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MANGLA DAM - PAST, PRESENT & FUTURE

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MANGLA DAM - PAST, PRESENT & FUTURE

By:

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Abstract

The scheme of creating a reservoir on river Jhelum at Mangla primarily for irrigation development conceived in 1950s was translated into reality in 1960s as part of Indus Basin Replacement Works. Despite odd condition encountered on discovery of sheared clays in Siwalik bedrock and late inclusion of Jari dam, the project was put in to operation in 1967, one year ahead of schedule. In 45 years of its operation, Mangla Dam Project has performed very well and contributed to both irrigation and power sectors of the national economy. In addition Mangla reservoir has alleviated flood damages by absorbing/reducing the flood peaks. Sediment has deposited in the reservoir at a rate of about half of the originally predicted.

Provision of raising the dam was kept in its design and original construction, which has been realized in the first decade of the new millennium. By raising of the dam, not only the reservoir capacity lost to sedimentation has been regained but additional capacity has also been made available for future sedimentation and storage of excess water which was being lost as flood releases in monsoon season. The addition of 2.9 million acre feet storage capacity to the limited national storages on rivers is also welcome since no substantial storage was otherwise added after completion of Tarbela Dam in 1970s.

On Mangla Dam Project, two-time resettlement has taken place. At the time of resettlement on original construction of the dam in 1960's, the adverse social impacts of resettlement were under estimated and most of the affectees allotted land for land could not settle in Punjab and Sindh provinces due to unfavourable conditions. The recent resettlement for the dam raising had plans developed in consultation with affectees and all the displaced population is being relocated in close vicinity. For this purpose, a new city near Mirpur and four towns around the reservoir have been developed. Livelihood development of the affected population has also been given due consideration.

Future of Mangla Dam is promising but at the same time demanding. For decades to come, additional water would be available as a benefit of raising the dam contributing both towards irrigated agriculture and hydropower generation. Power generation would be further enhanced by improved efficiency of refurbished/replaced generating units, as most of the existing ten units are already old enough to be attended to beyond routine maintenance.

A challenge to be faced in the coming decades would be approaching of sediment delta too close to power intakes associated with increase in concentration of sediment in water passing through turbines. Apart from its implications on turbines, excessive sediment deposition in Jhelum river channel between Mangla and Rasool Barrage would cause adverse morphological changes in the river basin and affect the irrigation system downstream.

It is therefore, high time that comprehensive study of conjugate sediment management, in Mangla Reservoir and the river basin downstream, be initiated and thereby a comparative evaluation of the potential management options be carried out to cope with the challenge for smooth and beneficial functioning of the project in future.

Key Words: Mangla dam, dam raising, resettlement, sedimentation, reservoir.

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Introduction

Since completion of Tarbela dam in 70's, the recent addition of 2.9 million acre feet (MAF) in the storage capacity of the country's reservoirs is like cool breeze in summer. This is achieved through raising of Mangla dam and coincides with the Centenary Celebration of Pakistan Engineering Congress. Befitting this occasion, history of Mangla dam is recapitulated, salient aspects of its raising are presented and attention is drawn to the future engineering needs for continuity in reaping irrigation and power benefits from this mega project.

Salient Features

The project (see plan on next page) includes four major zoned earth fill embankments with a total length of over 13 km and a maximum height of 454 ft. above core trench. The orifice-type main spillway has a design discharge capacity of 1.01 million cusecs. An un-gated, overflow-type emergency spillway with a design capacity of 0.23 million cusecs is provided for exceptional operation. For the ten power plant units of 100 MW each, there are five tunnels, each with a fixed wheel gate on the intake. The irrigation valves have been provided to supplement irrigation demands when the power house releases are less than the demand.

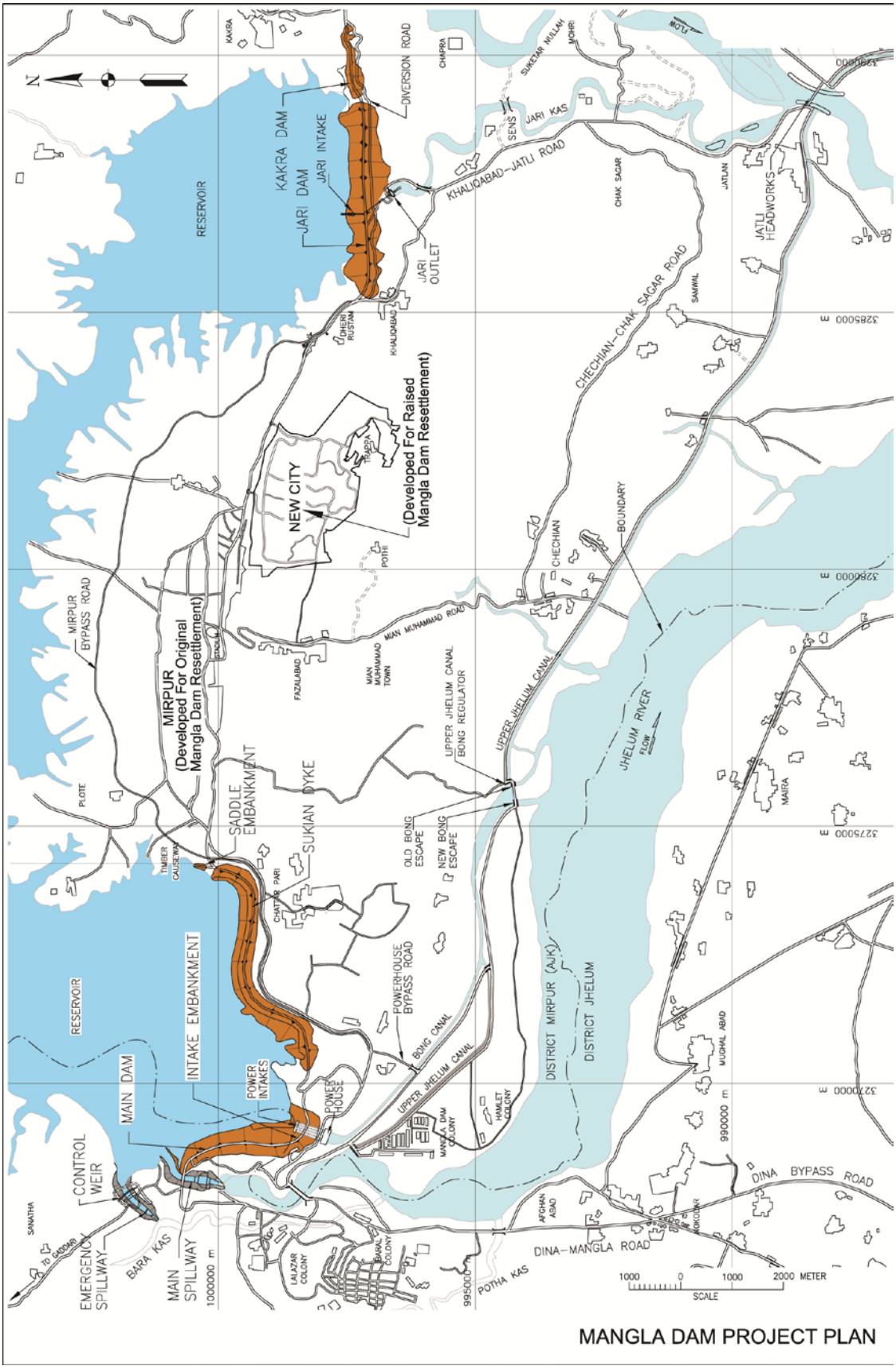
The Jari outlet consists of an intake, a tunnel and a regulating valve on the downstream end of the tunnel. The intake is fitted with a fixed wheel hydraulically operated gate. The outlet is used for municipal supply of water and to supplement irrigation demands when Jari reservoir gets separated from the main reservoir.

The project area rocks belong to Siwaliks group with ages ranging from Pliocene to lower Pleistocene and comprise alternate beds of sandstone and siltstone with clays and gravel beds at places. The sandstone beds are fine to medium grained and 90% of the beds are poorly cemented. The siltstone and clay beds are quite hard. The beds containing appreciable clay fraction, shrink rapidly and cracks develop when exposed to air. The clay beds are strongly stratified and are intersected by a number of discontinuities. Shear zones are found in a number of clay beds and are believed to have been formed by bedding slip during the folding of the Siwaliks series. The shear zones often occur near the top of clay beds that are overlain by thick sandstone beds. Gravel beds contain lenses of silt, sand and occasionally sandstone.

History

The storage reservoirs developed at Mangla and Tarbela play a major role in supply of irrigation water to the Indus plain and generation of hydropower in Pakistan. Prior to the development of these dam projects, irrigation water for the commanded area of the Indus plains was provided entirely from unregulated run-of-river flows of the Indus system. Water supplies for irrigation were subject to seasonal and year-to-year variation and crop failures were common.

Mangla dam was the first major storage project developed in Pakistan to provide a more reliable supply of water. The scheme for creating storage reservoir on river Jhelum at Mangla was initiated in 1951 by Punjab Irrigation Department. In 1952, it was transferred to Dam Investigation Circle under Central Government and feasibility study of a dam at Mangla was carried out. The consultants, in their report submitted in 1954, recommended 346 ft. high dam, having a gross storage capacity of 4.1 MAF. In 1957, Government of Pakistan set up Mangla Dam Organization and project planning study was carried out. In December 1958, the consultants submitted their report recommending 380 ft. high dam, creating a reservoir of 5.35 MAF gross storage capacity. In 1960 Mangla dam project was included in the Indus Basin replacement works because of its effectiveness in regulating the western rivers for transfer of replacement supplies when the eastern rivers were diverted by India.


KAKRA DAM
JARI DAM
JARI INTAKE
DIVERSION ROAD
RESERVOIR
JARI OUTLET
KHALIQABAD–JATLI ROAD
JARI KAS
SEHS
CHAK SAGAR
JATLI HEADWORKS
CHECHIAN–CHAK SAGAR ROAD
NEW CITY
(Developed For Raised Mangla Dam Resettlement)
MIRPUR
(Developed For Original Mangla Dam Resettlement)
MIRPUR BYPASS ROAD
MIAN MUHAMMAD ROAD
FAZALABAD
MIAN MUHAMMAD TOWN
CHECHIAN
BOUNDARY
UPPER JHELUM CANAL
UPPER JHELUM CANAL BONG REGULATOR
JHELUM RIVER
SADDLE EMBANKMENT
SUKIAN DYKE
OLD BONG ESCAPE
NEW BONG ESCAPE
POWERHOUSE BYPASS ROAD
BONG CANAL
INTAKE EMBANKMENT
POWER INTAKES
POWER HOUSE
MAIN DAM
CONTROL WEIR
EMERGENCY SPILLWAY
MAIN SPILLWAY
BARA KAS
POTHA KAS
DISTRICT MIRPUR (AJK)
DISTRICT JHELUM
DINA BYPASS ROAD
DINA–MANGLA ROAD
MANGLA DAM COLONY
HAMLET COLONY
LALAZAR COLONY
KANAL COLONY
AFGHAN ABAD
MUGHAL ABAD
MAIRA
SAMWAL
POTHI
PLOTE
SAWATHA
TO GADDAR
SCALE
1000 0 1000 2000 METER
MANGLA DAM PROJECT PLAN

The original construction

Construction contract for the project was awarded to a consortium of eight American firms in 1962. It was the largest single project undertaken under competitive bidding in the world at that time. Despite series of odd conditions during construction; like discovery of sheared clays and Indo-Pak war during river diversion, the works were completed in July 1967, one year ahead of schedule. The construction involved 120 million yd^3 of excavation, 142 million yd^3 of earth fill and 2.1 million yd^3 of concrete.

In appreciation of the fact that one cannot get enough information about the foundation of large engineering works unless it is opened up, the principle of "design as you build" was adopted for this dam. As a result, the contract design was liberally changed to make it in line with any new information gathered during construction. The discovery of sheared clay zones in the foundation of various works was indeed a big event which required significant design changes; such as addition of toe weight to the embankments, improving drainage measures of the structures to cater increased pore pressure, flattening of the cut slopes to improve stability, etc. Steel lining for Tunnels 1 to 4 was extended to the upstream portion, along with reduction of its diameter from 30 ft. to 26 ft.

The project initially included a 40 ft. high dyke at Mirpur ridge, to close the gap on the eastern periphery of the reservoir. The dyke was to be founded on a thick silt deposit. The review board for the project opined that the silt foundations were incompetent to support the proposed dyke, particularly during earthquake. This led to shifting of reservoir rim closing at Jari nullah, about 9 km south east of the ridge, with 274 ft. high dam. As a result, the storage capacity of the reservoir increased from 5.35 to 5.88 MAF.

Due to late inclusion of Jari dam in the project, its contract design was rather scanty which was significantly improved as a result of investigations carried out during construction and information revealed during foundation excavation. Similarly, design of emergency spillway was substantially beefed up as a result of further investigations and studies made during the construction.

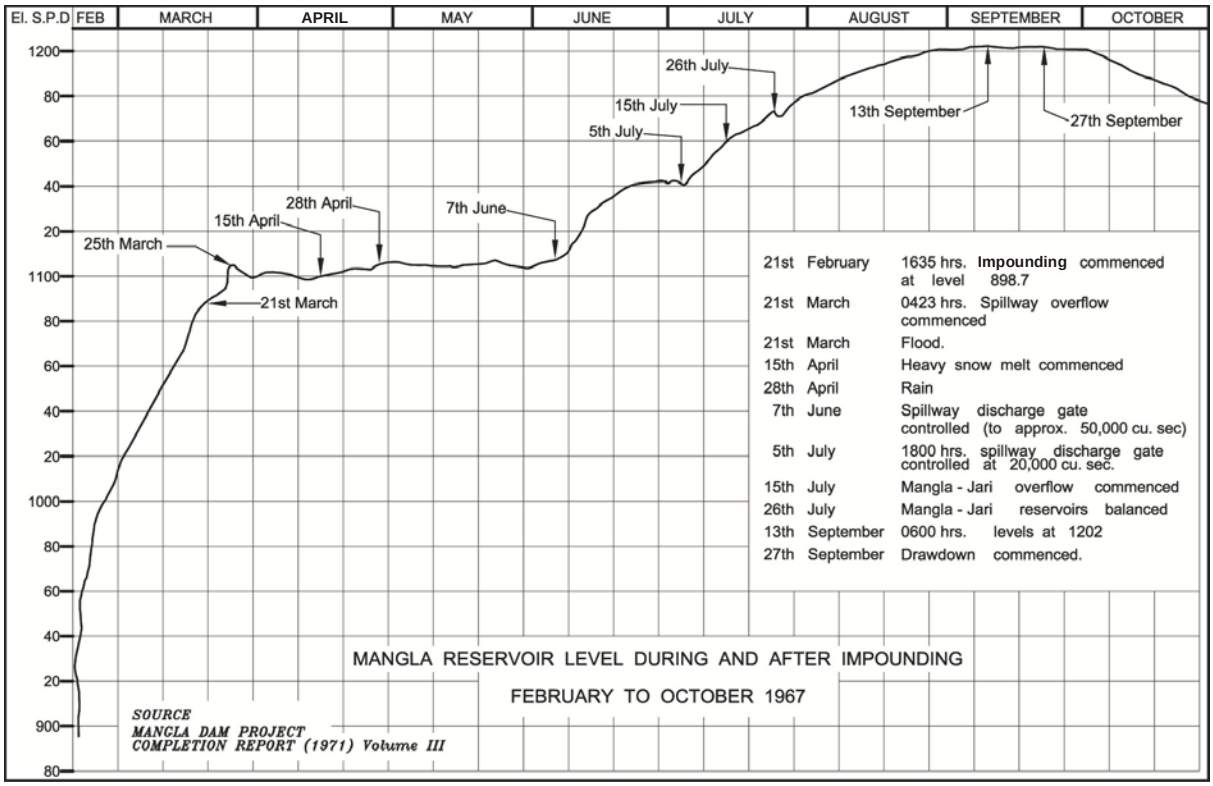
The powerhouse was designed to accommodate ten generator units, each 100 MW. However, the initial installation included three units and in the following years, additional units were installed until 1994 when all ten units were in operation. The total investment cost of the Mangla project is recorded as US$ 627 million, most of which was directed to completion of the initial project works in the 1960's but also including later expenditures to increase the power generation capacity to 1000 MW. There was an additional cost of US$ 90 million on resettlement.

Performance

The first impounding of Mangla reservoir was carried out in February-October 1967 at a rate of about 6 ft/day for the lower 200 ft. depth and about 1 ft/day for the upper 100 ft filling. Since then the project has performed as designed. Sedimentation has occurred at a rate below what was anticipated at the time of design. The overall performance of the various project components remained very satisfactory. The main spillway performed very well when the large flood of 1992 was passed at very near to its design capacity. The performance of its gate equipment also remained very satisfactory. However, there have been foundation seepages and build up of pore water pressures at places in the sandstone beds underlying main dam and Sukian dyke. The excessive seepages were addressed and necessary remedial works undertaken as part of the dam raising works.

The project was well instrumented at the time of its original construction in 1960's. A total of 673 instruments were installed to monitor the performance of various structures during construction,

reservoir impounding and operation. The instruments were provided with sufficient redundancy for critical installations to deliver meaningful measurements. They provided an excellent data base for the dam raising design. After over four decades of use, 40% of electrical piezometers, 92% of hydraulic piezometers and 76% of Casagrande pots were still in good working condition.



In addition to the water conservation and power generation benefits, the enormous flood control benefits, which accrued from Mangla dam deserve to be mentioned in the context of pre-Mangla scenario. Prior to completion of Mangla dam, floods frequently took a heavy toll of life and property in the Jhelum watershed. The peak flow of over one million cusecs in 1929 was reported to have inundated a large area of Jhelum city, causing loss of life and damage to property. In 1948, when peak discharge was 440,000 cusecs, 271 villages were affected and 30 were completely destroyed. The 1959 flood, when the peak discharge was 830,000 cusecs, affected 442 villages, washing away 77 of them. Fifteen lives were lost and over 10,000 houses were destroyed in that flood.

Since its completion in 1967, Mangla dam has successfully been able to shave the peak flows to eliminate/reduce the downstream damages that would otherwise have occurred. Even in 1992, when flood damage was reported to be in excess of US $ 2 billion, Mangla reduced the peak flow by 15 to 20 percent.

Alternatives to Mangla raising

In an attempt to avert second time displacement of huge population for the expanded Mangla reservoir, alternatives to raising of the dam were considered, which mainly included (i) constructing a number of storage dams upstream of Mangla and (ii) desilting Mangla reservoir.

Jhelum basin comprises five rivers; namely Jhelum, Poonch, Kunhar, Neelum and Kanshi. Generally the following unfavourable conditions exist on potential storage sites on these rivers, upstream of Mangla.

- Steep gradients of the rivers, requiring high dams even for small storages.
- Narrow river valleys, possessing small storage potential.
- Adverse geological conditions, adding to the project costs.
- Large spillway requirements against small storage capacities.
- Large population displacement.
- Inundation of towns, villages, infrastructure and cultivated land.

Because of small storage potentials coupled with highly unfavourable conditions, storage dams upstream of Mangla are technically and socio-economically not feasible; though their hydropower potential can be gainfully exploited.

Desilting of reservoir through dredging was considered. Some local dredging could be carried out in the reservoir as has been done for removal of sediment deposited on top of the existing intake toe weight berm as part of the dam raising works. But it has been practiced nowhere for desilting of large reservoirs. For prevention of further loss of Mangla reservoir capacity, one truck carrying 10 tonnes dry weight of sediment would have been required to leave the site every 5 seconds for ever. It is not practical. Moreover, disposal of huge quantities of dredged silt would have adverse environmental implications.

Raising of Mangla Dam was therefore adopted as an optimum solution as a long term strategy to compensate for the reservoir capacity lost to sediment deposition.

Dam raising

The provision for raising of the dam by 40 ft. kept in the original design and construction of the dam was re-examined through a feasibility study in year 2000. It was prudent to carry out the study due to a time gap of over three decades since the original construction. During this time, understanding of the geology, seismicity and hydrology of the area around Mangla had advanced significantly. In addition, design standards had changed, and communities had grown on the shoreline. The feasibility study (MJV 2001) looked at raising the dam by 20, 30 and 40 ft. and concluded 30 ft raising as the optimum choice from socio-economic considerations. The benefits of raising include, additional average annual water conservation of 2.88 MAF and 644 GWh of energy. Except for exceptionally high flood events, the flow peaks will be absorbed in the reservoir, thus enhancing the flood alleviation benefit.

The dam raising works included 30 ft raising of main dam, Sukian dyke and Jari/Kakra dam, throttling of the main spillway orifices by 5 ft. raising of the sill level, construction of concrete gravity control weir replacing erodible bund in approach channel of emergency spillway and shifting of gates hoisting equipment of power intake and Jari intake from the original crest to the raised crest level. In addition, drainage wells were installed in the foundations of main dam and control weir and foundation seepage control works were carried out for Sukian dyke, which included placement of upstream impervious blanket and construction of filtered drainage trenches along nullahs in the downstream. All these works were carried out while meeting the seasonal water storage requirements, keeping the reservoir operational and meeting the power and irrigation water demands.

The dam raising works were carried out under a single contract by a joint venture of indigenous firms led by Chinese firm from June 2004 to December 2009. The works were completed with a delay of 27 months for various reasons. The construction involved about 42 million yd^3 of earth fill, 55,000 yd^3 of roller compacted concrete and 145,000 yd^3 of conventionally vibrated concrete. Cost of the dam raising works was of the order of Rs. 17 billion.

Constraints were imposed on the dam raising works schedule for keeping the project operations virtually uninterrupted with regard to seasonal filling of the reservoir, irrigation releases, power generation and flood routing. The schedule of works on embankments, main spillway and power intakes was largely influenced by the constraints.

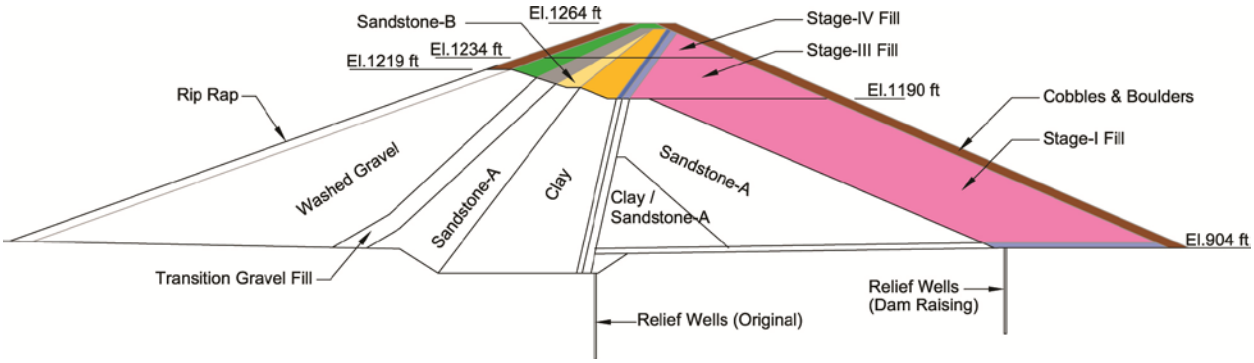
Observing the constraints, raising of the embankments was achieved typically in four stages. For the main dam, the construction stages are shown in the following and comprised:

(i) Construction of extended downstream shoulder starting from foundation level,

(ii) Excavation of dam crest to a depth of up to 44 ft.

(iii) Rebuilding of wider dam section to the original crest level, and

(iv) Raising of the dam from original crest level to the raised crest level.



Placement of a number of earth fill zones side by side without intermingling on the interfaces was a meticulous job as shown below for Jari dam.

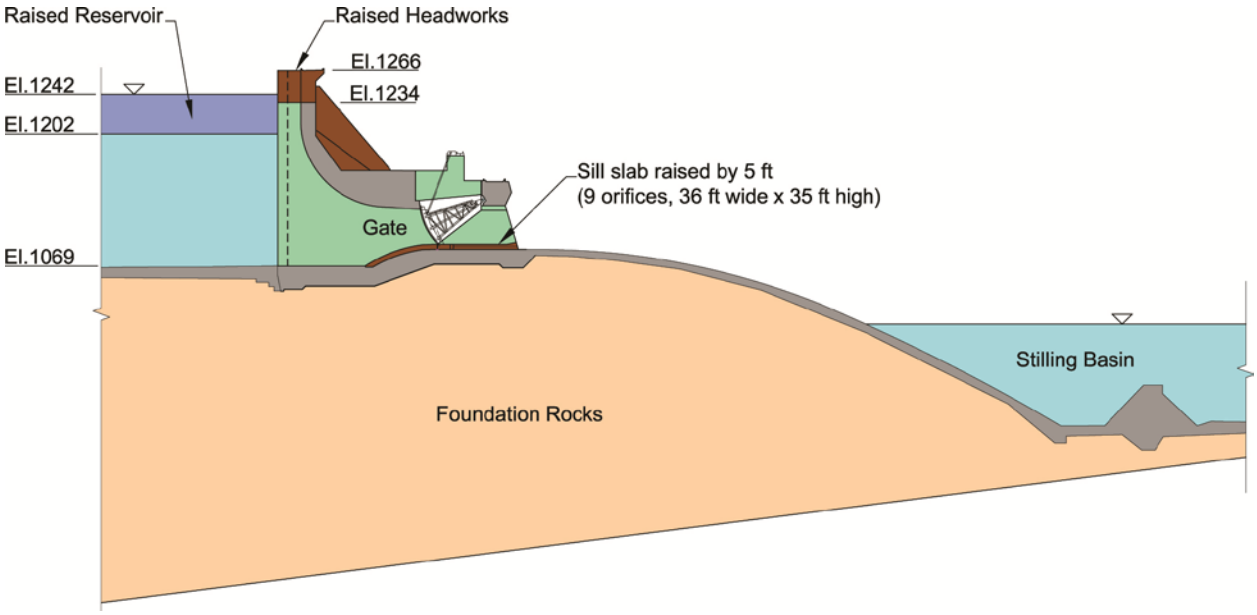


The works associated with main spillway included:

(i) Raising the sill level of the nine orifices by 5 ft.

(ii) Raising head works, wing walls and buttresses, and

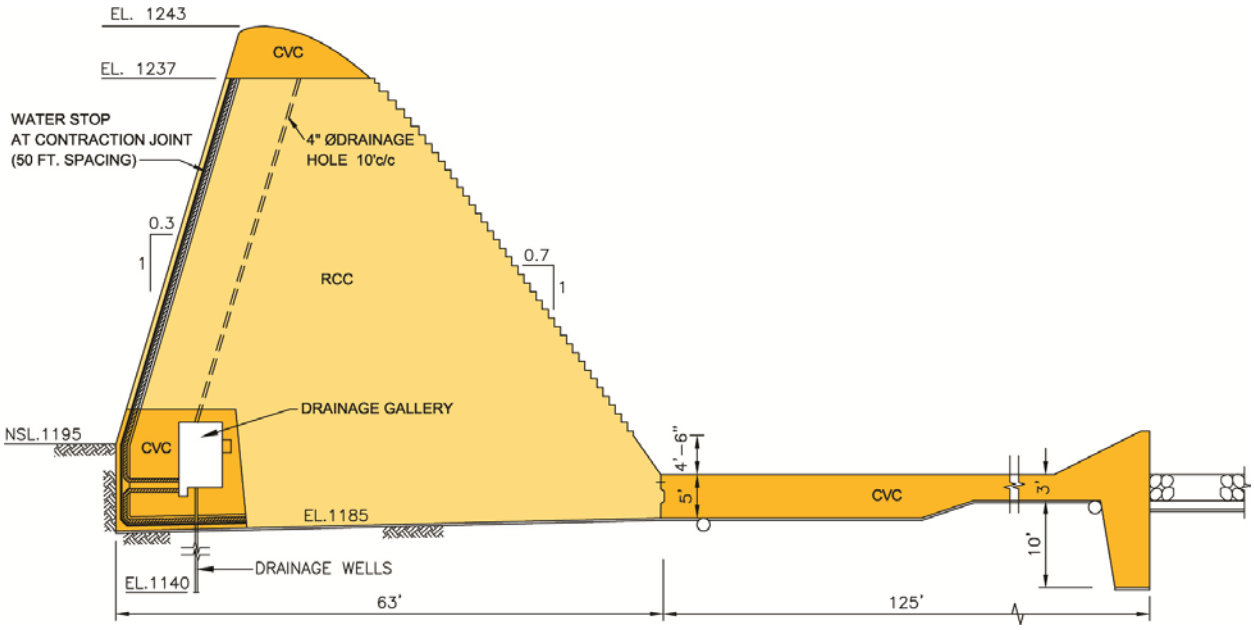
(iii) Construction of new buttresses.



On completion of the raising works, smooth flow through spillway with adequate aeration was achieved as shown below for partial opening of the orifice gate.



The 81 high gravity structure of the Control Weir was constructed mainly of roller compacted concrete (RCC), whereas the other components including stilling basin, retaining walls and weir abutments were constructed of conventionally vibrated concrete. A curtain of drainage wells was provided in the weir foundations to relieve the hydrostatic up lift pressures.



After completion of the raising works, high intensity monsoon rains occurred in July-August 2010 and generated floods, which were satisfactorily routed through main spillway. Subsequently, the reservoir was filled to 8 ft. raised level (El. 1210 ft) in 2011 and the performance of the raised embankment dams and ancillary structures and foundations remained satisfactory except for minor leakage through the RCC structure of control weir which was being taken care of.

Benefits of the relief wells provided in the main dam foundations and impervious blankets provided upstream of Sukian dyke were confirmed through relief in pore water pressures in the main dam foundations and reduction in seepage discharges through the sandstone beds in Sukian dyke foundations (MJV 2011).

The impounding was restricted to 1210 ft. level as resettlement of the affectees was lagging behind. On completion of the resettlement, the reservoir will be impounded to the full raised level (El. 1242 ft.).

Past Resettlement

The Mangla resettlement associated with the original construction of the dam was one of the largest resettlements of its type in the world at that time. The area acquired was 67,800 acres, which included 7,800 acres outside the reservoir for constructing the dam and townships. About 81,000 persons belonging to over 17,000 families were affected. Of these 54% families owned more than one acre of land and were eligible for resettlement in Punjab and Sindh Provinces while the others were paid cash compensation. New Mirpur city and five hamlets were developed for resettlement of the displaced families. The resettlement cost was Rs. 240 million equivalent to US$ 50 million.

There were shortfalls in execution of resettlement. Some of the eligible families settled in Punjab and Sindh Provinces were not allotted land as declared. Others could not take possession of the allotted land due to one or the other reason and some of them were not given allotment of residential plots. Overall, resettlement of the displaced population away from their culture and kiths & kins was not a success. The genuine lingering problems of the past were taken up for redressal while preparing for the dam raising resettlement and among other measures, a cash compensation of Rs.1,617 million was paid to the over 10,000 eligible old affectees.

Dam Raising Resettlement & Rehabilitation

While engineering provisions were kept in design and original construction of Mangla dam for its future raising, land on periphery of the reservoir was not acquired for that purpose. As a result, recent land acquisition for dam raising has caused second time displacement and the land compensation has been exorbitantly high. About 63,000 persons are displaced in dam raising while over 13000 houses and other buildings are affected.

At the time of original construction of the dam in 1960's, the adverse social impacts of resettlement were under estimated and most of the affectees allotted land for land could not settle in Punjab and Sindh provinces due to unfavourable conditions. In the light of the lessons learnt, the recent resettlement for the dam raising was planned in consultation with affectees and all the displaced population is being relocated in close vicinity and due consideration has been given to livelihood development of the affected population.

An unprecedented and liberal compensation package was given to the affectees. Main provisions of the package are summarized in the following.

- In the light of the pervious experience, policy of land for land was not followed and compensation was paid at the market rate plus 15% compulsory acquisition charges. Former owners were allowed cultivating land on recession of the conserved water. Cash compensation was also paid for orchards/other trees, wells, farm buildings, etc.
- Replacement cost of the affected houses was paid at market price. An additional 10% was given over and above the price and the affectees were allowed to take away the salvage material of their houses.
- Owners of the houses who had built houses on their own land were given residential plots in new city and four towns developed for this purpose. The area of plot was at least equal to the affected house subject to a maximum of one kanal (4500 sft) and a minimum of 5 marla (1125 sft). The refugees from Indian Occupied Kashmir (IOK) and other affectees settled on WAPDA/AJK land were given 5 marla plot and a minimum of over Rs. 500,000 per family for construction of 2-room house.
- A new city near Mirpur and four towns close to the affected areas were developed at the project cost to resettle the affectees. In addition to infrastructure development on modern standards, a large number of public utility buildings were constructed in the townships.
- A vocational training institute in the new city and four vocational training centres in the towns were established. This was in addition to imparting skill to males in Islamabad and up-gradation of four existing vocational training centres for females.
- The existing one-lane, light traffic suspension bridge was replaced with a two-lane, heavy traffic bridge on river Jhelum at Dhangali.
- Access to the various populated areas affected by the raised reservoir was rehabilitated. This included construction of two large dykes for the townships of Kharak and Panyam.

- Drinking water requirement of Mirpur was allowed to be met from Mangla reservoir and fishing rights were transferred from WAPDA to AJK Government.
- Hydropower generation profit from Mangla Dam was agreed to be given to AJK Government as per laid down policy and General Sales Tax (GST) was exempted on electricity generated by and supplied to AJK.

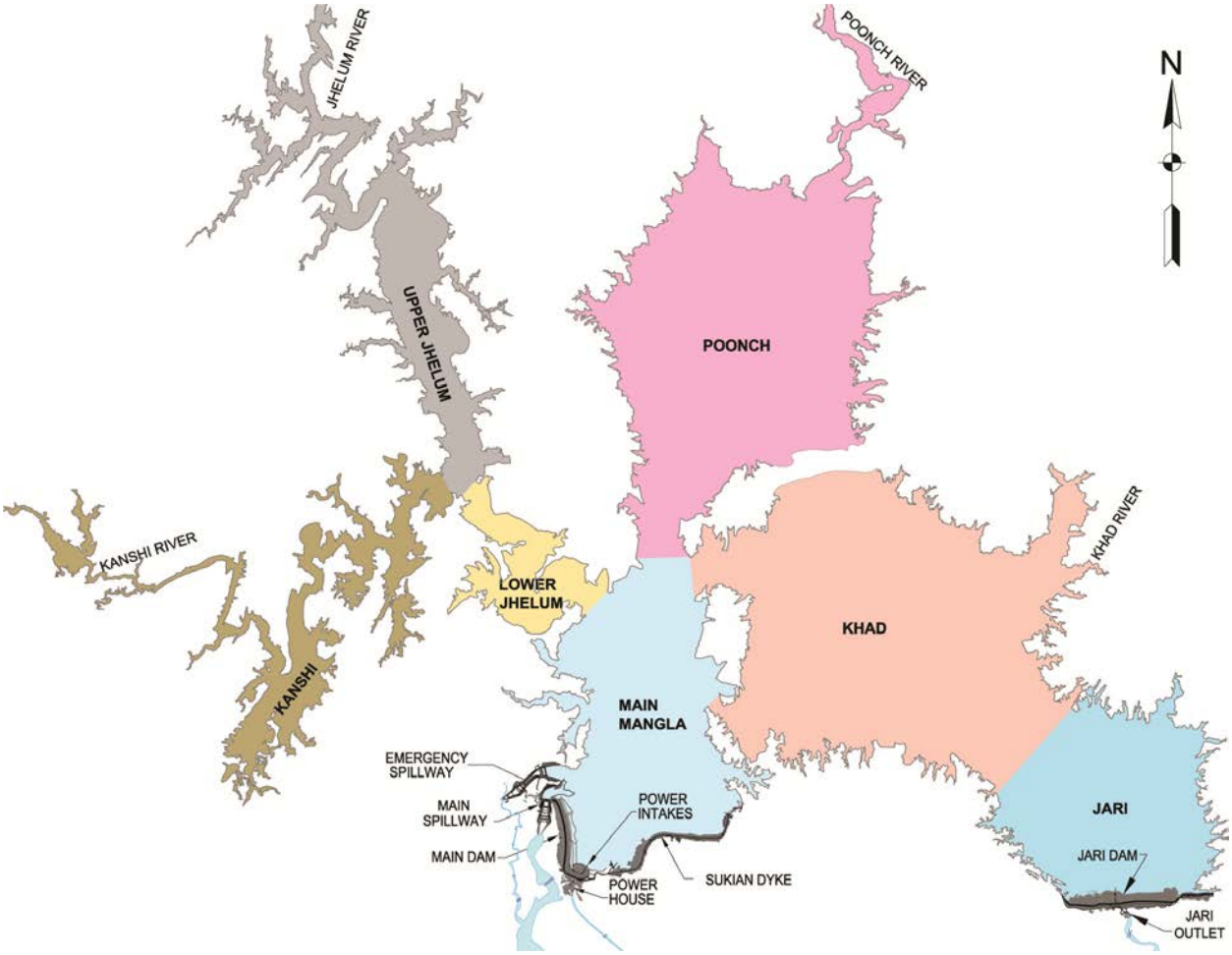
Though the compensation package was liberal and developed in agreement with the affectees, its implementation was delayed for various reasons, which encouraged the affectees to make additional demands. The delay also caused a substantial escalation in cost. Timely completion of R&R is a key to optimal cost.

Compared to the cost of the dam raising works (about Rs. 17 billion), the R&R cost was very high. About Rs. 75 billion had already been spent on payment of compensations, resettlement works and others. Over 80% of this was spent on payment of compensations. Another Rs. 6 billion might be spent on completion of the R&R process. This is a price paid mainly because of second time resettlement but still worth extending life of the project by over 80 years.

Future engineering needs

The future benefits of Mangla Dam are largely linked with how well its reservoir sedimentation is managed. It is therefore eminent to understand issues related to sedimentation and develop a long term strategy to resolve the issues. Raising of the dam by 30 ft. completed in 2009, has taken care of loss of reservoir capacity due to sediment deposition but advancement of delta towards power intakes leading to increase in the suspended sediment concentration are the future challenges for operation and maintenance of the power generating system. It is in this context that a brief review of Mangla sedimentation is presented followed by the issues which need to be addressed in the coming decades.

The average inflow of sediment to Mangla reservoir is about 73 million short tons per annum. The typical sediment particle size distribution is clay 26%, silt 62% and sand 12%. The pattern of sediment deposition is influenced by the shape of the reservoir, which comprises six pockets. Three of the pockets namely Upper Jhelum, Lower Jhelum and Main Pocket form main stem of the reservoir while Poonch, Khud and Jari pockets form side pockets on the left and Kanshi pocket is the side pocket on the right. In the context of the main stem, Jari pocket is an extension of Khud pocket and therefore the two are treated together.



Pockets of Mangla Reservoir

Sediment deposition

Extent of sediment deposition in the reservoir is monitored through periodic hydrographic surveys. Since first impounding of the reservoir in 1967, eleven hydrographic surveys have been conducted. By year 2010, about 1.29 MAF of sediment is deposited in the reservoir with an average of 29,300 AF per annum. The reservoir has been loosing its capacity at the average rate of 0.5% per annum (MDP 2010). The pocket-wise capacity lost to sedimentation is tabulated in the following.

Pocket	Capacity (MAF)		% Loss
	Original Gross Storage	Lost to Sedimentation by 2010	
Upper Jhelum	0.61	0.27	44
Lower Jhelum	0.36	0.15	41
Main	1.75	0.42	24
Poonch	1.28	0.25	19
Khud + Jari	1.60	0.12	8
Kanshi	0.28	0.08	29
Total	5.88	1.29	22

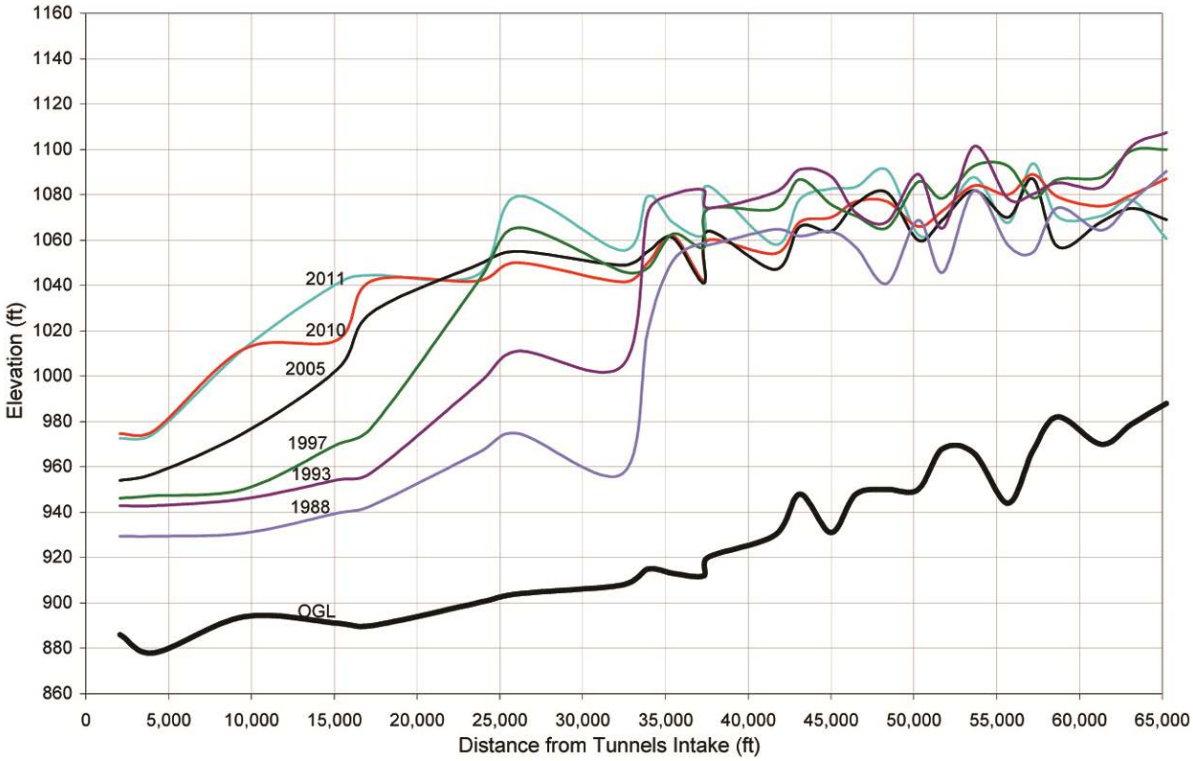
A substantial gain has now been achieved through raising of the dam. As in 2010, raised Mangla had a gross storage capacity of 7.49 MAF, which is 27 % higher than the original capacity of 5.88 MAF in 1967.

Advance of delta front

The sediment delta is advancing towards the tunnels intake. Progress of delta front along Jhelum valley and main reservoir is tabulated in the following (Ref. MDP 2010, 2011).

Year	Minimum Reservoir Level (ft)	Distance of Pivot Point from Tunnels Intake		Pivot Point Elevation (ft)	Mean Rate of Advance (km/yr)	
		ft	km		In Previous Period	Cumulative
1983	1086.70	43,100	13.1	1044	-	-
1988	1073.07	34,400	10.5	1050	0.53	0.53
1993	1078.72	32,000	9.8	1072	0.15	0.34
1997	1040.00	26,000	7.9	1056	0.46	0.37
2000	1040.00	26,000	7.9	1055	0	0.31
2002	1040.00	26,000	7.9	1058	0	0.27
2005	1094.60	26,000	7.9	1055	0	0.24
2010	1040.00	17,200	5.3	1042	0.54	0.29
2011	1081.15	15,200	4.6	1041	0.61	0.30

The pivot point was 4.6 km away from the tunnels intake in year 2010. After flood of 1997, there was no significant delta movement till the flood of 2010 when it advanced rapidly. The repaid advancement continued in 2011 as well.



Sediment Delta Front Movement

The pattern of sedimentation threatens to block free flow between the main stem and the sizeable storages in the side arms of the reservoir.

Sedimentation studies conducted in 2004 included prediction of quantities and pattern of sediment deposition assuming that dam raising will be completed in 2007. Sediment simulation was carried out on HEC-6 KC model. The future delta movement was predicted, its engineering implications were identified and mitigation measures were studied (MJV 2004).

The simulation study showed that sedimentation pattern is not significantly affected by raising of conservation level from 1202 ft. to 1242 ft. With minimum drawdown level kept at 1040 ft, delta would reach tunnel intakes in 20 years after raising and It would be delayed by 15 years if minimum drawdown level is raised to 1100 ft. After 80 years, the remaining storage of raised Mangla would be above 5 MAF with the predicted rate of sedimentation tabulated in the following:

Condition	Minimum Drawdown Level	Predicted Rate of Sedimentation (AF/Annum)		
		1-15 Years After Raising	16-30 Years After Raising	31-80 Years After Raising
Dam Raised	1040 ft	31,000	25,000	19,000
Dam Raised	1100 ft	33,000	34,000	19,000
No-Raising	1040 ft	30,000	21,000	17,000

Side storages

The storage capacity of Poonch, Khud, Jari and Kanshi pockets constitutes over 60% of the total reservoir capacity. Future management of the interaction of these side storages and the main reservoir is therefore important. The periodic hydrographic surveys of the reservoir have shown that sedimentation in Poonch, Khud and Jari pockets is much slower than in the Jhelum and main pockets and the side pockets can provide major storage well into the future. However, the pattern of sedimentation threatens to block free flow between the main stem and the sizeable storages in the side arms. This has already started happening in case of Kanshi pocket. The threshold sedimentation levels for isolation of the side pockets are as follows.

Pocket	Storage Capacity at El. 1242 ft.	Threshold Level for Isolation (ft.)	
		10% Volume	50% Volume
Poonch	1.76	1121	1192
Khud - Jari	2.58	1118	1190
Kanshi	0.39	1105	1200

In about 10 years time, the sediment in the main stem will reach 1120 ft. level, which will block 10% of the storage in Poonch, Khud and Jari pockets. It is therefore important for the long term

to give consideration to engineering measures to either ensure that these side storages can asses the power intake at the main dam or that they have new facilities built in Jari dam.

About 50 % of the storage of the side pockets is above El. 1190 ft. and sediment in the main pocket will not reach to this level even after 80 years.

Once isolation of storage in the Poonch, Khud and Jari pockets starts, it is still possible to utilize the storages, but this will require further engineering works, which may be one or more of the following:

(i) Dredging and local works to ensure free flow from these pockets to main stem during drawn down conditions.

(ii) Alternative connections via cuts and tunnels from Poonch pocket to Khud and possibly further from Khud pocket to main pocket near main dam.

(iii) Construction of works at the Jari reservoir to release larger flows for irrigation, power or both.

These and other possible options will need to be reviewed and engineered in the future. It should be noted that there are long term benefits of keeping the main sediment processes within the main stem and keeping these side storages isolated at low levels. The sediment inflows to Poonch pocket are low and to Khud and Jari pockets are insignificant. These side pockets can be filled annually from the Jhelum inflows when the reservoir is at high level. At such levels the main stem will act as a sediment trap and the inflow of sediment into the side pockets will be low. Hence they offer very long term storage. However, works as mentioned above may be required to fully utilize this storage.

Impact on downstream

Before building of Mangla dam, the river carried a significant sediment load and the channels downstream of the dam site naturally adjusted to carry this. Subsequent to impoundment of the reservoir, the sediment load initially ceased, but over time occasional sediment pulses have come with floods. A secondary change in regime is that the occurrences of floods have reduced significantly; the reservoir has the capacity to absorb or significantly reduce all but the largest of flood flows. Both of these processes have caused the downstream channels to reduce in size. Furthermore opportunistic developments have encroached on the downstream channel banks. The floods of 1992 and 1997 caused the population to temporarily withdraw from such encroachment.

The mathematical model simulation (MJV 2004) has shown that the sediment will start to pass through the turbines into the downstream river in about 10 years from now and the downstream channel will have to readjust to cope with the sediment load. Initially it is only the clays and fine silts that will be passed, however with time coarser silts and then sand range will start to pass. The time of the maximum outflow of coarse silt and sands from the reservoir is the period of lowest reservoir level; typically February and March. Therefore it is likely that this coarser material will be deposited in the downstream channel and along the banks due to flat terrain of the river, in the bays of the bridges and in the storage pond of Rasul barrage. The deposited silt will be re-scoured and transferred to the irrigation canals once the higher flows are discharged later in the year. This is estimated to start happening in 25 years from now and could ultimately change regime of the river channel potentially resulting in higher water levels and higher flood risk. Most effects should be manageable, but there will be a cost involved in resolving them. Specific effect on downstream channel will need to be evaluated in future and measures taken to alleviate negative impact.

Impact on turbines

As the sediment delta approaches the dam, the occurrence of significant sediment loads passing the turbines will increase in frequency and in particle size. There will also be occasional large flood that will carry very large quantities of sediment through the reservoir and turbines.

In 1992, a large flood with peak of greater than one million cusecs, passed through the reservoir causing significant sediment movement. The power tunnels and the main spillway were both operational during the flood. Peak sediment concentrations of 30% by weight were recorded at the outlet structures and concentrations exceeded 10% for over 100 hours. Significant sediment flows passed both through the power tunnels and through the main spillway. No serious damage to the turbines was recorded, although the cooling system was chocked with sediment and subsequently had to be unblocked. During a high flood in 1997 the power tunnels were closed and no damage noted.

With the movement of the delta closer to the dam the occurrence of sediment events such as those described above will increase. Although the sediment from Jhelum basin is fine and therefore, the effects induced at Mangla are likely to be less yet it is likely that damage will occur to the turbines at some time in the future. The timing of that damage and the extent of the damage will depend upon the operation rules adopted. Studies in this regard are needed to be taken up. In addition, impact of sediment load on cooling system of turbines needs to be studied to ensure that the system can operate irrespective of the presence of high concentration of sediment in water adjacent to the intakes.

Mass movement of sediment

As delta approaches the dam, possibility of mass movement of sediment into tunnels increases. Upstream toe weight berm raised by 80 ft. (to El. 1020 ft.) provides protection for the next 15 to 20 years. Slumping of delta foreset due to instabilities caused by operating rules or passage of large flood would be possible. Appropriate contingency measures should be put in place well in time to remove blockage and debris in an eventuality.

Liquefaction potential

Offshore drilling carried out in 2002 revealed presence of about 50 ft. thick layer of silty sand overlain by a 15 t. thick layer of silt/silty clay at the pivot point. A 90 ft. thick silt layer is deposited below the silty sand layer. Most of the sediment is in a very low state of compactness and this is particularly so with silty sand deposit at 20-40 ft. depth. Analysis indicates liquefaction potential in OBE condition (horizontal acceleration 0.14g). Consequently large mass of liquefied sediment could reach tunnel intakes. Raised toe weight berm is estimated to contain the sediment for next 10 to 15 years. Contingencies for removal of blockage at intakes might then be needed.

Future sediment management

Sediment management is a key to future benefits from Mangla dam. For that purpose, continued vigilant monitoring using current techniques and testing of sediment deposit is essential. Periodic mathematical model simulations incorporating latest data, knowledge and advancement in technology should be carried out. The future sedimentation model should also include the Jhelum river channel for a considerable distance downstream, the potential problems areas should be identified and studied in detailed, morphological consequences should be evaluated and measures devised and taken to alleviate the adverse affects.

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