prevailing in Pakistan also lead to accumulation of salts in the rootzone. In addition, irrigation supplies add salts every year to the rootzone. Groundwater pumping, which is unregulated, further aggravates the situation by mobilizing salts dissolved in the aquifer to the soil profile.

The salts presently occurring in the Indus Basin are of different origin. Firstly there are the fossil salts deposited during the drier period in the geological formation of the Indus plains. These salts occur at various depths in the substrata and in the groundwater. Secondly there are the marine salts originating from the deltaic alleviation in a marine environment. Most of the salts in the substrata and groundwater in Sindh Province are of this origin. Thirdly there are the salts imported by the Indus River water. Although this water is mostly of low salinity (only some 200 - 300 ppm at Tarbela and other Rim stations), it nevertheless adds some 35 milion tons (Mtons) of salt per year to the irrigated land. Minor salt sources (salts released by mineral weathering, imported by the applied fertilizers and by the rain, etc.) are generally too insignificant to be considered in the salt management planning. Most of the fossil salt is safely stored at deep depths but some is mobilised by the ongoing tubewell pumping and by the deeper groundwater flows. These mobilised salts then become part of the salt dynamics of the rootzone and underlying shallow groundwater zone, mixed with the marine and imported salts.

Table 2 indicates the volume of agricultural saline effluent and wastewater production. The main sources of pollution in order of their magnitude are the municipal effluent, industrial effluent, agricultural saline effluent and commercial waste water. The pollution in the Ravi River and the Fuleli Canal, which pass through Lahore and Hyderabad, respectively are the highest due to municipal and urban effluents. None of the cities in Pakistan, except Karachi and Islamabad, have functional wastewater treatment facilities.

Table 2: Saline effluent and waste water production in Pakistan

Sr. No.	Source	Volume		Reference
		MAF	percent	
1	Industry	0.32	6	NNWC and WWF 2000
2	Commercial	0.24	5	NNWC and WWF 2000
3	Urban residential	1.32	25	NNWC and WWF 2000
4	Rural residential	2.48	48	NNWC and WWF 2000
5	Agricultural	0.84	16	WAPDA 2005
	Total	5.20	100	

5. EXISTING AND FUTURE WATER MANAGEMENT

Water using sectors are agriculture, drinking water supply and sanitation, industry, fishery, environment and recreation. A growing population and a rising level of economic activity increase demand for water. Pakistan's population in year 2002 was 140 millions and in the year 2025 it is estimated to be 220 millions. There will be greater demand for food, fiber and increased economic activity. Economic activity and development affect income, its distribution and life styles. Development, technological changes, income distribution and life style affect the level of water demand. Water use by different sectors in the year 2000 and the requirement by the year 2025 are given in Table 3.

The growing competition among the various sectors is evident from Table 3. Demand for agriculture sector shows an increase of 28 percent over the existing use. For water supply and sanitation, the increase for next 25 years is 100 percent indicating heavy urbanization and development of rural water supply. Overall, 37 MAF of more water would be required by year 2025 to sustain the development requirements. All these uses generate drainage effluent but at present only agriculture sector is held responsible for drainage effluent disposal.

Table 3: Water Use by Different Sectors in Pakistan

Usage Sector	Existing Use (Year 2000)		Requirement (Year 2025)	
	Total (MAF)	Percent	Total (MAF)	Percent
Agriculture	100.0	90.6	128.0	86.9
Urban water supply and sanitation	5.2	4.7	10.5	7.1
Industry	2.2	2.0	3.5	2.4
Environmental/Recreation	1.3	1.2	1.7	1.2
Rural Water supply	1.6	1.5	3.6	2.4
Total	110.3	100	147.3	100

Source: National Water Policy – ACE – Halcrow, December 2002.

6. IMPACT OF WATERLOGGING AND SALINITY

The rise of table near the ground surface in certain areas, and the consequent soil salinization continues to be the cause of serious environmental problems associated with irrigation in the Indus Basin. The impact of salinity on agricultural productivity is severe; a 25% reduction in the production of Pakistan's major crops is attributed by many experts to soil salinity alone. In Sindh Province, where the problem is much more severe, it is estimated that the impact may be closer to 40 - 60%. The critical threshold at which salinity begins to affect the productivity of agricultural land varies by crop. Similarly, the impact of waterlogging on yields is alarming. A high watertable inhibits root growth and therefore reduces crops yield.

Waterlogging and salinity have very adverse social and economic effects on communities causing poor living standards in affected areas, health problems for humans and animals, crumbling of mud and brick houses and traffic difficulties. Many people are forced to migrate to other areas. Reclamation of affected lands is therefore essential for the sustainability of agriculture in the country.

The municipal and industrial waste waster is being disposed into irrigation and drainage network, which is used by agriculture, human and animals. This is causing loss of lives of human being and animals.

7. ENVIRONMENTAL IMPACT

The environmental issues of the drainage include: waterlogging and salinity, groundwater depletion, saline effluent disposal, deteriorating water quality of water bodies due to disposal of the increased quantity of sewage, industrial toxic wastes in the irrigation and drainage system. Groundwater quality and resettlement issues relates to the construction of main drains.

The drainage development and water management project affects the physical, biological and socio-economic set-up of an area. The impacts may be positive or negative and minor to major in magnitude. A major positive environmental impact of the drainage would be the rehabilitation/ reclamation of affected lands and increase in crop yield. Prevention of disposal of untreated industrial and municipal sewage into the drainage system would be another significant positive achievement. But this can be only achieved by integrating municipal, industrial and agricultural sectors to drainage development and water management.

While the overall impacts of drainage are positive, there are a number of negative impacts also, which will require determination of mitigation measures at the time of detailed studies of individual drainage basins. Protection of wetlands and Environmentally Significant Areas (ESA) is one such field, which requires special attention during the project design and implementation.

8. ISSUES AND OPTIONS FOR DRAINAGE

8.1 Waterlogging and Salinity

The available waterlogging data indicate that the trend of annually increasing affected areas of the sixties and seventies has come to a halt and in large parts of the basin is even on the reverse. While the halt may well be attributed to the various preventive and remedial measures undertaken in the past, the reverse is at least also partly due to the prevailing drought conditions of the last 4-5 years. The extent of the waterlogged area has decreased, with currently only some 10% the land being classified in the disaster category, pre-monsoon groundwater table depth of <5 ft. The impact of drought conditions on the soil salinity has been less apparent in the recent salinity data. The seriously affected area currently indicated to be in the order of some 10-15%. By far the most of the waterlogging and salinity affected area is located in Sindh Province. Efforts needs to be strengthened for salinity management in the coming years.

8.2 Salt Balance

Salt balances provide insight in the ongoing salt movement, accumulation and disposal processes. The available salt balance data for the Indus Basin clearly indicate that the rate at which salts are imported and mobilised exceeds the rate at which salts are being disposed to the sea or to other ultimate salt sinks and that salts on aggregate are accumulating in the basin. Not all of this salt accumulation in the basin is necessarily harmful and a much more disaggregated understanding of the salt accumulation processes and mapping of the accumulation sites is necessary before a final assessment of the significance of the salt balance figures can be made. However, in the meantime, salt leaching, drainage and disposal measures may justifiably be taken at local level where harmful salt accumulation is occurring. There is a dire need to study salt balance/movement in soil profiles and groundwater.

8.3 Disposal and Management of Saline and Polluted Effluent

Each drainage basin has its own drainage characteristics depending upon topography and geo-hydrological conditions. Therefore, drainage facilities must be provided after thorough investigation of the problems and studying the agro-socio-economic and environmental impacts of the recommended plan.

In the SCARP-VI and the Fordwah Eastern Sadiquia South (FESS) project evaporation ponds have been provided to dispose the saline effluent. SCARP-VI evaporation ponds have many adverse effects on the environment. The disadvantages are: loss of land, seepage and deep percolation of saline effluent. The ponds, having a large water surface area attract and become a breeding heaven for mosquitoes, flies and other insects. Though evaporation ponds provide an option for disposal of drainage effluent they can only be considered as an interim measure. The limitation of reduction in effluent storage capacity due to salt built up and associated environmental hazards disqualify this method as a long-term solution. Recent studies have indicated that the volume of waste water of municipalities and industrial sectors has increased than agricultural drainage effluent.

The options for dealing with saline effluents include reduction in recharge through canal and watercourse lining, land levelling, improved irrigation scheduling and improving on-farm water application practices, reuse of effluents, re-cycling of effluents, disposal through seepage wells, desalinisation, development of saline agriculture, drainage water treatment, treatment of municipal and industrial effluent, evaporation ponds and disposal to the sea. Management of saline effluent within the basin through local use should be preferred. This will need integrated water resources management.

8.4 Groundwater Regulation

Regulation of groundwater is not only an institutional issue but also a water management issue, as groundwater extraction in the Indus plains is very much dependent on surface water availability. The irrigation duties may need to be looked at to manage both groundwater and drainage conjunctively. Municipal and industrial water supplies mainly depend upon groundwater. The needs should also be integrated.

8.5 Sustainability Cost Recovery

The main problem in drainage has been the inadequate maintenance of surface and subsurface drains. Ideally all tertiary and on-farm drainage systems should be implemented, financed and maintained by the farmer's organization. The available in-country experiences indicate, however, that this foreseen role of the private sector is a highly optimistic expectation. This applies especially to the installation of subsurface (pipe) systems. This reliance on the private sector, therefore, introduces considerable uncertainty into drainage development and water management. The option of government financing of field drainage on the basis of full cost recovery of the initial investment might be considered. However, farmers involvement in planning, construction and maintenance will give sense of ownership to them. This will also bring down the investment cost.

8.6 Storm Water Drainage

Drainage can not be considered to be complete when it does not also deal in equal depth with the discharge of storm water. Storm drainage seems to have lost its past attention and be overtaken in this respect by salt drainage. The extensive inundation following the high rainfall of July 2003 in Sindh Province may serve as a reminder. Recommendations include the adequacy of the capacity and density of the present surface drainage systems, the disposal and outfall of storm drainage water, suitable drain sections, the balance between rainfall conservation and retention and rainfall disposal, and the merits of providing for holding ponds and wetland restoration.

8.7 Bio-drainage

Bio-drainage and saline agriculture are sensible approaches for problematic areas where conventional drainage and reclamation are not feasible. Considerable research and pioneer work in this field has been done, the bio-drainage and saline agriculture have reached a stage at which it can be confidently applied at the large scale. However, answers would have to be provided to questions such as, how to be implemented, and what would be the role of the private sector and the government, which agencies will be involved, what institutional arrangements will be required, is there enough professional capacity in the country to implement such a large program etc.

9. BRINGING DRAINAGE TOWARDS INTEGRATED WATER RESOURCE MANAGEMENT

Each drainage solution has different impacts on the functions of the land and water resources of Pakistan. The most important functions probably are: agricultural productivity, industrial productivity, suitability for housing and living environment, fish productivity, domestic water production, flood regulation, coastal protection, and seawater intrusion. An assessment of the main functions and how they will change under different solutions would be required. Comparison of alternatives would not only have to consider economic impacts, but also take into account social and environmental values. Such a study will be difficult but has to be carried out with full participation of local stakeholders. Final selection of a solution, will be the responsibility of the stakeholders. The solutions have to be site specific and would have to be determined locally and then be subjected to an effect-impact analysis and discussions of trade-offs, mitigation measures, and alternative solutions that satisfy the stakeholders sharing the resources. National water policy gives enough emphasis for integrated water resource management. Therefore, drainage needs to be brought under the same umbrella.

10. CONCLUSIONS AND RECOMENDATIONS

Drainage plans and projects cannot be taken up in isolation. Drainage and its effluent disposal and management have implications for the downstream users. So drainage needs should be integrated and planned in a holistic manner for the entire Indus Basin. This can only be achieved by bringing drainage towards integrated water resource management. This is also in line with the National Water Policy of Pakistan.

10.1 Conclusions

It concludes that the problem of waterlogging and salinity persists in about 15% of the irrigated areas. The following are the findings:

(i) Drainage problems of other than agriculture sectors are generally not mentioned;

(ii) The disposal of drainage effluent of one basin, may have impact on the water management of other, mainly downstream irrigation basins, and other land and water resources.

(iii) Drainage effluent of municipalities and industries has become more than the effluent generated from agricultural sector. To analyse the situation for the whole Indus Basin, it may be required to have these effluent figures, both the quantities and the quality wise.

10.2 Recommendations

A given area has natural resources that perform a number of functions (goods and services) which are used by society (or different user groups in the society) and therefore have a certain value, to the satisfaction or dissatisfaction of the stakeholders. For bringing drainage towards integrated water resource management, the following recommendations are being made:

(i) the landscapes, their functions, stakeholders and values would have to be known beforehand to be able to identify the problems and opportunities for improvement. Stakeholder participation in this analysis can give the relevant information;

(ii) a physical change (caused by an intervention) in the natural resources has an effect on its functions, and thus an impact on the stakeholders of the functions, because the value of the functions will change;

(iii) an institutional analysis is required to understand whether or not functions match the demands of the user groups and identify the distribution of power and responsibilities for reliable service delivery;

(iv) the cause-effect chains will have to be analysed (intervention-physical change-effect on functions-impact on socio-economic values of stakeholders to assess the consequences of a project and eventually redesign it). Again participation of stakeholders is a prerequisite;

(v) interventions in one landscape may influence the natural resources and the functions and values of other landscapes. This may expand the boundaries for analysis;

(vi) an institutional design of a project will have to be made which responds to the institutional gaps.

(vii) it is, however, worthwhile to mention also the need to examine possibilities for local or regional disposal solutions. Since this can only be done in a study at individual basin level, it would have to be mentioned that a thorough analysis of each drainage basin is required, covering more than drainable surpluses only.

The different functions and values should be considered for preparing a drainage project with an integrated approach to develop natural resources. To be able to do so requires policy support. National Water Policy gives more focus that an integrated approach is part of the policy. Such an integrated approach is the basis for integrated water resource management.

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INTRODUCING MODERN ENVIRONMENT FRIENDLY TECHNOLOGY FOR WATER MANAGEMENT IN CUSTOMARY ENVIRONMENT OF PAKISTAN

Abdul Hakeem Khan, Sarfraz Munir[1], Dr. Hugh Turral[2]

ABSTRACT

The lower part of Upper Swat Canal (USC), which is being supplemented by the Pehur High Level Canal (PHLC) from Indus River (Tarbela reservoir), is a remodeled and modern automatic irrigation system in Pakistan. The water allowance for this system is 0.70 liters per second per hectare, which is almost three times of the conventional irrigation systems. The proposed new concept of irrigation system operations which is known as "Crop-Based irrigation Operations (CBIO)" is management-intensive and crop water requirement responsive leading to controlling groundwater recharge and saving of water and energy.

CBIO schedules were prepared to be implemented during Kharif 2004, however, the offtakes could be closed during the low demand period for only about 15 percent of the proposed closure. The response of water users and irrigation department was good but were taking their time to come out of the decades long experience and habit with conventional operations. Major irritant was tobacco and hybrid maize, which was irrigated every week and did not allow closing the offtakes. Night irrigation varies from place to place and has allowed 31 to 71 percent water either refused by farmers by closing outlets or letting it flow to drains. Return flows in the drains from the area can serve about 7,700 hectares of new land if put into use.

KEYWORDS

Conventional and modern irrigation systems, water allowance, operations, water use, capacity building.

INTRODUCTION

The gigantic and contiguous irrigation system of Pakistan was enormously expanded and formalized during the British era, mostly during the nineteenth and early twentieth century. Pakistan's heavy dependence on irrigated agriculture for

1 Research Officer, International Water Management Institute (IWMI), 12 km. Multan Road, Thoker Niaz Baig, Lahore, Pakistan. Phone: +92 42 5410050, Fax: +92 42 5410054, E-mail: s.munir@cgiar.org

2 Project Leader, International Water Management Institute (IWMI), P.O. Box 2075, Colombo, Sri Lanka. Phone: + 94 11 2787404, E-mail: h.turral@cgiar.org

food, industry and economy has given its irrigation system an important role to play by providing water to about 16.50 million hectares (mha) of land. However, the historic water allowance varied from 0.25 to 0.28 liters per second per hectare (l/s/ha), which could serve only 80 to 100 percent command area during two crop seasons of a year to meet the food and fiber requirements of the area when the system was built 100 to 150 years ago. The challenge of more food for more mouths is being met by bringing more area under cultivation by developing new and modernizing the existing surface irrigation system, and exploiting the groundwater reservoir. Remodeling of the old canals along with the constructions of some new ones has been carried out recently in the North West Frontier Province (NWFP) of Pakistan with enhanced capacity and water allocations for increasing cropped area and productivity. Water allocation of the remodeled and the new canals varies from 0.60 to 0.70 l/s/ha, which is more than double of the old system for serving about 150 to 185 percent area per year.

Operation of Conventional System

The conventional system with lower water allowance had a simple design compatible with the conditions and requirements of the period when it was developed. The comparatively rigid system with minimum human intervention and regulation facilities was supposed to be run continuously at full supply level all the times as long as water was available in the source. Rotations were implemented among the off-taking channels whenever supplies fell short of 70 to 80 percent of the design requirements. Water deliveries did not cater to the requirements of the cropped area or the cropping pattern but was distributed mostly on weekly-turn-basis (warabandi) to the users on the basis of landholding regardless of actual requirements. Day and night irrigation is practiced because the system does not have provisions for storage or for local control. Water is pushed into drains (where available) if not required or the channel has to be closed at head to avoid flooding of tails. Substantial groundwater development has taken place in many canal command areas, especially in the tail sections, since surface supplies could not meet the growing water demand of increased cropped area.

Operation of Remodeled and Modernized System

Irrigation canals with higher water allocations have been designed and constructed with facilities, which can cope with peak water demands on one hand and can satisfy the requirements of the lean periods on the other through mid-system regulation structures. The primary system has this flexible system while the secondary offtakes are expected to operate for almost balancing the crop water requirements, which vary with the stage of the crop. Initial and later stages need less water than the middle peak period and water deliveries in the irrigation system should be in response to each stage taking into account the prevailing weekly warabandi arrangements for water users. Accordingly, the main system gets full supply discharge for a fraction of the crop season while 50 percent, 67 percent and 80 percent supplies are provided during the low demand period. The offtakes are grouped together so that the total discharge of each group is almost equal and each group remains closed for one week during each cycle of operation. The closure does not exceed one warabandi cycle, which is one week in most cases. When crop water requirements are minimum, the system is divided into two groups for 50 percent discharge in the main canal. Both groups remain closed and open for one week each. For 67 percent discharge in main canal for meeting crop water demand, the system is divided into three groups and each group remains closed for one week and open for two weeks, and so on. This type of operation that is being implemented in the Upper Swat Canal (below RD 242) since December 2003 has been termed as crop-based irrigation operations (CBIO).

Concept of CBIO

CBIO is applied in systems with higher water allowance (more than 0.50 l/s/ha) where supplies should almost match crop water requirements. Development of irrigation system operational schedules in accordance with the water distribution arrangements in the system and based on actual cropping pattern and intensity in a command area for a crop season are the basis of CBIO. Contrary to the traditional operational method of continuous supplies where irrigation canals are operated at full supply throughout the year depending on water availability, CBIO is aimed at employing rotational closures of the secondary offtakes during low demand periods for controlling groundwater recharge. Saving environment from waterlogging, water for other uses and energy by releasing only the required volume of water are the easily achievable goals by implementing CBIO schedules in a certain system. Discharge in the main canal is adjusted according to demand either manually or automatically depending upon the infrastructure and is available for delivery into offtakes whenever required. Regulation facilities provided in main canal can cope with the fluctuating demand, which usually, would not change in less than a wrarbandi cycle of a week period. Water users and managers have prior information of system regulation and can adjust their activities accordingly.

Secondary offtakes are grouped into two, three or four depending upon crop water requirements. The total discharge of each group is almost equal. The group of two means that demand is minimum which is 50 percent of the main canal capacity in which case one group of offtakes is kept closed for one week and another open, and vice versa in the following week. Similarly, the group of three means about 67 percent discharge of main canal where one group is closed for a week and the other two are open to be closed turn by turn in the following two weeks, and so on. All the offtakes are open during peak demand period when main canal is run at full supply.

STUDY AREA

The Upper Swat Canal (USC) in the North West Frontier Province (NWFP) of Pakistan derives its supplies from the Swat River, through Amandarra Headworks, for an area of about 111,740 ha (Figure 1). The system has been remodeled by increasing its capacity from 0.34 to 0.70 liters per second per ha to bridge the gap between supply and demand while the design annual cropping intensity has been increased from 120 to 185 percent. About 75 kilometer length of USC (RD 0 to 242) was remodeled under the Swabi Salinity Control and Reclamation Project (SCARP) in 1998, while the remaining portion of about 50 kilometers was remodeled under the Pehur High Level Canal (PHLC) Project in 2002. The system remodeled under the PHLC Project uses automatic downstream control gates (AVIS and AVIO type) installed at about five kilometer intervals. These gates are sensitive to water level and open or close when level falls below or rises above a fixed level. This study has been conducted in the area under the PHLC Project.

Table 1 gives details of the three offtakes selected in the upper, middle and tail reaches of Maira Branch of Upper Swat Canal system. Three outlets were selected along each offtake for detailed crop monitoring.All the three offtakes are different from each other in some respect. The Dagi Disty command soil lies on clay loam, Yaqubi Minor has silt clay loam and Pirsbaq Disty has silt clay loam and sandy loam. Dominant crops are wheat, maize, tobacco and sugarcane with varying degrees of cultivation of each crop in each command. Dagi and Yaqubi command are better drained than Pirsabaq.

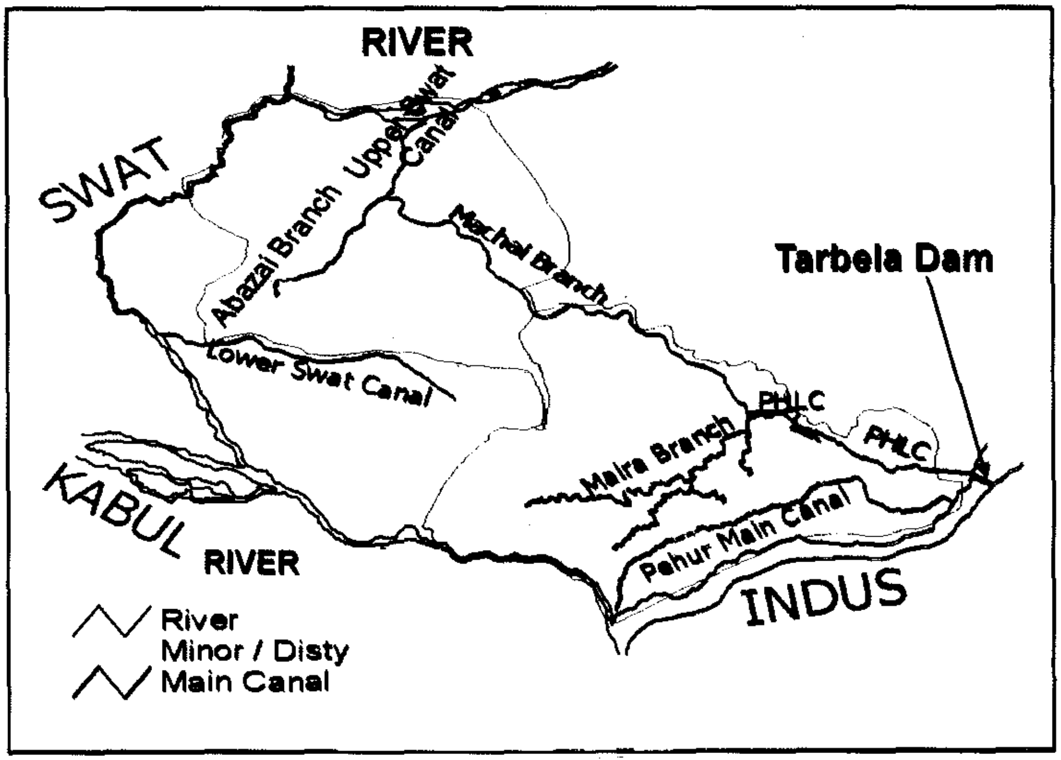

Figure 1: Upper Swat and Pehur high Level Canal (PHLC) system.

Table 1. Capacity of selected offtakes and outlets.

S.NO.	Selected Channel	CCA (ha)	Discharge (cum)	Selected outlets		
				Outlet No.	CCA (ha)	Discharge (cum)
1	Dagi Disty	2464	1.920	3485-R	35.22	0.025
				10450-L	55.87	0.039
				15850-L	61.94	0.043
2	Yaqubi Minor	1354	1.000	2095-R	86.23	0.060
				6300-R	87.85	0.061
				16300-TF	139.68	0.098
3	Pirsabaq Disty	3181	2.391	19020-R	122.67	0.086
				4200-L	31.58	0.022
				15000-TF	103.24	0.072

OBJECTIVES

The new concept of CBIO is being implemented in the PHLC Project area since December 2003, where three main actors are involved. Firstly, International Irrigation Management Institute (IIMI) which has developed the CBIO model and is supporting the second actor, NWFP Irrigation Department, in introducing and implementing the schedules. Water users are the third actor who are used to continuous supplies and are influenced by modern operations. There are two main objectives of this paper.

1. Analysis of CBIO schedules implementation during Kharif 2004.
2. Evaluation of DoI and water users willingness and preparedness in adapting the modern mode of operations.

DATA COLLECTION

Crop water requirements

Crop data of the concerned area was collected from DoI for the past five kharif seasons (1997 to 2002) for initial estimation of crop water requirements by using CropWat version 4.0, Windows Version 4.2 of FAO. The secondary data was updated by actual data collected from the sample offtakes in April-May 2004 where intensity had increased due to increase in water supply after its availability from Indus River through PHLC.

CBIO schedules

The estimated crop water requirements were used for calculating discharge and for developing weekly operational schedules of the system. The boundary condition of seven days (one week) has been applied due to the prevailing warabandi system for water distribution at the tertiary level. The offtakes were grouped into two, three, four, etc. of almost equal discharge depending upon water requirements.

Minimum discharge in the main canal is about 50 percent of design when the cycle of two weeks is operative where one group is closed and another is open. Similarly, the discharge is about 67 percent of design when three weeks cycle is going on where one group of offtakes is closed and two are open to be closed in the following weeks one after the other, and so on. The system is run at full supply during the peak demand period.

Grouping and clustering

Secondary offtakes are grouped and then clustered of almost equal discharge so that the canal could be run without frequent fluctuations for longer durations.

Direct outlets' operation

There are 62 tertiary outlets withdrawing directly from the main canal. Most of them are ungated and are, therefore, very difficult to regulate flows into them. These outlets are often difficult to be included in the rotation cycles of CBIO schedules implemented during low demand period. Their full supply design discharge is 1.33 cumecs (47 cusecs) and are assumed to be drawing the design discharge only.

RESULTS

Cropping Pattern and Intensity

The Project area has a diversified cropping pattern during kharif. Usually, farmers try to cultivate as much area as possible because water availability is not a big problem anymore. The upper part is mainly cultivated with tobacco (local variety plus Virginia) maize and sugarcane. Middle part is mainly Virginia tobacco, maize and sugarcane while the lower part is occupied mainly by maize, sugarcane and tobacco. Intensity of each crop from the results of sample survey in the selected offtakes is given in Table 2.

Table 2: Cropping pattern in selected offtakes of Maira branch Upper Swat Canal, in Percent.

Offtake	Percent of Cropped Area						
	Tobacco	Maize	Sugar Cane	Vegetables	Fodder	Other Crops*	Fallow
Dagi Disty	34.62	56.53	1.33	0.74	3.87	2.57	0.34
Yaqubi Minor	43.10	48.84	4.15	0.55	2.07	0.60	0.69
Pir Sabaq Disty	5.03	64.57	6.65	12.59	6.60	1.32	3.24

*Other Crops include melons, peanuts and sugar beet, etc.

Maize is sown on area vacated by wheat, local tobacco and early Virginia, which is evident from Table 2. Dagi Disty has more local tobacco than other offtakes while Pirsabaq Disty has comparatively small area under tobacco but higher vegetable intensity.

CBIO SCHEDULE IMPLEMENTATION

The schedule was prepared based on water requirements for the prevailing cropping pattern and intensity in the area. In all, there were seven rotation cycles comprising of one three-weeks cycle, four four-weeks, two six-weeks cycles during kharif 2004. Each secondary offtake was supposed to remain closed for 6 to 7 weeks i.e. one week in each cycle out of the total 26 weeks according to the proposed schedule. However, the actual operation did not match the proposed schedule. Each offtake remained closed for different number of days as shown in Figure 2. Sadri Minor was the highest closed with about 44 percent of the proposed duration followed by Ghazikot Minor with 35 percent closure. Sarbandi Minor, Gumbad Minor II and Toru Minor remained open throughout the season. Generally, the offtakes were closed for about 15 percent of the proposed duration while the system should have remained closed for about 23 to 25 percent of the season.

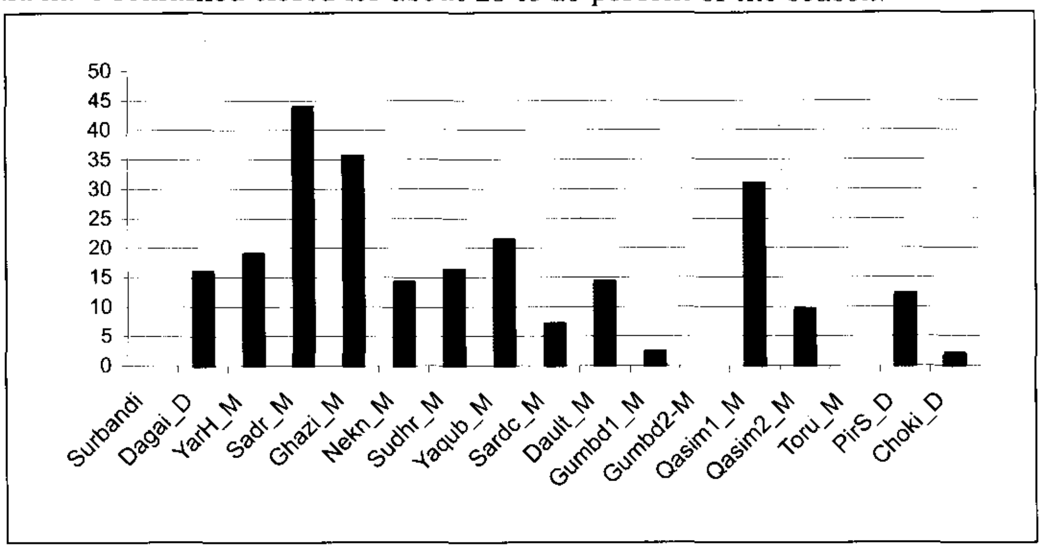

Figure 2: Actual closure of offtakes concerning CBIO schedules.

Water users' insistence on irrigating tobacco every week and the cultivation of hybrid maize that require frequent irrigation, were the main causes for violating the schedule. The two major tobacco companies in the area, Pakistan and Lakson, have differing opinions on frequency of irrigating tobacco. Pakistan Tobacco Company advocates water stress on the plants for better quality having more nicotine while Lakson continues with weekly irrigation. Political influence for keeping the system open also has a role.

CUSTOMARY ENVIRONMENT

Conventionally, the Upper Swat Canal and other irrigation systems in Pakistan are continuous supply-based systems, which run twenty four hours a day and seven days, a week throughout the year depending on water availability, except January when canals are closed for maintenance purposes for about one month. The modern and automatic system below RD 242 of Machai Branch of Upper Swat Canal with assured and increased supplies is supposed to run crop-demand-based where rotational closures are introduced during low demand periods. However, the creation of general environment and changing the old mindset for implementing such operations are going to take its time. The awareness and education program about CBIO was initiated well in time before and during the Kharif 2004, but its acceptance and proposed implementation was not according to expectations for different reasons like avoiding night irrigation, natural resistance of stakeholders to accept change and problems with system operation. Conventionally, unwanted water is allowed to flow down to drains due to good natural topography while the new automatic system can store water to a certain extent as well as can adjust the system at head according to demand.

Manual operations

The Pehur High Level Canal is automatic and should be run accordingly as it adjusts the gate opening according to the demand of the downstream system. But, the actual operation was manual for much of the kharif season for different reasons leading to low water level in Maira Branch and subsequent less withdrawal by offtakes. Sometimes, mal-functioning of automatic gates and interventions by less experienced staff of operating agency also adversely affected the operations.

Night Irrigation

The prevailing water distribution system at the farm level in Upper Swat Canal and other systems in Pakistan is based mostly on weekly turns for fixed durations proportionate to land holdings and day-night irrigation. These water turns rotate from day to night and vice versa every year to avoid continuous night irrigation sufferings for certain farmers. Night irrigation has been declining after increased supplies have been made available. Table 3 shows the results of night irrigation monitoring on selected offtakes. Water users on Dagi Disty have used only 29 percent of water at night, Yaqubi Minor has used about 57 percent and Pirsabaq Disty was more efficient with about 85 percent use at night.

Table 3: Night irrigation monitoring in selected offtakes of Maira Branch, Upper Swat Canal.

Offtake	Water used in percent		Water not used in percent		
	Irrigation according to warabandi		Water goes to drain	Out Let Closed	Not Observed*
	Yes	No			
Dagi Disty	7.84	21.57	37.25	21.57	11.76
Yaqubi Minor	48.57	8.57	22.86	11.43	8.57
Pirsabaq Disty	62.96	22.22	3.7	11.11	0.00

*Not observed due to heavy rainfall, which has been assumed as not used.

Water Users' Response to CBIO

An aggressive water users and irrigation department staff education and training program through audio-video aids and discussions has been undertaken in the area for introducing the new concept of CBIO in the area. Giving up traditional practice of continuous supplies and accepting a change with rotational supplies during low demand period is always time consuming. Similarly, reaching every farmer and then his agreement to the new concept in one visit is almost impossible. Initially, the response was poor, which improved with passage of time and continuous interaction with all concerned. About 121 meetings were arranged in about 70 percent of the area where 2,750 water users had participated. Initial response in the very first meetings was about 52 percent in favor of CBIO as it would control groundwater recharge and save water for other uses while the remaining were reluctant about its actual implementation and wanted water for certain uses like vegetables, domestic and other uses. Understanding of the new concept is going to take its time, which has substantially improved with subsequent meetings and further discussions after kharif 2004, which was the first season of awareness campaign.

DoI's Response

Being managers of the system, DoI has an essential role to play in introducing and implementing CBIO in the area. The senior managerial staff was trained on the concept and development of CBIO schedules while the field staff was educated on the concept and implementation of schedules. DoI had agreed that managerial staff in the Project area would not be transferred during the Project period but in fact three out of four key people deputed to Consultants were either transferred or they quit the department. Similarly, most of the field staff, working in the same area have decades long experience with conventional operations, finds it difficult to immediately switch over to modern operations where main canal remains full all the times while water users are refused water for whatever use. Field staff was quite helpful with continuous strict supervision, however, like water users, their own response was lukewarm. Continuous education and training is required in order to enable them to adapt the system.

Return Flows

Daily water deliveries at offtakes heads were monitored, however, the crops did not use all of it. Many water users closed their outlets at head and many let it flow down to drains, when they did not need water. Results from drains monitoring covering much of the Project area show that an average of about 5.51 cumecs (194 cusecs) flow has been observed going into main drains. Figure 3 shows daily variation of flows in the drains from 1st September to 15th October 2004. Average flows into drains are almost three times of the design discharge of Dagi Disty and more than double of the Pirsbaq Disty design discharge. Discharge has increased considerably in October when water was not needed by sugarcane while maize had already been harvested. Drains flow includes both surface as well as subsurface' flows either through tile drains or mere seepage from the adjoining area.

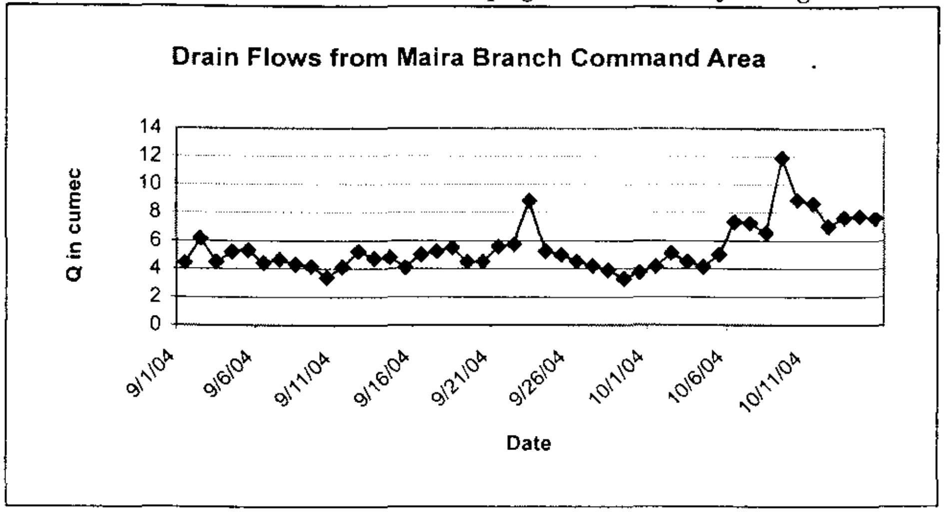

Figure 3: Daily flows from Project area into drains.

DISCUSSION

Tobacco and maize are the leading kharif crops followed by sugarcane, which is more in the tail reaches than in the upper parts along Maira Branch. The cropping intensity in the area varies from 97 to more than 99 percent during kharif when maize is cultivated both on land vacated by wheat as well as some of tobacco. Land cover is not high during May to mid-June after wheat harvest but farmers insistence on continuous supplies for irrigating tobacco every week kept the system open for most of the period. The campaign initiated by Pakistan Tobacco Company in the area for fewer irrigations for improved quality of the end-product had also been not easily accepted by farmers for fear of loss of weight. Sugar cane and fodder are covering a small fraction of the total area but mostly in the tail area, which is sandy loam requiring frequent irrigation. On the other hand, field observations suggest that water table is coming up necessitating necessary steps from the line agencies to check the trend.

CBIO schedules prepared on the basis of prevailing cropping pattern suggested the closure of the secondary offtakes for about 27 percent of the total 26 weeks of kharif 2004. However, the actual operations did not follow the proposed schedules mainly for water users unwillingness and the reluctance of the implementing agency's field staff. Manual operations of Pehur High Level Canal, which did not cope with the downstream crop demand and unwanted interventions, also affected the schedules seriously.

Night irrigation is customary in Pakistani irrigation system and has been taken into account while developing CBIO model because the design and construction of the infrastructure at the secondary and tertiary has not been provided with facilities for storing water when not required. Increased supplies fulfilling much of the requirements during daytime and non-implementation of CBIO schedules have lead to wastage of water in the area. 71 percent of water from Dagi Disty and 31 percent form Yaqubi Minor flowing down to drain at night is substantial and could be checked. Wastage of expensive water coming from Tarbela reservoir has serious consequences not only for system operation but also environment. The automatic system installed in the PHLC-USC can easily cope with demand for avoiding power generation loss at Tarbela and wastage of water to a larger extent.

Initial reaction of the two main stakeholders (irrigation department and water users) with limited understanding of the modernized operations has been positive, when not more than one meeting had been held with irrigation department field staff. About 70 percent of the area was covered by the end of the season while only a few meetings had been organized with water users in the beginning of the season. It will take time for complete understanding and adaptation of CBIO. Transfers of the deputed irrigation department staff had a negative impact on the overall implementation of CBIO schedules because the new comers did take their time to understand automatic and modernized system. The process of education and training beyond kharif 2004 should help further improve the awareness and preparedness of the concerned parties.

The natural topography of the area allows farmers for disposing off surplus water into drains. Sticking to conventions, water users were still putting the extra water into drains, which was more expensive than the previous continuous supplies from Swat River. Similarly, the irrigation department and the expected farmer organizations must now see a different and proactive role in managing irrigation in the area. Discharge in the surrounding drains has been equal to almost irrigate 7,700 hectares (19,500acres) of land by adapting the PHLC Project criteria if it could be efficiently used or it can be used for irrigating 15,000 hectares by using the old design criteria. Every drop of water coming from Indus River to PHLC and USC has direct and indirect cost attached to it.

Introduction of modern technology and procedures for better and efficient water management in part of the Upper Swat Canal system is a step in the right and forward direction after more than 120-140 years of conventional canal irrigation operations. However, the customary environment prevailing in the department and the normal approach of water users to increased water supplies is affecting the introduction of modern environment friendly operations. The education program initiated in the area would go a long way in changing the mindset and approach of the stakeholders but with sustained and continuous efforts.

CONCLUSION

Modern operations have been introduced in order to control groundwater recharge and save water. The operational schedules prepared according to crop water requirements for running the system could be implemented only partially. The offtakes could be closed only for about 15 percent of the time they were proposed to be due to resistance from farmers and lack of experience and understanding irrigation department filed staff. Overall, the response of water users and irrigation department staff was good but was not as encouraging as it should have been. Water users' fears regarding damage to tobacco if a weekly water turn was missed was the real obstacle in implementing the CBIO schedules.

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ASSESSING THE BEHAVIOR OF GROUNDWATER RECHARGE USING WATERTABLE FLUCTUATION METHOD

Jehanzeb Masud[1], Asaf Sarwar[2]

ABSTRACT

Assessment of net recharge to groundwater is of paramount importance for efficient management and sustainable exploitation of the groundwater. Different approaches exist for estimation of net recharge. The approaches vary from simple based on watertable fluctuation to the complicated requiring large number of data such as irrigation delivery, water losses, crop water requirements etc. In this study, watertable fluctuation method used for recharge estimation in canal command area within Rechna Doab. The whole area was discretized into a network of Thiessen polygons which were superimposed on the study area. The net recharge was estimated from 1986-2004 on the basis of nodal effective area. The results of study revealed that the net recharge fluctuates between +1.5 to -1.62 mmd^{-1} with an average of 0.62 mmd^{-1} during Kharif season while in Rabi, it was -0.88 mmd^{-1} with overall negative net recharge of -0.26 mmd^{-1} showing depletion of aquifer over the period.

INTRODUCTION

Pakistan relies heavily on irrigated land for more than half of their domestic food production. On irrigated farms, two or three crops per year are commonly grown (Ahmad, 2002). During the last 10 to 20 years, there has been a significant increase in the utilization of groundwater resources for agricultural irrigation, because of their widespread distribution and low development cost (Clarke *et al.*, 1996) while due to climatic variations natural source of irrigation i.e. rainfall has become unreliable. Variation in rainfall for the area is shown in figure 1.

Groundwater contributes about 40-50% of over all crop water requirements and is no more a supplemental to surface supplies but an integral part of the irrigated agriculture (GOP, 2004). During the last few decades, development of groundwater resources has increased manifold to meet growing demand of water for agriculture. (Bhatti, 2004).The density and growth rate of public tubewells confirms the significant role of groundwater usage in the irrigated agriculture of Punjab as the area irrigated from tubewells increased from 9.4 mha in 1996-97 to 9.92 mha in

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1 Lecturer.

2 Assistant Professor.

1999-2000 (Arshad *et al.*, 2005). Historically, the use of ground water has resulted in dramatic growth in the number of tubewells which has been increased drastically from about 3000 in 1950 to over 700,000 in the year 2003. This has been due not only to government programs to devolve tubewell ownership, but also to farmers investment in tubewells to overcome inadequate and unreliable supplies provided by public canal or tubewell systems.

Most of the tubewell installation has taken place in Punjab due to intensive agricultural development. Pumping of groundwater from private wells has provided more than adequate vertical drainage in many areas: in Punjab as a whole, withdrawals exceed groundwater recharge by an estimated 27 percent, raising serious questions about the sustainability of groundwater irrigation (NESPAK, 1991).

In the Punjab province, the greatest proportion of groundwater supplies comes from private tubewells, which was minimal in the initial stages of the development of this resource. The rapid development of tubewells is a clear indication of the current level of Department of Irrigation & Drainage, University of Agriculture, Faisalabad farmer's reliance on groundwater for irrigation.

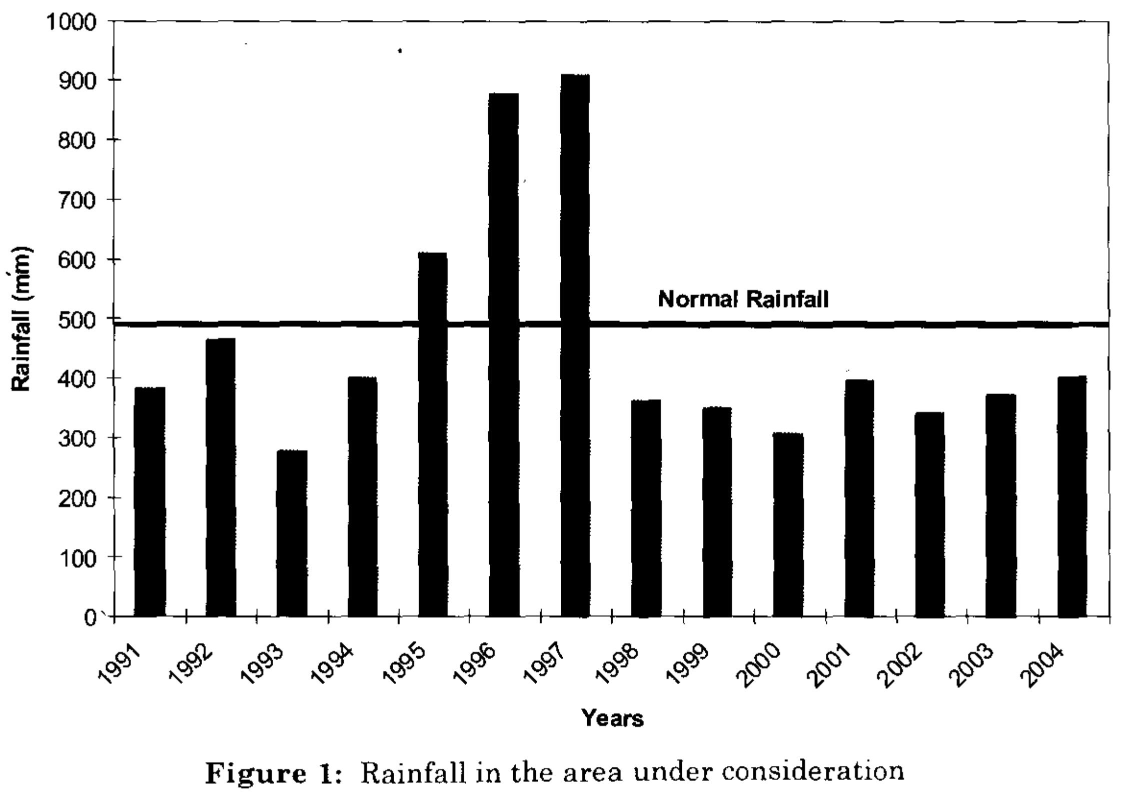


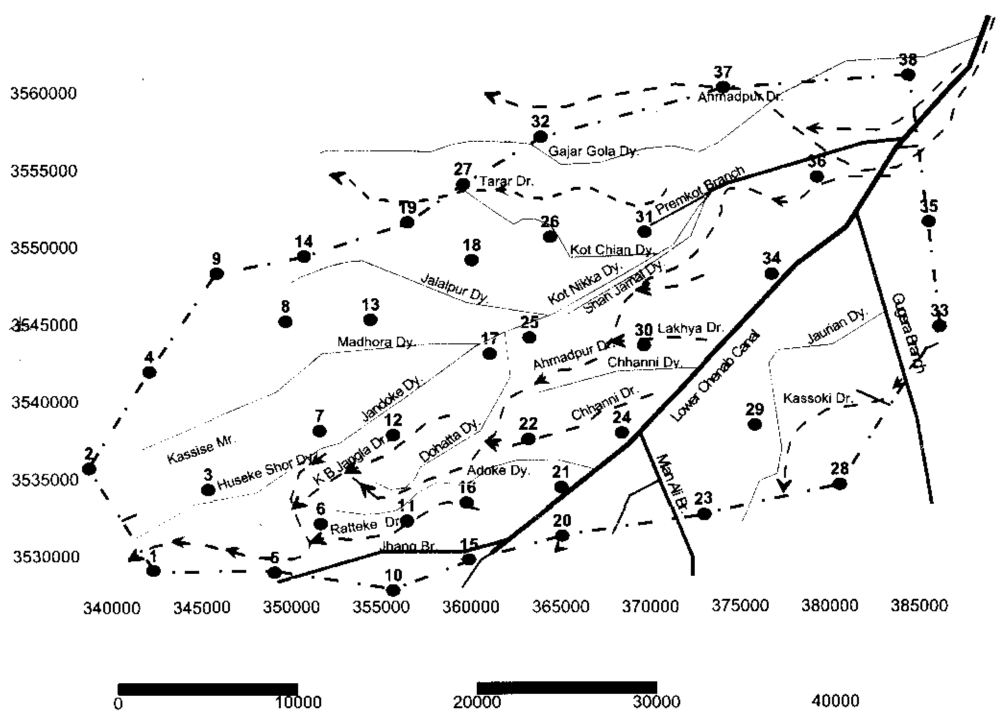
Figure 1: Rainfall in the area under consideration

As the main recharge and discharge components being irrigation and pumpage respectively. Hence mostly the rise of water table occurs when the irrigation without simultaneous drainage is done while on the other hand mining of the aquifer results when the groundwater is pumped extensively exceeding its capacity. Many aquifers in the world are suffering from groundwater mining due to its unplanned abstraction by the tube wells. In this context, reliable assessment of net groundwater recharge is of great importance for the efficient management and sustainable exploitation of ground water resources.

Different methods have been developed to measure net recharge such as empirical methods, direct measurements, tracer techniques, Darcian approaches and water balance methods (Lerner *et al.*, 1990). However, in this study a simple approach that uses fluctuations in groundwater levels over time for recharge estimation is used. This approach is termed as watertable fluctuation (WTF) method which is based on the premise that rises in groundwater levels in unconfined aquifers are due to recharge water arriving at the watertable.

METHODOLOGY

A representative area within Rechna Doab was selected to apply WTF approach for the estimation of net recharge to groundwater. The selected area covers about 1067 km² (with a network of observation wells) and is a part of the large scale project SCARP-1.The salient features of the study area showing canal and drainage net work are shown in Figure 2.



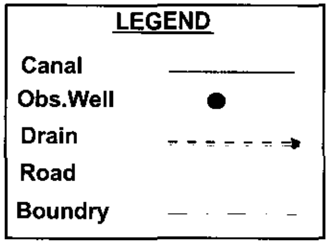


Figure 2: Salient features of the study area

Detailed topographic maps and watertable data were collected from the SCARP Monitoring Organization (SMO), Lahore. Since SMO has a network of observation wells and collected data bi-annually; once pre-monsoon and secondly, post-monsoon, and recharge was estimated on the basis of Kharif and Rabi seasons to study the effect of rainfall on the net recharge. The contours of ground surface elevations and watertable fluctuation were drawn using Kriging method of interpolation using Surfer Software. The values of aquifer parameters such as hydraulic conductivity, storativity and geology of underlying aquifer was taken from the aquifer tests reported by Water and Soil Investigation Division of WAPDA. For the purpose of estimating recharge from the watertable data, the whole area was discretized into nodal areas by superimposing the network of polygons on the selected area as shown in Figure 3. The polygons were developed using Thiessen Polygon Method.

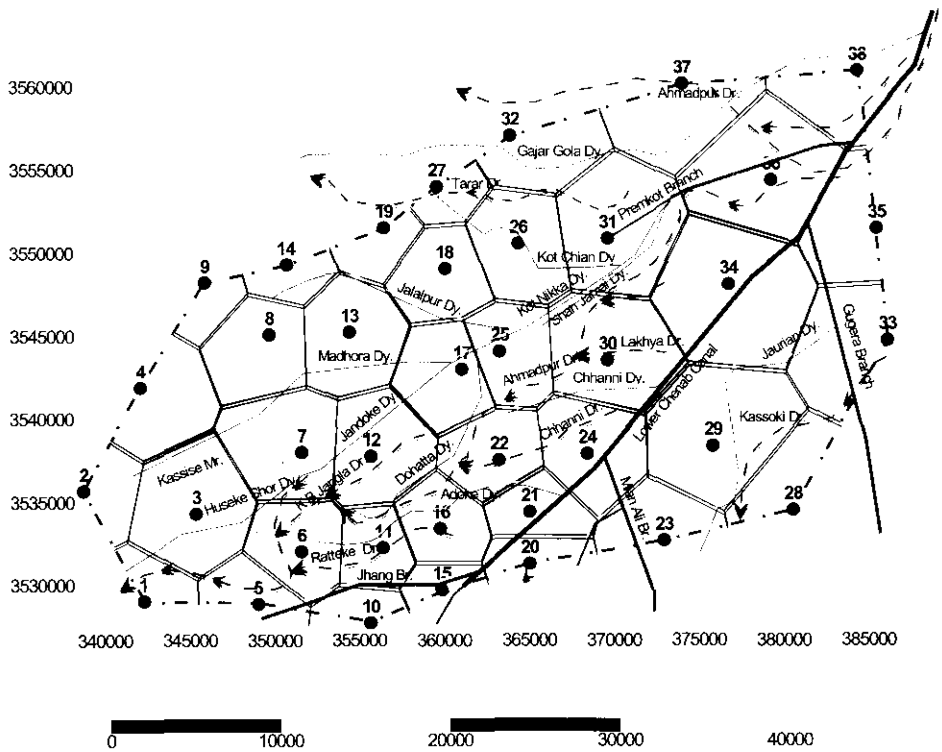


Figure 3: Nodal network superimposed on the study area

In such a network, a distinction was made between internal and external nodes. The internal nodes were each representative of a nodal area, whereas the external nodes acted as boundary conditions.

Water table fluctuation (WTF) for recharge estimation within the study area requires knowledge of specific yield and changes in water level over time. Advantage of this approach includes its simplicity and insensitivity to the mechanism by which water moves through the unsaturated zone (Healy, 2002).

The WTF method (Hall et al., 1993) is based on the premise that rise in ground water levels in unconfined aquifers are due to recharge water arriving at the water table. Recharge is calculated as:

$$R = Sy * {dh}/{dt} \qquad (1)$$

Where

R = Recharge (L/T)

S_y = Specific yield

dh = Change in water table over time (L)

dt = Time step (T)

Thus change in storage over a particular node can be determined by the equation given below:

$$Sy = \frac{1}{A}\left({dv}/{dh}\right)$$

or

$$dv = Sy * A * dh \qquad (2)$$

Where:

A = Nodal effective area(L^2)

dh = Difference of water table over a period under consideration (L)

dv = Change in storage (L^3)

From Eq (2)

$$Sy * dh = {dv}/{A} \qquad (3)$$

By substituting the values obtained from Eq 3 to Eq 1, the net recharge can be determined. The specific yield value of the area was taken as $S_y = 0.02$ (Nazir, 1995).

The rise or fall for every observation well, before monsoon in May/June and after monsoon in Oct/Nov was calculated for every season by taking difference of observed water levels. The nodal network was developed around each observation well as shown in Fig. 3. Each node was assigned an effective area based on Thiessen Polygons. It was assumed the rise or fall in water level in a particular node represents the effective area of that node. Then this rise or fall at each node was multiplied by effective area of that node and specific yield to calculate change in storage. The net recharge of all the individual nodes was thus assessed for entire period from 1985-2004 to study the behavior of net recharge with time while the sum of all nodal recharge values gives the "net recharge" of the study area.

RESULTS AND DISCUSSION

Annual rainfall data of the station nearest to the study area showed variations in rainfall from the normal rainfall of the area which is 490 mm and most of the time the rainfall is less than normal. To meet this water shortage and to improve water supplies to the area, public and private tubewells with an average capacity of 25 lps were installed on a large scale. These tubewells are operating more during the kharif season than rabi to supplement canal supplies.

As a result of this climatic variation and increased withdrawals of groundwater the watertable has fallen down. The fluctuation of the water table based on the average of all nodes during different seasons is shown in the Fig. 4.

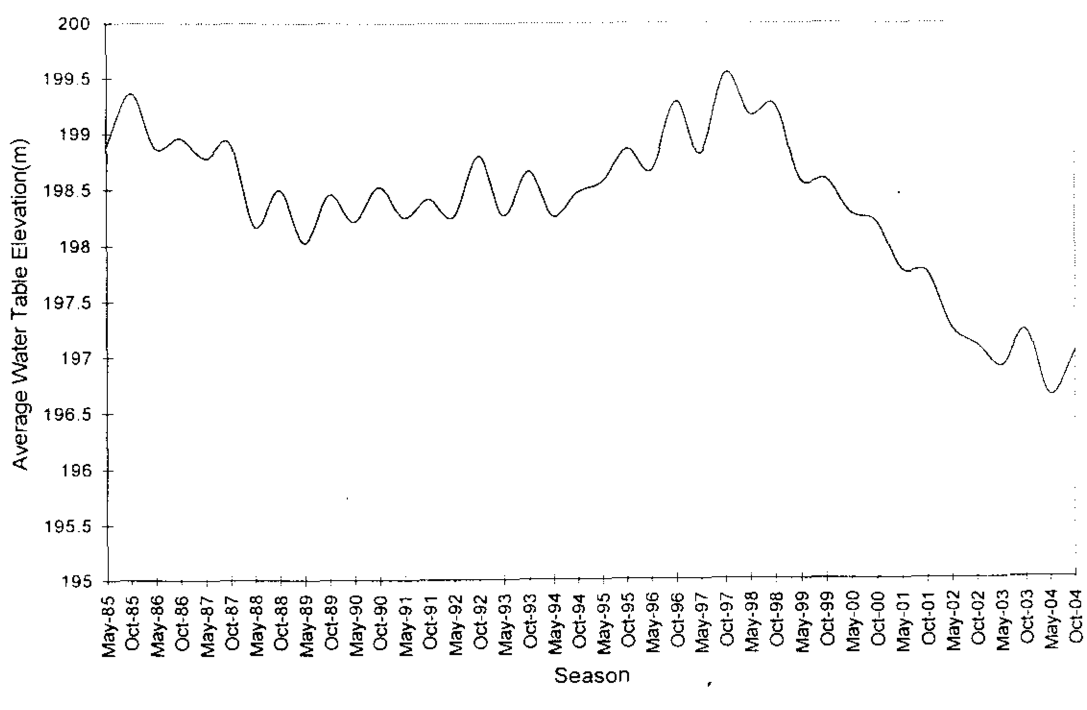


Figure 4: Temporal Fluctuations of Water Table Elevations above MSL

It is evident from Fig 4 that during the early years (1985-1988), the watertable elevation was gradually lowered. From 1989 to 1995 the water table fluctuations showing a relatively normal behavior and no significance variation is observed during this period but from 1996 water table rises and reaches at highest level (199.544 m) in October, 1997 which is due to the recharge contribution from heavy rainfall during this periods. After May, 1998 the water table is showing a continuous downward trend and reaches at the lowest level of 196.635 m in May, 2004.

The net recharge was assessed using Eq 1 and results show that net recharge in the study area fluctuates between +1.5 to – 1.62 mmd^{-1} with an average of 0.62 mmd^{-1} during Kharif season while in Rabi, no recharge occurred and average net recharge is –0 .88 mmd^{-1} with overall negative net recharge of -0.26 mmd^{-1} which shows that the aquifer is depleting over the period.

This behavior of depleting aquifer can easily be understood from the Fig. 5 (a) & (b) that show a trend of decreasing net recharge value when compared post-monsoon 1985 ,1997 and 2003 for all the nodes within the study area while between pre-monsoon 1986,1998 and 2004, the negative net recharge values are further increasing in pre-monsoon 2004 season, which is because of reduced rainfall and increased groundwater abstraction.

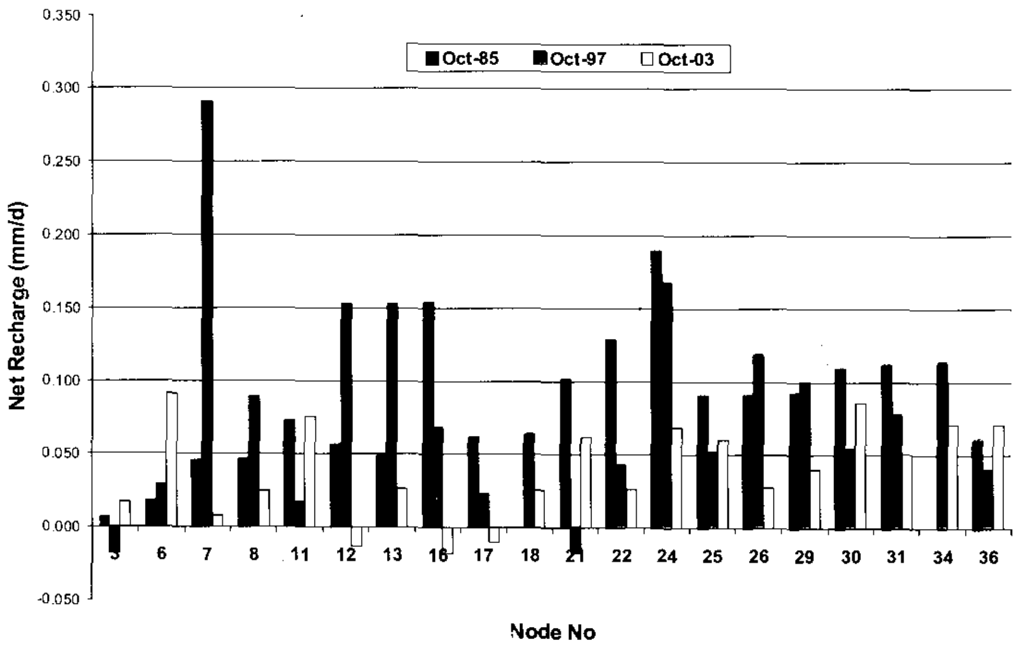


Figure 5(a): Net recharge computed using WTF method (post-monsoon)

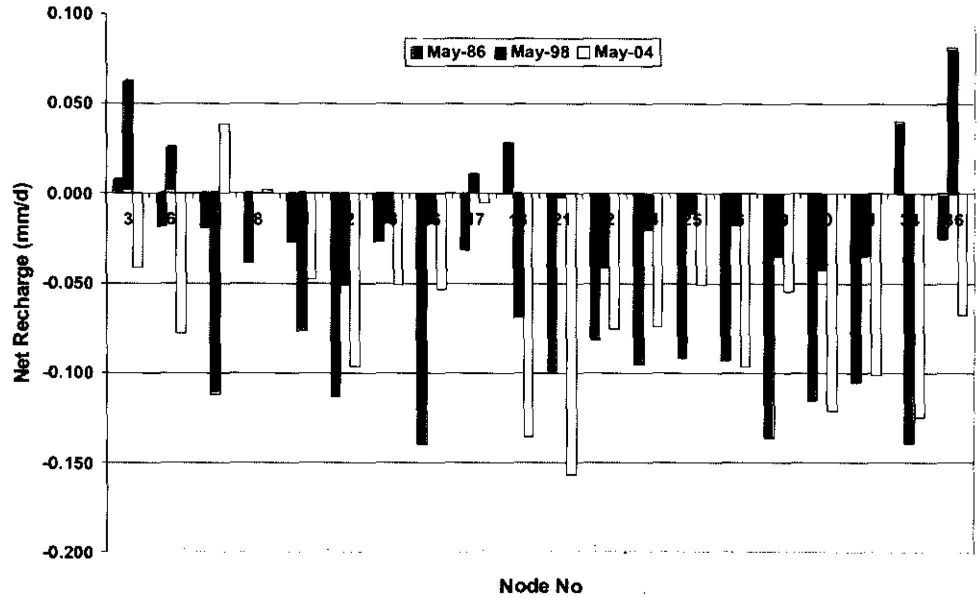


Figure 5 (b): Net recharge computed using WTF method (pre-monsoon)

The net recharge (positive/negative) calculated for each time step indicates that during the pre-monsoon season the net recharge value falls while post-monsoon period shows a significant rise in net recharge.

Net recharge thus estimated, shows that after the year 1997, the net recharge is continuously showing a negative trend thus depleting the aquifer which is because of low rainfall during that period and increased number of public and private tubewells in the area which were abstracting the groundwater to supplement the surface water supplies. Fig. 6 shows the yearly development of tubewells and its effect on net recharge.

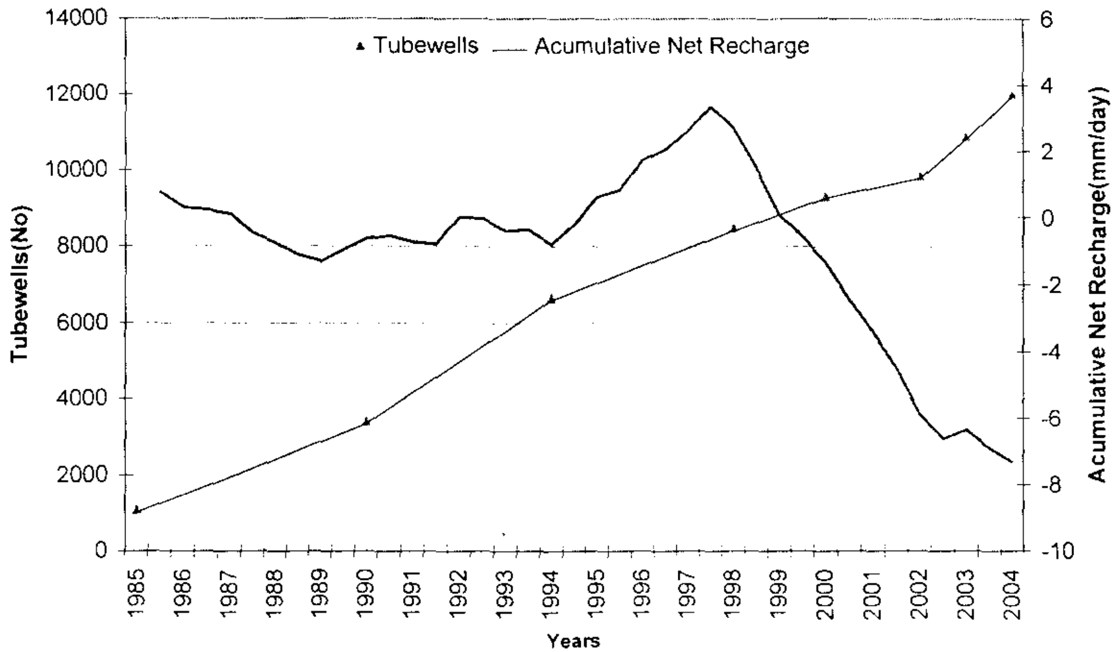


Figure 6: Yearwise Tubewell Development alongwith Fluctuation of Accumulative Net Recharge (mm d^{-1}) above MSL in the Study Area

Fig 6 reveals that the accumulative net recharge decreases upto 1989 and then a gradual rise has been observed until 1997, afterwards a consistence decrease in the accumulative net recharge shows that the precipitation has been reduced and the tubewell development has resulted in the extensive groundwater exploitation in the study area.

CONCLUSION

The net recharge in the study area fluctuated between +1.5 to – 1.62 mmd^{-1} with an average of 0.62 mmd^{-1} during Kharif season while in Rabi, no recharge occurred and average net recharge was –0 .88 mmd^{-1} with overall negative net recharge of -0.26 mmd^{-1} showing depletion of aquifer. Moreover, the extensive pumpage of groundwater from the area to supplement limited surface supplies has lowered the overall watertable of the area while due to uncertain climate, aquifer is not recharging at the required pace and overall net recharge is showing a negative trend.

RECOMMENDATIONS

- The groundwater pumpage should be encouraged only in those areas which are closer to some recharge component like canals/distributaries from where seepage may contribute to the net recharge and hence water table can be balanced.

- Water banks/on farm ponds should be constructed to conserve precipitation water when it is available in abundance which may be used in the water stress period.
- Use of efficient irrigation techniques such as bed-furrow irrigation, zero tillage and pressurized irrigation should be promoted to save and improve water availability and thus minimizing the stress on groundwater development.

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HYDRO-ENERGY AND WATER VISION IN PAKISTAN

Engr. Abdul Qayyum[1]

ABSTRACT

Pumped storage and generation is relatively a newly developed technology, now well established and considered as economically viable source of hydro energy throughout the world. It is best suited for several existing / future plants at Rivers Indus and Jhelum.

Pakistan is not benefiting from this universally recognized type of technology. WAPDA, being a national organization responsible for the planning, designing, generation and transmission of hydropower, thermal power and prevention of waterlogging and salinity in an economical way, is requested to recognize the importance of this type of energy generation. At present, *the overall (Thermal+Hydel) load factor is 45% where as* the productivity of hydropower generation plants is almost 29% which is rather a far too low productivity even in winter. The provision of pumped storage plants and generation will not only raise the level of load factor but will also help in meeting the peak demands. This will decrease the unit cost of energy in Pakistan to a considerable extent.

Productivity of present agricultural command areas will increase due to inexpensive hydro-energy and additional availability of water. Hydro-energy quantum will increase throughout the year and hence agricultural areas can also be increased.

Implementation of pumped storage plants and power generation, both at prospective existing and future hydropower plants is recommended to be taken up on priority basis.

22 March 2006

[1] Director Hydraulic Structures WAPDA.

1. Introduction

Tomorrow belongs to hydro energy. There are three naturally compatible types of hydro power (Fig. 1); a. Impoundment like Tarbella and Mangla. b. Diversion like GBHP Project and, c. Pumped Storage. Pakistan is well suited for all the three hydro powers, and it, can meet its all present and future electricity requirements only by this inexpensive type of hydro-energy, due to its unique favorable environment for them. With proper planning, it should be possible for Pakistan to export this type of hydro-energy. A careful study has shown that the total potential of hydro energy in the world is not less then 15 billion MW. Out of this, only 20% has yet been exploited and most of the unused and untapped hydro potential is in the under developed/developing countries. Pakistan is one of them.

In financial year 2003-2004, the total generation in Pakistan was 68,987 MKwh, in which hydel component was only 27,358 MKwh (39.6%) and the thermal component was 41,629 MKwh (60.4%). In 2004-2005 the total generation was 73,000 MKwh, in which the hydel component was 25500 MKwh and the ratio of hydel to total was further decreased to 0.349. Pakistan's economical survival, at least, requires the reversal of this ratio. If exploited properly, even in the existing (Tarbella, GBHP Project, Mangla) arrangement, with the introduction of pumped storage and generation, the annual power shortages can be greatly minimized if not eliminated.

Regulated water releases are permitted through all the main hydel power plants in Pakistan. Capabilities of Tarbela, Mangla and Barotha remain as 760 MW (load factor= 21%), 400 MW (load factor = 40%) and 580 MW (load factor = 40%) against the installed capacities of 3478, 1000 and 1450 MW in winter. The balance of installed capacity in winter and peak demand throughout the year is met through thermal generation. Power generation, especially after the present oil crises, oil fired stations are the costliest among various thermal power units. The thermal units also require to be shut down during annual maintenance.

To meet the varying power demands, the provision of thermal and hydel mix of power stations (plants) is adopted both for the improvement of load factor of the base plant and the adjustment of the power generation to match the daily and seasonal load fluctuation of the national grid. But increasing the energy production by the present pattern can not help reduce unit price of electrical energy. The most reasonable means to increase the productivity of plants or decreasing the unit cost of energy in Pakistan is the use of pumped storage plants and generation *(Fig 2&11)*. When the load enters in base phase *(Fig 7)* of the plant or when productivity is less due to limited water flows, pumped storage starts working and there are more than one mode of its configuration. The net result is that the unit cost of generation comes down as the load on the unit increases and is minimum at full load.

Therefore, if during the low demand period or during low load factor due to limited water flows an artificial load is created, the unit cost of power generation will come down, benefiting the network *(Fig 2)*.

Base load plants work for a period of 5,000 hours or more in a year (i.e. > 57% of time). Medium load plants work between 2,000 and 5,000 hours a year and peak load plants work for less than 2,000 hours in a year i.e. < 22% of time. Base load plants have to run continuously and, therefore, there is very little operational flexibility.

Medium load plants are operational predominantly on week days. These plants may have some operational flexibility.

The peak load plants are used for a short duration, the load factor being 10% to 25%, investment in these is comparatively less and corresponding reduction of productivity is, in general, acceptable and economically justifiable.

Fossil fuels are getting exhausted rapidly therefore the world is turning its attention towards renewable resources of energy such as hydro-power, solar-energy etc. In Pakistan, the bulk of our known reserves of hydro-power potential are yet to be tapped. However, great fluctuations in river flows do not permit uniform production round the year. Pumped storage / plant and generation is one such type of energy production which promises filling the gaps.

In this type of plant, energy is stored up in a high level lake by pumping up water during low demand periods such as the nights, during weekends, and in countries like Pakistan throughout the winter, when our limited availability of water does not allow the impoundment/diversion hydro energy production at an appropriate load factor (table-2). This stored water is used for power generation during the peak – demand period. Figures-4 & 6 show the load curve of a network with a pumped storage plant working in conjunction with the base plant.

It will be seen from the figure that the load fluctuation for the base plant has been considerably reduced. Also there is a bulk transfer of energy from the low-demand period to peak period. The pumped storage plant assists the network in two ways (1) It improves the load factor during the low-demand period, benefiting the network and (2) It reduces the demand on the base plant by generating peak power making it possible to use lower capacity units.

Thus it is prudent to explore feasibility of pumped storage and generation on existing hydropower plants and on most of the future hydroplants, so that the availability of water and production of hydro-energy is increased to the required level.

2. Why Pumped Storage / Generation

Electricity itself cannot be stored, but the potential to generate electricity can ---- for example, in a battery. Pumped storage plants provide a way to store the potential energy of water. This enables meetings peak power demands by pumping tail basin water to upstream reservoir during low demand period and utilizing this additional water to generate electricity during peak demand period of the day.

a. *Economic Justification*

(i) Many countries have a special tariff for peak-load power which is about 2 to 3 times more than the normal tariff. In future, a similar situation may develop in Pakistan. Therefore, the plant can be made to earn additional revenues because of the conversion of cheap off-peak power to costlier peak power. These revenues can pay back the investments made in the plant.

(ii) The alternative of generating peak power by using fossil fuels is prohibitively costlier.

b. *Need of Reserve Plant*

The base units are deficit in providing the peak demand. The deficiencies of a base unit can be over come by providing pumped storage as an auxiliary plant which should be able to perform following functions:-

(i) To generate peak power quickly and efficiently during the peak demand period

(ii) To create an artificial load during low demand period and to improve the load factor of the base plant

(iii) To adjust the power generation to match the load fluctuations of the network

(iv) To be able to take the full load quickly from the stand-still or from shut down position.

3. Constitution

The plant has most of the components of a normal hydroelectric plant namely the high level lake, the power tunnel or penstocks, the powerhouse and the tail race channel. The only difference is an additional lake at the lower end in which tail water is stored up for pumping in the existing powerhouse, additional machinery has to be provided for pumping. Reversible units would be used for new powerhouse. The conduit system in some cases has to be designed for the two-way movement of water. The transmission lines connecting the powerhouse to the grid can also be used to draw power from the grid during pumping operations. Figure-8, typically represents the pumped storage scheme configuration.

In the year 2000 the United States had 19500 MW capacity of pumped storage. They consume more power filling their reservoirs than they generate by emptying them. Still the technique is considered a worthwhile addition to the electrical grid as the most cost effective means for regulation of electrical power.

In 1999, EU had 32 GW capacity of pumped storage out of a total of 188 GW of hydropower and representing 5.5% of total electrical capacity in the EU. A worldwide list of some pumped storage plants may be seen at Annexure-1.

4. Cycle Efficiency of a Pumped Storage Plant

The cycle can be divided into two portions the pumping cycle and the generating cycle. While pumping, losses will be incurred in the transformers, motors, the pumps and the penstock pipes. While generating, losses will be incurred in the penstocks, the turbines, the generators and the transformers.

The efficiencies of the machines are given below:

Transformer	-	98 per cent
Motor-generator	-	96 per cent
Turbine	-	92 per cent
Pump	-	88 per cent
Penstocks	-	96-98 per cent (depending upon the length)

There are 20 - 30 percent losses, therefore, the overall cycle efficiency obtained ranges from 70 to 80 percent. That means for every 3 to 4 MW drawn from the network during off-peak period and throughout the winter in Pakistan, 2 to 3 MW are returned back to the network while about 1 MW is consumed and may be considered as waste.

5. Advantages of Pumped Storage Plant

a) The plant has a long life. Plants are giving efficient service even after 25 years of operation.

b) There is reliability of operations. Outages are low and maintenance costs are small.

c) There is a great flexibility of operations. The unit can be fully loaded from standstill within few minutes and it can be shut down quickly. There can be rapid change over from one mode of operation to another mode. These features help the network in efficiently meeting sudden peaks and shock loads. The set can do spinning reserve duty at a very low cost, compared to a thermal set. (Presently used in Pakistan).

d) In Pakistan unutilized capacity in winter at Tarbela, and Ghazi-Barotha and even at Mangla can be activated at very low cost along-with meeting the peak demand by hydropower. This provision should be considered in the feasibility of all future plants at Indus and Jhelum to increase their load factor.

Because of these advantages, a pumped storage unit of 100 MW in U.K. was equated to a thermal unit of 120 MW, when the preliminary estimates were prepared. These days when new power plants are being planned, a provision for a pumped storage plant with a capacity of 15-20 per cent of the thermal capacity is provided for. It is found that a combination of a pumped storage plant of 500 MW capacity along with a thermal plant of 2000 MW capacity benefits the network more than a thermal plant of 2500 MW capacity.

6. Scenario in Pakistan

Pumped storage generation in Pakistan has special attraction due to the reason that at major hydropower plants almost 71% of their capacity (4200 MW) remains unutilized during winter season. Load factor lowers down up to 3% on some days. In other words the potential exists much more than to fulfill the peak demand only. In deed the present ratio of hydel to thermal production can be reversed by the use of this type of hydro energy by exploiting it in existing setup. *(Fig 10(a-d))*

7. Pumped Storage Generation - Scope in Pakistan

a) *Pattern of Demand*

The demand for power fluctuates from minute to minute, day to day and season to season *(Figure-10(a-d))*. To study the pattern, the quantitative scenario in tabulated form of all the sources, as of April 2005, is shown on next page:

Installed Capacity & Capability of WAPDA System (As of April 2005 – Table 1)

Sr. No.	Name of Power Station	Installed Capacity (MW)	Capability (MW)	
			Summer	Winter
1.	Tarbela	3478	3691	760
2.	Mangla	1000	1020	400
3.	Chashma Low Head	184	184	75
4.	Ghazi Barotha	1450	1450	580
5.	Warsak	243	195	145
6.	Small Hydels	108	68	34
	Sub-Total (Hydel)	**6463**	**6608**	**1994**
	GENCO-I:			
7.	TPS Jamshoro #1-4	850	695	695
8.	GTPS Kotri #1-7	174	130	150
	Sub-Total GENCO-I	**1024**	**825**	**845**
	GENCO-II:			
9.	TPS Guddu Steam #1-4	640	430	430
10.	TPS Guddu C.C. #5-13	1015	875	945
11.	TPS Quetta	35	22	22
	Sub-Total GENCO-II	**1690**	**1327**	**1397**
	GENCO-III:			
12.	TPS Muzaffargarh #1-6	1350	1260	1260
13.	NGPS Multan #1&2	130	100	100
14.	GTPS Faisalabad #1-9	244	175	210
15.	SPS Faisalabad #1&2	132	100	100
16.	Shahdra G.T.	59	40	40
	Sub-Total GENCO-III:	**1915**	**1675**	**1710**
	GENCO-IV:			
17.	FBC Lakhra	150	35	35
	Sub-Total WAPDA Thermal	**4779**	**3862**	**3987**
	Total Capacity (WAPDA)	**11242**	**10470**	**5981**
	Private Projects			
18.	KAPCO	1638	1342	1342
19.	Hub Power Project	1292	1200	1200
20.	Kohinoor Energy Ltd.	131	120	120
21.	AES Lalpir Ltd.	362	351	351
22.	AES Pak Gen (Pvt) Ltd.	365	344	344
23.	Southern Electric Power Co. Ltd.	117	112	112
24.	Habibullah Energy Ltd.	140	126	126
25.	Rouch (Pak) Power Ltd.	450	395	395
26.	Saba Power Company	134	123	123
27.	Fauji Kabirwala	157	150	150
28.	Japan Power Generation Ltd.	135	107	107
29.	Uch Power Project	586	548	548
30.	Altern Energy Ltd.	10.5	10	10
31.	Jagran Hydel	30	30	6
32.	Liberty Power Project	235	210	210
33.	Chashma Nuclear (PAEC)	325	300	300
	Sub-Total (Private)	**6107.5**	**5468**	**5444**
	Total (WAPDA System)	**17349**	**15938**	**11425**

In Pakistan the total installed capacity (hydel & thermal) is 17349 MW where as the average daily demand is less then 8000 MW (table 1& Fig 10(a-d)). Therefore, the today's need, to decrease the unit cost is to increase the load factor (LF) of existing system and not to enhance the conventional (hydel or thermal) installed capacity. This requirement be maintained for future plants also.

From the above Table the ratio between installed capacity of hydel and thermal component is:-

$$\frac{Hydel}{Thermal} = \frac{6463}{10886} = 0.59 \qquad \textbf{A}$$

Ratio of capability in winter between hydel and thermal = $\frac{1994}{9431} = 0.21$ **B**

Our emphasis is to increase both ratios **A** and **B** and this objective can be obtained by increasing the hydel component both in summer and winter.

For simplicity, the load factor of hydel component in winter may be taken as (Tarbela, Mangla & Ghazi-Barotha).

Capability in Winter / Installed Capacity = 1740 / 5928= 0.29 **C**

Present average daily capability/installed Capacity = Load Factor (LF) = 3002/5928 [Table 1 & 3]

= 0.51 **D**

Capacity to be installed in MW = Installed Capacity /Average Load Factor (D)

= 5928 / 0.51 = 11623 MW.

In other words to get 5928 MW effectively, in the conventional manner, we have to install 11623 MW, which is extremely expensive.

b) Alternatively if 11623 MW is installed with pumped storage;

Already installed capacity	= 5928 MW.
Pumped Storage cushion	= 5695 MW.
25% wastage during pumping	= 1424 *MW.*

Net achievable pumped storage generation = *11623 – 1424 MW – 5,928 = 4271* MW.

May be it is just theoretical and hence optimistic figure to some extent but practicable generation has to be worked out and this needs to study whether appertain with main structures can be accommodated Annex-2 or otherwise on prorate basis.

Even if part of the net achievable 4271 MW, (average daily) is obtained additionally, from our existing hydel stations, it will;

i) Increase the productivity of already installed hydel units by using their unutilized capacities throughout the year.

ii) This arrangement will decrease the per unit generation, capital as well as maintenance costs many folds.*(Fig-11)*

iii) Make possible the best utilization of national resources and reduction in production cost will lead to real economical growth.

c) A statistical analysis of present scenario/scope in Pakistan is produced below.

Load Factors (LF) of Tarbela, Mangla and GBHP at 4 Representative Days and the Average Daily Load Factor (LF) Table - 2

Date	% LF		
	TARBELA	MANGLA	GHAZI BAROTHA
January 10, 2004	16.3	41.1	33.1
April 20, 2004	31.3	78.0	57.4
August 20, 2004	94.7	46.0	87.2
December 20, 2004	44.1	53.6	29.3
Average daily LF	46.6	54.675	51.75

Fig 2 shows the relation between the unit cost and the load factor of a plant. *Fig-11* depicts that the present cost of production at the three plants in Pakistan can theoretically be decreased more than fifty percent of the present cost by utilizing pumped storage hydro energy. As in the conventional design of future plants at Indus/Jhelum, the load factor cannot be increased to an acceptable value, the provision of pumped storage be considered.

Table-3 depicts, both, capabilities/load factors of all the main existing plants, individually and when combined together.

Daily Average with/without Pumped Storage Load Factor (LF) and the Generation Capabilities Table – 3

Plant	Present		Unutilized (Potential) %LF	75% of Unutilized LF	LF/Capabilities Accumulative with Pumped Storage	
	% LF	Capabilities (MW)			% LF	Capabilities (MW)
Tarbela	46.6	1697	53.4	40.1	86.7	3174
Mangla	54.67	556	45.33	34.00	87.67	894
Ghazi Barotha	51.75	749	48.25	36	87.75	1272
Told Daily average	51.00	3002	49.00	36.7	87.37	5340

For Pakistan, we find that through the conventional (without increasing the load factor by use of pumped storage generation) design/ construction of hydro/ thermal plants. There seems no hope to meet our energy requirements in an economical way. Present/ Future average scenario of load factor/ generation/ capabilities is shown in Table-4.

Daily Average with/without Pumped Storage
Load Factor (LF) and the Generation Capabilities Table - 4
(With two Future Plants)

Plant	Average Load Factor in Conventional Method %	Load Factor with Pumped Storage %	Average Capability in Conventional Method MW	Average Capability with Pumped Storage MW
Tarbela	46	87	1697	3174
Tarbela Ext. – 4	46	100	441	960
Mangla	55	88	556	894
Ghazi Barotha HPP	52	88	749	1272
Kalabagh	51 (Liberal side)	88	1836	3200
Basha	51 (Liberal side)	88	2300	4000
Total			7579	13500

Present Load = 8000 MW

Load in 2016 at the increase of 400 MW/ year = 12000 MW

Above discussion leads to the following conclusions

i) Without Pumped Storage;

Total average daily generation (in year 2003-2004) in Pakistan 189.00 Mkwh

Average daily hydel generation 71.23 Mkwh

Ratio between Hydel and total *generation* 0.376

ii) With pumped storage only at Tarbela:

Average daily hydel generation $\frac{4479}{1000} \times 24$ Mkwh

107.49 Mkwh

Ratio between Hydel and total *generation* 0.568

iii) With pumped storage at all the three existing plants

Average daily hydel generation	128.16 Mkwh
Ratio between Hydel and total generation	0.678

iv) Tarbela 4th extension

By providing reversible Pumped Storage generation in the future extension 4 project, we can get further 960 MW which is equivalent to 23.04 MKwh.

v) Changing the present conventional design of Kala Bagh Dam plant to the mixture (55% conventional + 45% reversible pumped storage) the total average generation can be increased to 76.68 MKwh.

	= (3600x0.55) + [(3600x0.45) x 0.75]
	= 1980+1215=3195 MW
Daily average generation	= 76.68 MKwh
Total hydel daily generation	= 151.2+76.68= 227.88 MKwh

vi) Changing the present conventional design of Basha Dam Project to the mixture (55% conventional+45% reversible pumped storage)

Total average hydel increase	= (4500x0.55)+[(4500x0.45)x0.75]
	= 2475+1518.75= 3994 MW
Daily average generation	= 95.86 MKwh
Total hydel daily generation	= 227.88+95.86
	= 323.74 MKwh say 324 MKwh

324 MKwh average daily hydel generation is about 70% more than the total (hydel+thermal) present generation in Pakistan. It means that we will become self sufficient with some surplus for possible export and simultaneously we can get rid of or at least reasonably reduce the thermal component just after the construction of Kala Bagh Dam Project and Basha Dam Projects.

Thus, it emerges that during the year, the unutilized hydel capacity of existing plants can be used in pumping and future hydel plants can be designed in conjunction with pumped storage generation so that the maximum hydel component is achieved. *(Table-1 to 3, Fig 10 (a-d))*

8. Planning for the Future

"Prior planning prevents poor performance". It should be possible to think in term of international super grids in the future for which a number of countries may cooperate with each other to make the best use of the different resources available

for power generation. Example is the EU, which is getting the benefits of cooperative efforts in the integrated thermal, nuclear and hydel power stations. There should, therefore, be no hesitation to change/improve our present stations of □ 60% load factor and design future plants having load factor > 80% throughout the year. For this purpose; paras 3 & 4 in view, presently, at Tarbela *(Figure-9)* we have;

a) High Level Reservoir (Tarbela) with,
   - i) Maximum conservation level - 472.41 m.
   - ii) Crest of Main Dam - 477.90 m.

b) Low Level Reservoir (Ghazi) with,
   - i) Maximum conservation level - 341.50 m.
   - ii) Crest of Barrage - 342.00 m.
   - iii) Live storage capacity - 60.20 M. m^3.

c) The Conduit system for generation

d) Transmission lines connecting to / from the National Grid

Only additional machinery along with pipe system has to be provided for pumping. Similarly the provision of pumped generation at future plants at Indus / Jhelum rivers should be checked.

At present the average daily capability of Tarbela is about 1700 MW due to low reservoir and average daily generation is 41 Mkwh. By installing pumping we can enhance the average daily capability to say 3174 Mw where as average daily generation can be increased from 41 Mkwh to 83.4 Mkwh. Load factor of the system will increase accordingly. Hence Tarbela can be upgraded in two phases. In first phase only pumping upto 1500 MW is suggested and in 2nd phase extension 4 of Tarbela be carried out by installation of reversible units. For 100 cumecs of pumping nearly 192 MW motor is required at Terbela. Experts services are available in the market.

Even for Mangla and Barotha powerhouses, it appears feasible that by installing the pumping arrangements and providing suitable downstream ponding weirs, the hydel capability can be increased to 5340 MW and average daily hydel generation can be enhanced to 128.16 Mkwh. A proper feasibility study should be carried out.

Construction of future dams through conventional design, method /systems at Indus/Jhelum rivers cannot increase the load factor, and hence, it cannot decrease the unit cost of generation. Therefore, there is pressing need that conventional design be changed, and about 45% provision of the pumped storage generation be incorporated in all the future plants.

9. Other Requirements / Implications

This is a Concept Paper and, the other important aspects such as type and working of plant, site selection, lake classification / machinery and power house for pumped storage plants should be taken care of through proper feasibility studies and reports.

Pumped storage stations can adopt a number of roles within the operation of an electrical supply grid, and can perform some of these roles concurrently. It is common for the operation of pumped storage plant to vary over time as they are to respond to changing market conditions. *(Annex-2)*

The environmental impact of pumped storage stations is usually much less than that of a conventional hydropower station since the required downstream water storage is usually much smaller in size. The need for a pump-priming head usually positions the pump-turbine below the level of lower reservoir, often underground. The typical design life of a pumped storage station is 80-100 years.

The principle areas of pumped storage benefits can be summarized as under:

a) Improved energy regulation and operation of the supply grid

b) Delivers ancillary services to the supply grid, such as standby and reserve duties, frequency control, and flexible reactive loading

c) No gaseous emissions and have little environmental impact during its operation

d) Allows flexible and rewarding commercial operations across a variety of electrical power supply scenarios.

e) Availability of water is enhanced through recirculation. Agricultural areas can be increased.

10. Recommendations

- Pumped storage and generation appears most feasible for Tarbela Dam. A proper feasibility should be carried out by HEPO or through some outside consulting firm.
- A study of all existing hydel plants be conducted to investigate the potential for pumped storage and installation of pumps / reversible plants.
- For future plants, it is recommended to study the possibility for about 45% supplemental provision of pumped storage generation.
- When the cheap hydro-energy and water are made available in abundance the agricultural areas can be increased through tube wells by extending transmission lines in those areas.
- Construction of future thermal plants be avoided or discouraged and taken up only under special circumstances.

11. References:

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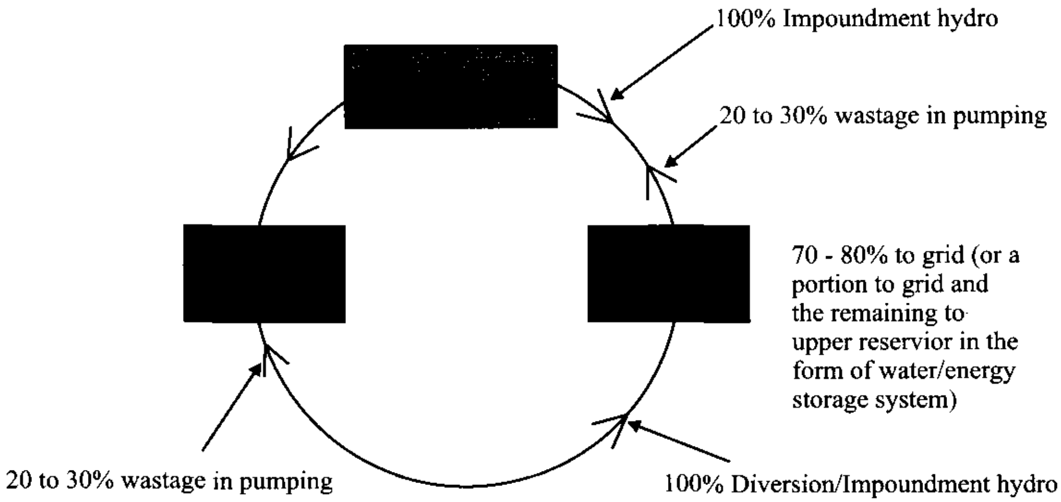

Figure 1: Three efficient types of hydro power generation

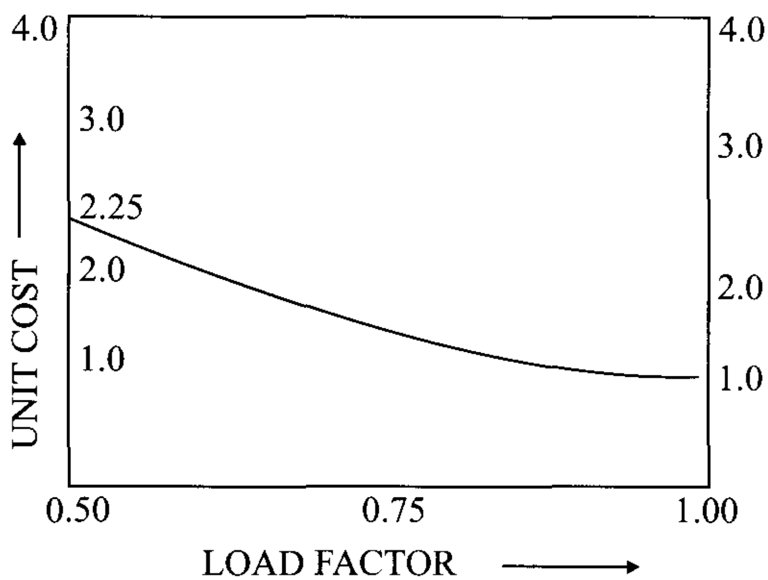

Figure 2: Curve of Unit Cost V/s Loaf Factor

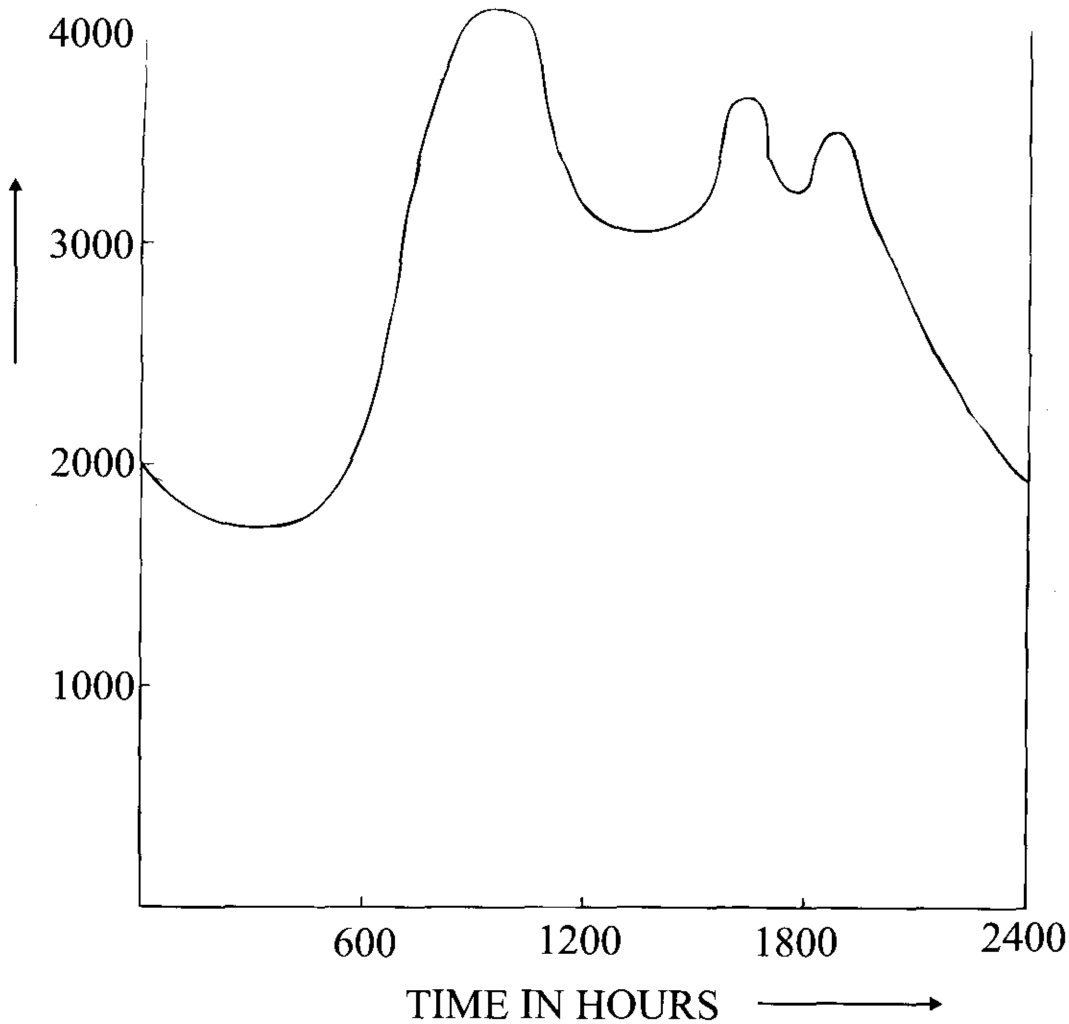

Figure 3: Daily load curve of a network

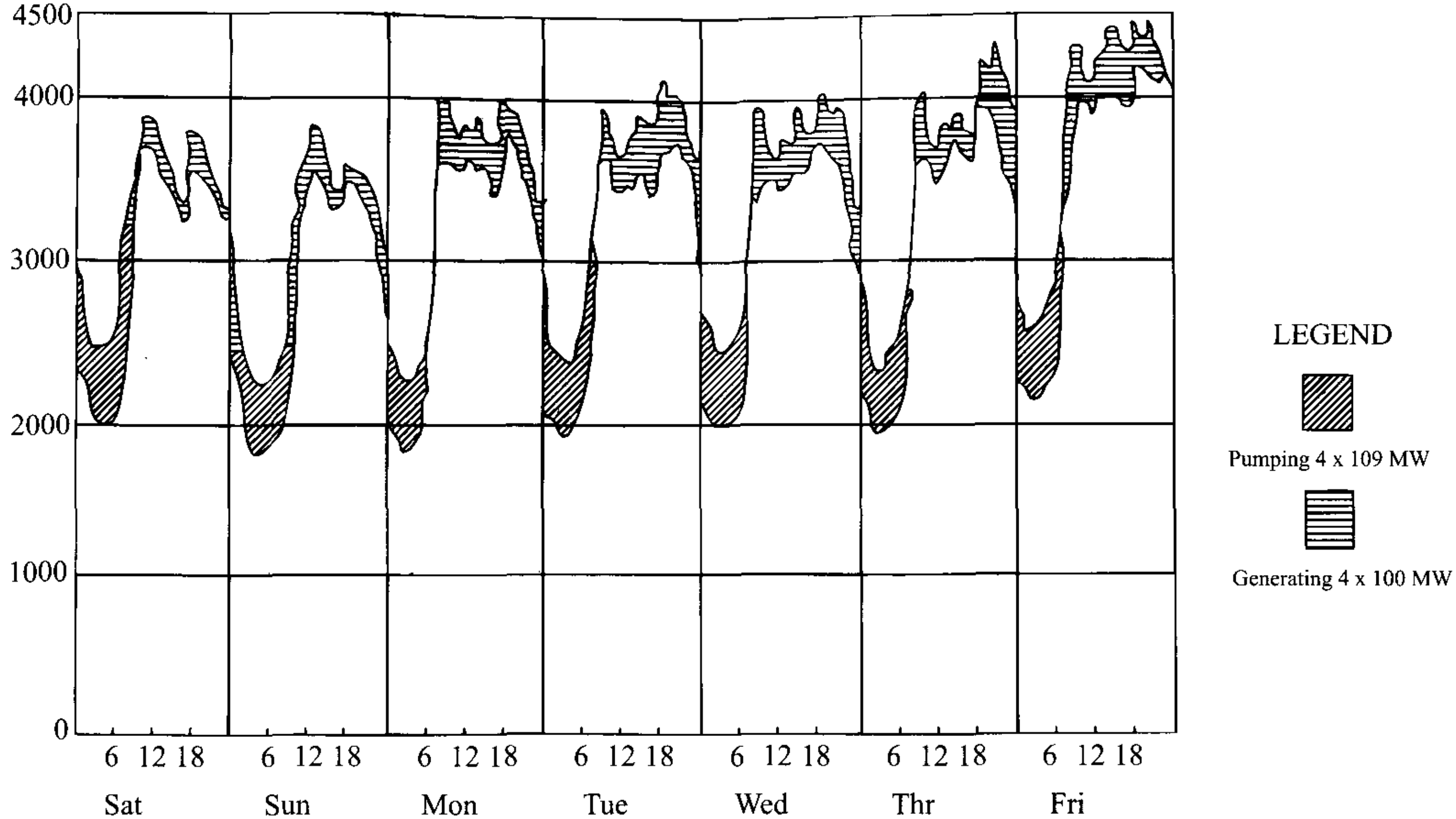

Figure 4: Weekly operation of a power Grid in conjunction with Pumped Storage arrangements

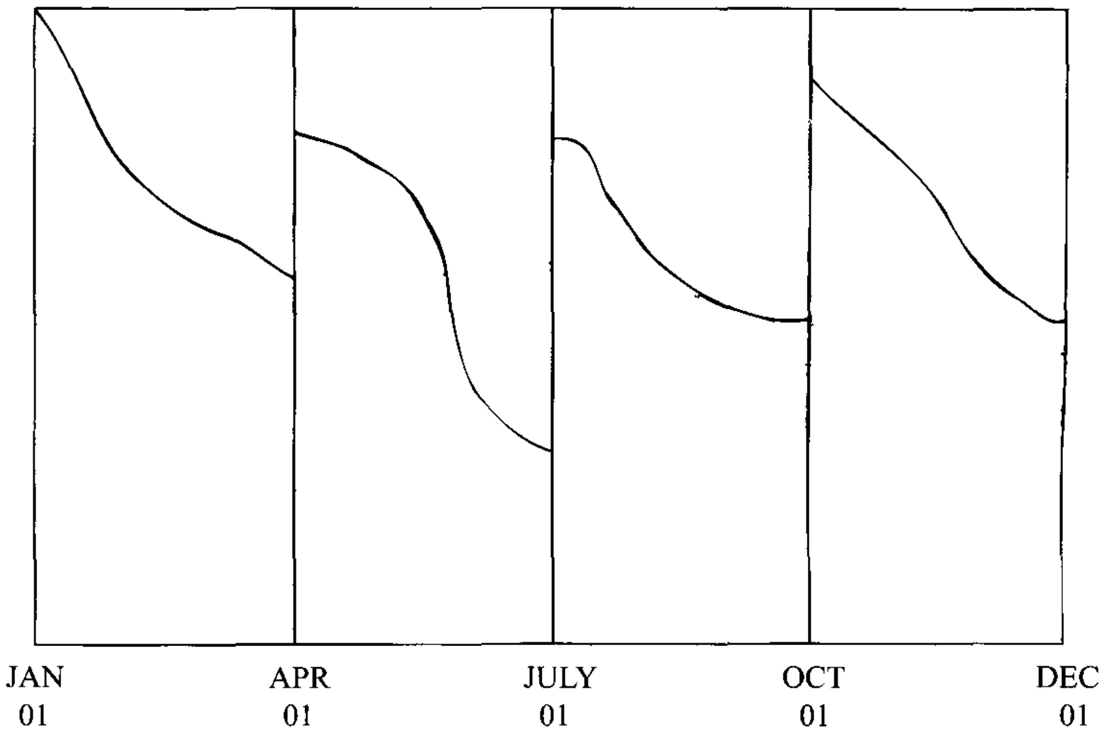

Figure 5: Quarterly load duration curve

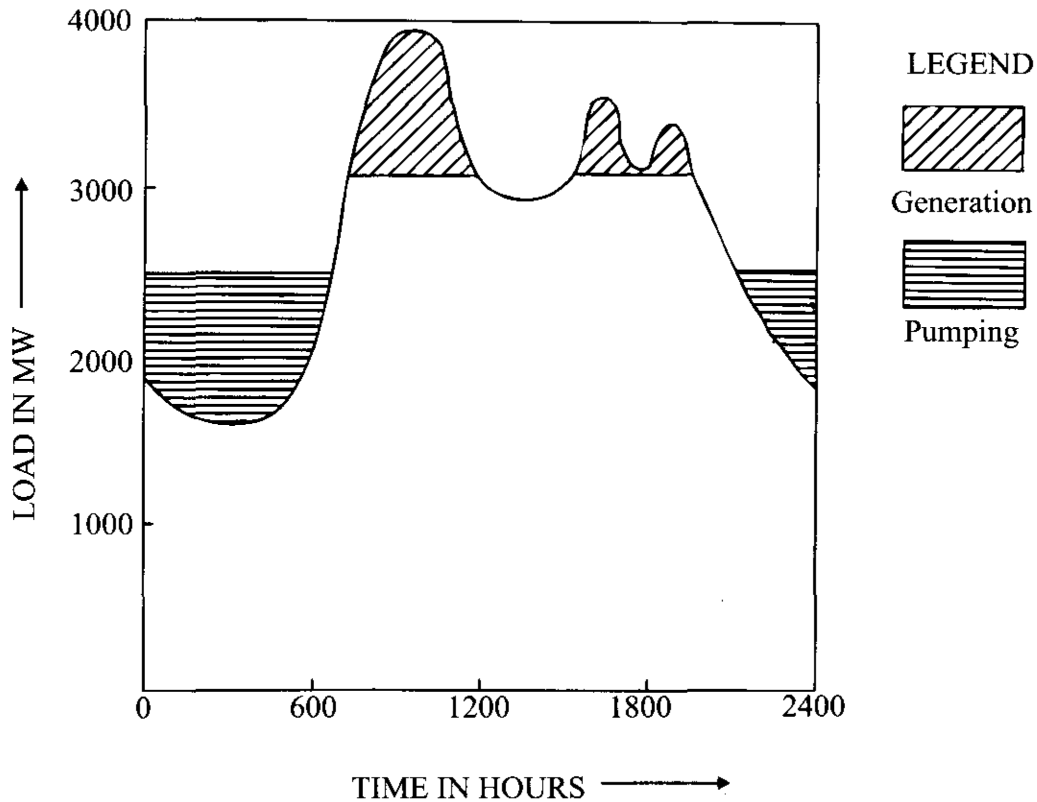

Figure 6: Load curve of a network with pumped storage arrangements

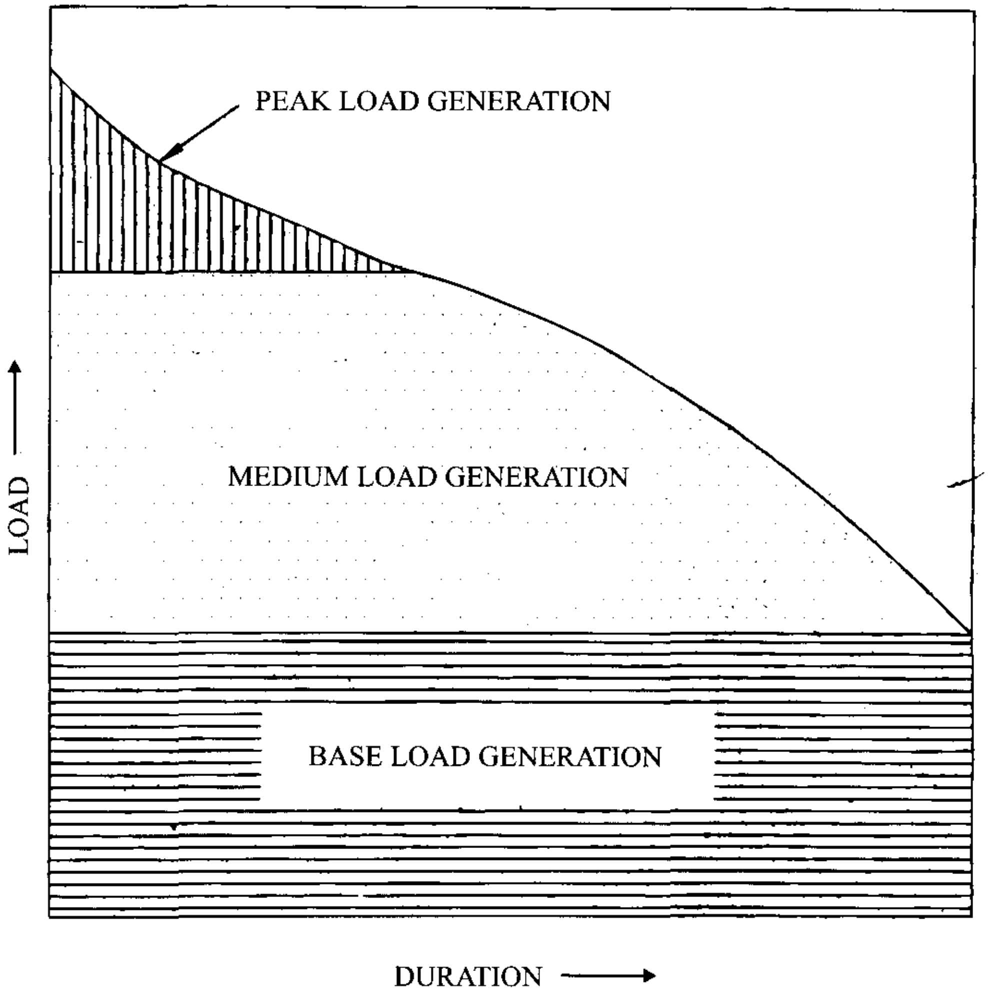

Figure 7: Annual load duration curve (Typical)

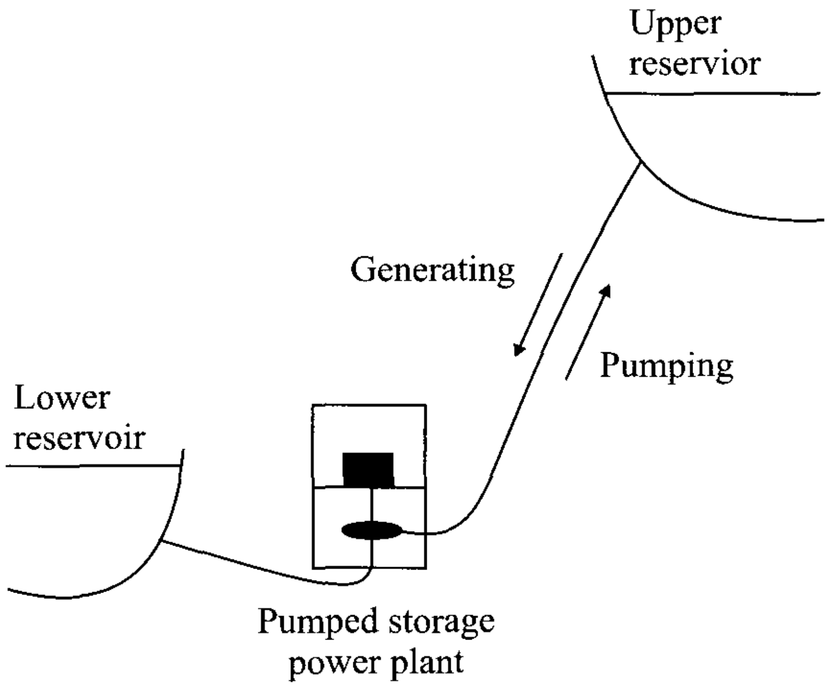

Figure 8: Pumped Storage scheme configuration

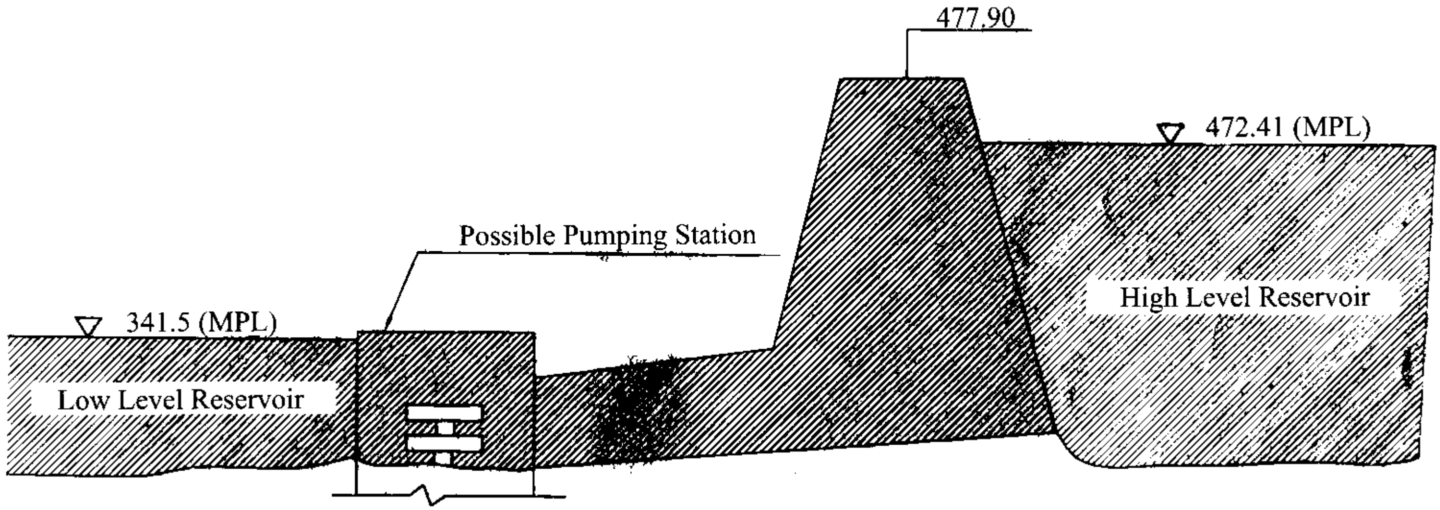

Figure 9: Present Scenario of lakes at Tarbela
with Possible pumping arrangements

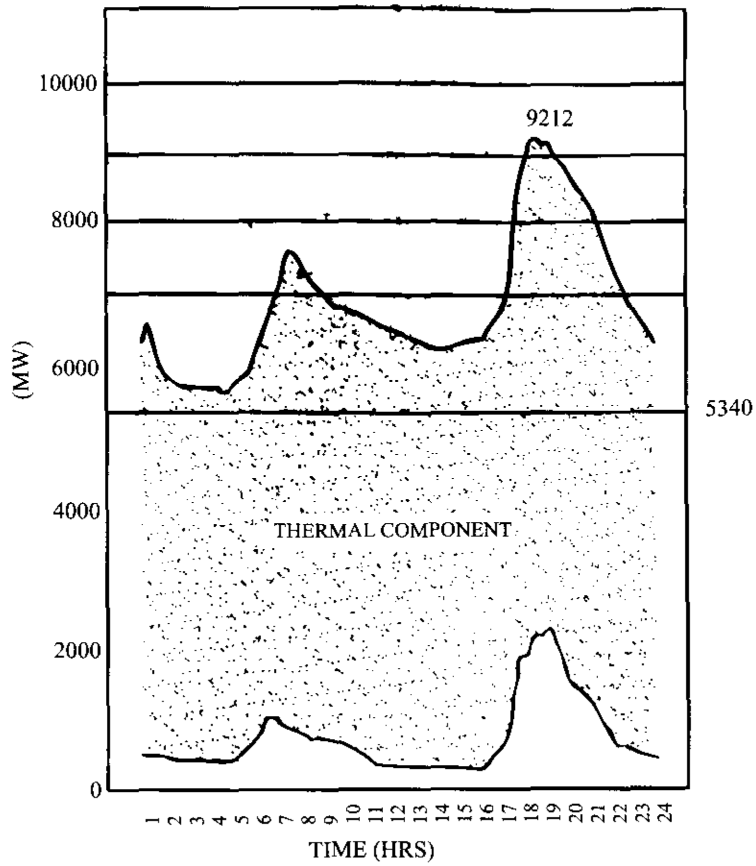

Figure 10(a):

Load Curves in Pakistan on Jan 10, 2004
Total = Top
Hydel = Bottom (without pumped storage)
= Middle (Average daily Hydel with pumped storage)

Note: After the full provision of pumped storage in existing plants thermal component below middle line will be converted to hydel component.

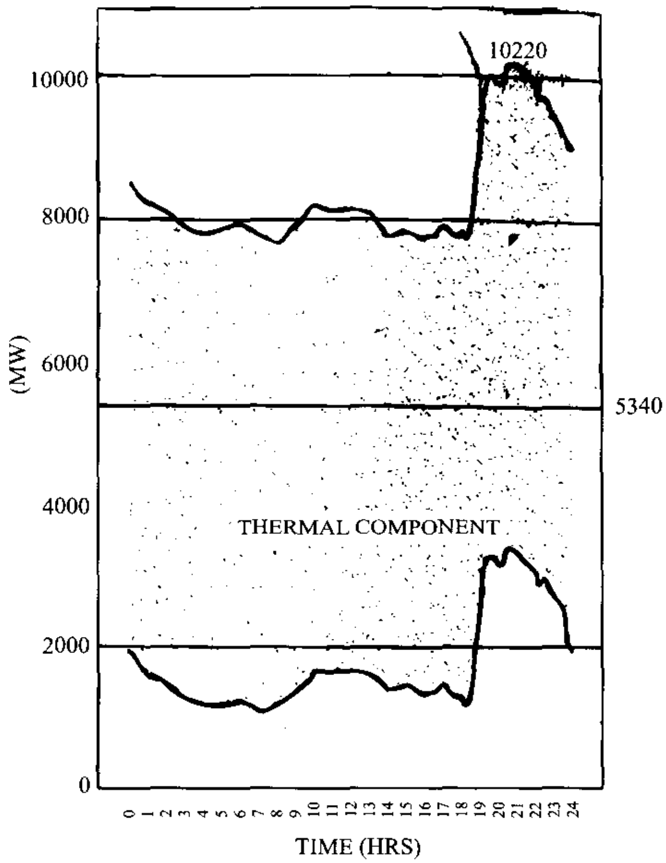

Figure 10(b):

Load Curves in Pakistan on Apr 10, 2004
Total = Top
Hydel = Bottom (without pumped storage)
= Middle (Average daily Hydel with pumped storage)

Note: After the full provision of pumped storage in existing plants thermal component below middle line will be converted to hydel component.

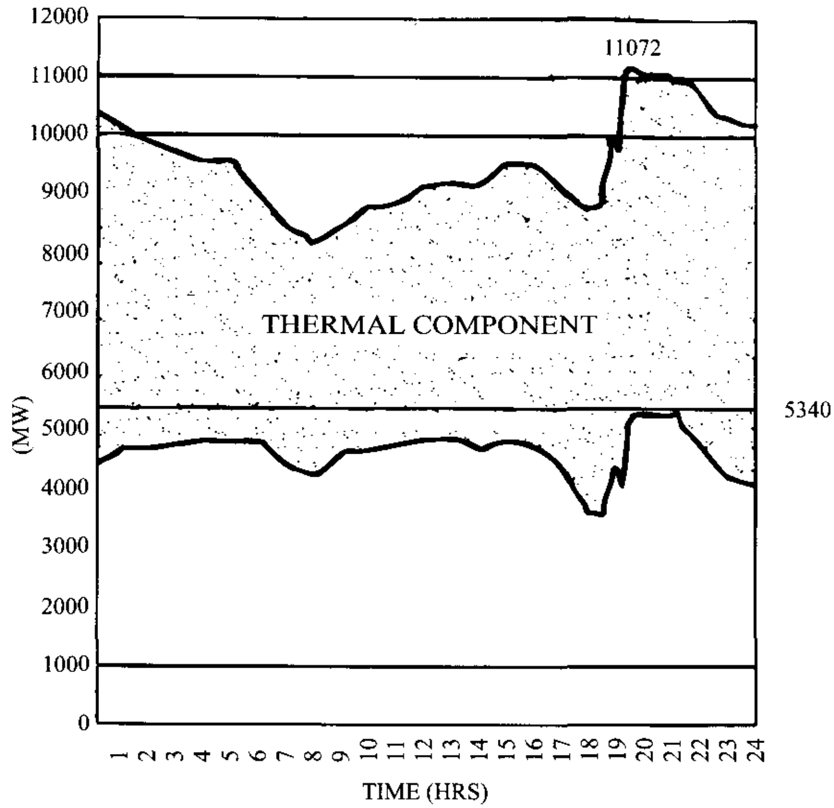

Figure 10(c):

Load Curves in Pakistan on Aug 20, 2004
Total = Top
Hydel = Bottom (without pumped storage)
= Middle (Average daily Hydel with pumped storage)

Note: After the full provision of pumped storage in existing plants thermal component below middle line will be converted to hydel component.