

**SELECTION OF DAM TYPE AND PLANNING ASPECTS
OF DASU HYDROPOWER PROJECT**

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SYNOPSIS

The 4320 MW Dasu Hydropower Project is one of the cascade of water resources development projects conceived on Indus river. The river in the 75 km stretch between Basha and Dasu drops by about 200 m flowing in a very narrow valley with steeply sloping rocky mountains on both banks rising hundreds of meters above the river. The valley thus offers very conducive conditions to build a high dam and generate hydropower.

The bedrock of igneous origin exposed on the river banks is competent and allows construction of almost any type of dam. Choice of the type of dam was therefore studied with multiple considerations including topography, construction materials, spillway sitting, environmental impacts and economy of the project.

The Dasu project is planned with the sole purpose of exploiting the hydropower potential with no provision of seasonal storage, as the reservoir created in this narrow valley will have very limited capacity in comparison with the Indus river flows. Except for an insignificant contribution of the intervening nullahs, inflows to Dasu will be governed by the releases from the Diamer Basha reservoir, which will be operational when the Dasu project is built. Environmental consideration was a significant influencing factor in selection of the dam site. As part of the detailed feasibility study, the project was shared with the effected population and full regard was given to their views.

The detailed feasibility study completed in early 2009 has yielded a hydropower facility comprising a 233 m high RCC gravity dam and underground powerhouse with eight units of 540 MW each. The project's economics indicators are very attractive indicating an excellent investment for Pakistan.

1. GENERAL

1.1 Need for Dasu Project

The power availability situation in Pakistan is critical with the periods of load-shedding that is causing adverse economic and social impacts across the country. To meet the short-fall, generation from burning of fossil fuel is being expanded, which is environmentally damaging due to the emissions produced and is also unsustainable. Added to this is the fact that much of the fuel has to be imported. Compared to that, well managed hydropower is environmentally the least damaging and most sustainable power generation option for the country and also has by far the lowest operation cost.

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For development of the much needed mega hydropower schemes, river Indus provides perennial flow and a large number of sites in the northern Pakistan. Dasu is one of such sites where a detailed feasibility study has been completed in early, 2009. Pakistan Water and Power Development Authority (WAPDA) undertook the study through a consortium of indigenous and expatriate consultants. Construction of about 230 m high RCC dam at this site will provide a gross head of over 200 m for power generation with an installed capacity of 4320 MW. At a capital cost of US\$ 7.8 billion and the average annual energy output of over 21000 GWh, the project's Economic Internal Rate of Return (EIRR) is 18.6 % and the benefit/cost ratio is 1.89 indicating it to be an excellent investment for Pakistan.

The paper presents a case history of the comparative study of the dam type for the Dasu site in terms of both the technical considerations and the cost. For the selected dam type, alternative project lay outs are compared and the best suited for the site from the technical, cost and environmental considerations is selected. Prior to presenting the comparative studies, the site-specific and project related information is given for appreciation of the study.

1.2 Morphological Aspects

The Dasu Hydropower Project site is located on Indus river, 7 km north of Dasu town in Kohistan District of the North West Frontier Province (Exhibit 1). About 74 km upstream is the site of the Diamer Basha Dam Project.

The Indus river in the stretch between Diamer Basha and Dasu dam sites drops by some 200 m, flowing in a very narrow valley, with steeply sloping mountains on both banks, rising hundreds of meters above the river. The reservoir created by about 230 m high Dasu dam in this narrow valley will have a small capacity in comparison with the Indus river flow. The gross reservoir capacity will be 1.4 billion m³ (1.13 MAF), which corresponds to less than 8 days of the average river runoff at the Dasu site. The morphology of the valley also implies that the large project proposed to be built in this stretch will have to face the lack of ample flat area desirable for construction purposes.

Dasu town represents the downstream limit of possible dam site in this stretch, as the river valley widens significantly further downstream, making a dam far more expensive, and on the other hand, the submergence and resettlement of the entire Dasu town would never be accepted by the local inhabitants. Even the resettlements of smaller communities would represent a significant social problem, given the difficulty to find adequate resettlement areas in the region.

1.3 Water Resource

The average annual flow of Indus river at Dasu is about 2,080 m³/s (≈73,000 cusecs), with a pronounced variation between the winter period, December to April, when the average flow falls below 500 m³/s (≈18,000 cusecs), and the summer period, June to August, with average monthly flows exceeding 6,000 m³/s (≈ 212,000 cusecs). Almost all the runoff at Dasu comes from Basha, the contribution of the intermediate catchment being just about 5% of the total.

The combination of available head of 200 m and average flow of 2080 m³/s gives the installed capacity of the Dasu plant in the order of over 4,000 MW, much higher than the 2,400 MW capacity considered in the 1984 Inventory and Ranking study by Monenco.

A partial seasonal regulation of the natural flow will be achieved in the Basha reservoir, according to requirements of the downstream irrigation systems, but without drastically changing the natural sequence of flow in high runoff months. Dasu reservoir cannot effectively contribute to a seasonal regulation of the flow because of its small capacity. Thus, on the one hand, hydropower development at Dasu will be totally depending on the outflow from Basha; and on the other hand, it will be essentially a run of river scheme, with the reservoir being used essentially to provide storage for daily peak energy production.

To maximize the power benefits of the Dasu project, it is logical to adopt a maximum normal reservoir level equal to the tailwater level of Diamer Basha Dam, which ranges from minimum of El. 947m to maximum El. 970m under PMF condition. At Dasu the maximum normal reservoir level has been adopted as 950m being the normal tailwater level of Diamer Basha. Higher than the normal tailwater level would have increased the cost of Dasu dam without achieving any significant gain in the energy production.

Without considering Glacial Lake Outburst Floods (GLOF), floods in Indus river at Dasu range from 9,000 m³/s (\approx 318,000 cusecs) for a 2 year return period, upto 20,200 m³/s (\approx 713,000 cusecs) for 10,000 year return period. The GLOF of August 1929, with peak discharge of 23,710 m³/s (\approx 837,000 cusecs) has been taken as the basic design flood for Diamer Basha Dam Project. Taking into account a minimum flood routing effect in Diamer Basha reservoir and adding the contribution from the Basha-Dasu intermediate catchment, the corresponding peak inflow in the Dasu reservoir is 20,908 m³/s (\approx 738,000 cusecs).

In addition to the above design flood, the Diamer Basha project considered a safety check flood with peak inflow of 49,410 m³/s (\approx 1,744,000 cusecs) resulting from a combination of glacier and snowmelt, added to a flood caused by failure of a natural dam in the upper Indus Basin. Routing of this flood in the Diamer Basha reservoir gave a peak outflow of 35,690 m³/s (\approx 1,259,000 cusecs). For Dasu, the outflow of the safety check flood from Diamer Basha superimposed to the estimated 10,000 year flood of the Basha-Dasu intermediate catchment gives a peak inflow to the reservoir of 36,640 m³/s (\approx 1,293,000 cusecs).

The estimated average annual sediment inflow into the upstream Diamer Basha reservoir is in the order of 200 million tons/year. The sediment yield of the Basha-Dasu intermediate catchment is about 10 million tons/year. The sediment load is estimated to comprise 14.4% clay, 39.6% silt and 46% sand.

1.4 Geology and Geotechnic

At a regional scale, the rock formation prevailing in the project area include amphibolite or granulite/diorite rocks in the project area with mafic to intermediate plutonic rocks of the Chilas complex outcropping further north along the reservoir. The rock formations are in principle, suitable for a high dam and for large surface and underground excavations, provided proper attention is given to joint systems and to local faults and weak areas. The contact between the two formations has been evaluated through neo-tectonic studies as an inactive fault. The geological survey of the reservoir area has not indicated any major slope stability problem that could jeopardize the feasibility of the project. The geologic plan of the proposed project area is shown in Exhibit 5.

Seismicity of the area is generally high, as it shall be expected for the region. The horizontal ground accelerations evaluated for the Dasu site are 0.19g for OBE condition and 0.51g for MCE condition.

Locally available construction materials include rock for embankment and concrete aggregate production, in practically unlimited quantities. Natural coarse and fine aggregates are not available in the required quantities within economic distances. Impervious fill materials in the quantities required for an earth-core embankment dam are also not available around the project area. All other materials required for the civil construction; cement, pozzolanic material, reinforcing steel, fuel, etc. shall be transported over large distances along the Karakoram Highway.

1.5 Logistic Aspect

The presence of Karakoram Highway (KKH) along left bank of river Indus in the Dasu project area is an important advantage. However, the KKH is the only access road from Islamabad to Dasu and is probably the most important bottleneck for the logistics of the project construction both for the transportation of heavy permanent equipment and for bringing to the site the huge quantities of materials required for the civil construction. Upgradation and widening of the KKH is underway for construction of the Diamer Basha project. The Dasu project to be constructed later will benefit from this improved logistic facility. However, the constraints given by the many towns/villages crossed and by the relatively heavy general traffic (trucks, cars and pedestrians) and animal herd moved along the road will remain.

The flood of summer 2010 has caused extensive and severe damage to KKH requiring large scale rehabilitation.

2. ALTERNATIVE DAM AXES

The area of interest for locating a high dam which could develop the hydropower potential of the river stretch between Basha and Dasu is a 10 km segment of Indus river upstream of Dasu town. At the initial stage of the feasibility study, seven possible dam axes were identified on the 1:50,000 scale, Survey of Pakistan, topographic maps and the sites were then inspected in the field by the study team. The locations of the seven alternative dam axes are marked on plan in Exhibit 2, while the views of Axes 5 and 6 are shown in Exhibits 3 and 4 respectively.

The dam axes 1, 2 and 3 are located in the same metamorphic rock formation consisting of fined grained, layered to laminated amphibolites. Of these three, the Axis 2 (originally proposed by Monenco consultants in the ranking study of 1984) is the narrowest. The Axis 1, shortly downstream is wider and does not seem to present any advantage. The Axis 3 is located across a sharp bend of the river, which could be of use to develop a compact layout. But, tectonic features are present in the left abutment downstream of Axis 3 raising questions about its suitability as foundation of a high dam and this axis was discarded on the basis of the unsatisfactory geotechnical conditions.

At the Axis 4 and further upstream, the bed rock is massive meta-diorite with its contact with the amphibolite formation between Axes 3 and 4. Much of the right abutment at Axis 4 is covered by an extensive fluvio-glacial alluvial terrace and nullah deposits with the rock out cropping far away from the river bed; thus a dam at this location would be far larger than the other competing sites.

Axis 5 is as narrow as the Axis 2 downstream with comparatively less excavation needed in the abutments for the dam foundations. Further upstream, the river bed and the valley broaden, thus the dam volume increases, and the available head is reduced. In particular, there seemed no benefit in the most upstream Axis 7, where the valley is as wide as Axis 6 and the head is lower.

Based on the above findings, Axes 2, 5 and 6 were retained for further investigations and conceptual layouts were developed for these sites with the purpose of developing ranking of the various possibilities, in particular, about the type of dam to be retained for further studies.

3. Comparative Study of Dam Types on Alternative Dam Axes

Keeping in mind the characteristics of the Dasu site, the following dam types could be possible.

i) Earth-Core Rockfill Dam (ECRD)

Due to non-availability of impervious material in the project area, an earth-core rockfill dam would be highly uneconomical as impervious earth material will have to be transported from far away sites.

ii) Concrete-Faced Rockfill Dam (CFRD)

Concrete-faced rockfill dam in the order of 200 m height would be technically possible at Dasu.

iii) Concrete Gravity Dam (CGD)

The foundations are generally suitable for a concrete gravity dam at Dasu. Roller Compacted Concrete (RCC) technology offers economic advantage over Conventional Vibrated Concrete (CVC). Thus an RCC Gravity dam is considered.

Due to non availability of impervious core material, ECRD did not stand as a competing candidate and a comparative study of CFRD and RCC gravity dam was undertaken.

Geological and geotechnical factors that influence selection of dam type fall into the following categories:

- General foundation bedrock acceptability.
- Sliding resistance, geo-mechanical performance and deformation characteristics of foundations.
- Required foundation depth to achieve acceptable foundation materials.
- Measures required for treating the foundation to improve physical properties and control seepage.
- Long-term performance of the foundation under normal operation conditions and extreme events, especially earthquake.
- Stability of abutments and abutment slopes, and
- Availability of suitable construction materials.

In case of the Dasu site, there is little difference between selection of a CFRD and concrete gravity dam from a geologic or geotechnical point of view. The real difference between these dam types involves design detailing, construction procedures and cost.

Comparative study of the CFRD and RCC gravity dam types on alternative axes 2, 5 and 6 is briefly described below.

3.1 River Diversion

In view of the V-shape of the river valley at the Dasu site, diversion through a channel is not feasible and tunnels are the only possibility for river diversion during construction.

The regulated outflow from Diamer Basha reservoir remains below 7,000 m³/s except for the flood prone months of June, July and August when higher discharges occur. The diversion floods at Dasu for the various return periods are as follows.

Diversion Floods at Dasu

Season/Return Period	Discharge (m ³ /s)
Dry Season	< 7,000
Wet Season:	
1 in 5 Years	10,380
1 in 10 Years	11,270
1 in 25 Years	12,370
1 in 50 Years	13,240
1 in 100 Years	14,050
1 in 200 Years	14,870

For the given flood flow pattern and magnitudes, a design flow of 7000 m³/s was adopted for the RCC dam alternative, where overtopping can be tolerated in the wet season. As CFRD cannot tolerate overtopping, the diversion facilities were planned for wet season floods of 25 to 100 year recurrence period. The diversion facilities planned for the two dam types are described below.

In case of CFRD, the upstream part of the rockfill embankment is raised including the concrete facing in the first stage to an elevation that will keep the dam safe from overtopping against flood of high return period. The construction of this first stage should take no more than two dry seasons and one intermediate flood season, and thus the protection from overtopping for this initial construction stage has been limited to floods of 25 years return period. In the second stage the dam protected by the first stage is completed.

By applying this concept, the diversion facilities for the CFRD alternative were conceived comprising three concrete lined diversion tunnels and upstream cofferdam with crest at El. 820 m to be built in one single dry season. This arrangement protects the works against the 25 year return period flood, and the first stage CFRD is built to El. 830 m which then protects the second stage construction of CFRD for the 100 year flood. A 100 year flood would pass through the tunnels with velocities of about 20 m/s, without causing any serious damage to the concrete lining.

An alternative possibility could include four unlined diversion tunnels with upstream cofferdam with crest at El. 815 m. However, in this case the 100 year flood will cause the velocity in the tunnels to exceed 15 m/s, which could cause serious damage to the unlined tunnels. Other options like two concrete lined tunnels or three unlined tunnels are deemed not feasible, because the upstream cofferdam would be too high to be completed in one dry season and because the velocities inside the tunnels in case of high floods will be excessive.

With an RCC dam at Dasu, planned overtopping of the dam can be allowed during flood season from June to August. In this case the diversion facilities are sized for the dry season flood, on the order of 7000 m³/s. The arrangement considered includes two concrete lined diversion tunnels and an overtoppable hardfill coffer dam with crest at El. 805 m to be built in one single dry season.

3.2 Low Level Outlets

The main purpose of the Low Level Outlets (LLOs) is to allow the sediments sluicing from the reservoir. This means that the outlets shall be able to first lower the reservoir to the elevation required for the effective sluicing and then to maintain that elevation during the sluicing period. Other functions of the LLOs include:

- Control the speed of the reservoir rising during the initial filling.
- If necessary, lower the reservoir to allow inspection and maintenance works to the power intakes.
- Supplement the capacity of the spillway.
- Supplement the capacity of the diversion tunnels.

A capacity of the LLOs in the order of 6400 m³/s with reservoir at El. 860 m is sufficient to assure a fairly efficient flushing, assuming the flushing operation is done in July, after the flushing of Diamer Basha reservoir has been done and the Basha power plant is back in operation.

An evident solution for a CFRD layout would be to install the outlets in the diversion tunnels carrying out conversion at the end of the construction period. It is foreseen to convert two out of the three diversion tunnels to be used as low level outlets with their intakes constructed at a higher invert elevation. For the RCC dam solution, it was foreseen to incorporate the outlets in the dam body, under the dam section housing the spillway.

3.3 Spillway

The floods considered for the design of the spillway at the stage of comparative study of the dam types were:

- Basic Design Flood (BDF) = 23,330 m³/s
- Safety Check Flood (SCF) = 35,260 m³/s

Disregarding the flood routing effect, but taking into account the contribution of the low level outlets and assuring that the BDF will be discharged with the reservoir at its normal maximum level (El. 950 m) while the SCF will be discharged with no more than 5 m surcharge, the required spillway capacities and the corresponding basic characteristics adopted for the alternative layout studies for the CFRD and the RCC dam solutions are shown in table below:

Spillway Discharge Capacities and Characteristics

Flood (m ³ /s)	23,330 (BDF)	35,260 (SCF)
Reservoir Elevation (m)	950	955
CFRD		
Outlet capacity (m ³ /s) (Not useable at max. reservoir level)	-	-
Required spillway capacity	23,330	35,260
Actual spillway capacity (7 gates – 18.8m x 20.0m high)	24,119	35,532
RCC Dam		
Outlets capacity (m ³ /s)	6447	6585
Required spillway capacity (m ³ /s)	16,883	28,675
Actual spillway capacity (6 gates – 17.7m x 20.0m high)	19,544	29,100

For the large design and safety check floods indicated above and the morphology of the stretch of the river under consideration, only gated spillway arrangement with downstream chute channels and terminal flip buckets can be realistically conceived. An ungated spillway solution, with the crest at the maximum normal reservoir level, would require a much higher dam. Other solutions (morning glory, siphon, tunnel chute spillway) would hardly be possible for the floods under consideration.

For concrete dam, unless a powerhouse at the toe is foreseen, the logical arrangement is to locate the spillway at the dam crest, with chute channels and terminal flip buckets arranged on the downstream face discharging into a pre-excavated plunge pool.

For the CFRD solution, the spillway shall be arranged in one abutment, with a long chute and terminal flip bucket discharging back to the river. Excavation required would be huge, and extremely high excavation slopes required is a critical aspect, which weights heavily in favour concrete dam solution.

3.4 Power Facilities

The energy production and the costs of power facilities were assumed to be the same for the CFRD and RCC Gravity type of dam. However, for the purpose of comparing energy production and costs of the power facilities at the alternative dam axes, the following installed capacities were considered assuming in all cases the powerhouse discharging immediately downstream of the dam.

Power Facilities Design Parameters

Axis	2	5	6
Installed Capacity (MW)	4,320	4,069	4,000
Rated Net Head (m)	189	178	175
Total Flow at Rated Net Head (m ³ /s)	2,516	2,516	2,516

Only Francis units are applicable to the range of heads under consideration and the total installed capacity in the order of 4,000 MW can reasonably be split in a number of units ranging between 6 and 12. The main characteristics of the generating units for Axis 6 were estimated as tabulated below:

Generating Units Characteristics

Number of Units	6	8	12
Unit Capacity (MW)	667	500	333
Flow at Rated Head (m ³ /s)	432	324	216
Design Speed 'n' (rpm)	115	136	167
Runner Diameter (m)	6.73	5.69	4.65

According to the initial reservoir simulations carried out, for 85% of the time the reservoir remained at the maximum level (El. 950 m). The absolute minimum level reached along the entire simulation period was about El. 915 m. Taking into account the required submergence, the sill of the power intakes was established in all the cases at El. 875 m. There seemed to be no reason to set the power intakes at a lower elevation; rather, this would increase the risk that in long-term the lower intakes will be affected by sediment.

For the purpose of the alternative dam axes evaluations, eight equally sized generating units were considered. The main justifications for adopting 8 units arrangement are the following:

- (i) The cost of the waterways and the powerhouse equipment and civil structure increases with the number of units, therefore, the smallest possible number of units should be adopted.
- (ii) The 500 MW size is proven and within the transport limitations that will apply to the upgraded KKH. The 6 units alternative, with each unit larger than 650 MW, would be probably on the borderline of the transportation possibilities.
- (iii) The size of the powerhouse and the power waterways for the selected number of units is deemed consistent with the rock conditions of the sites considered.

For the layouts with an underground powerhouse, the arrangement applied in these initial studies was 4 headrace tunnels, 4 pressure shafts with terminal bifurcations, 4 tailrace tunnels and surge chambers provided downstream of the underground powerhouse.

The key technical characteristics of the alternative layouts developed for each dam axis (Axes 2, 5 and 6) and the two dam types (CFRD and RCC) are summarized in table below.

Alternative Layout, Key Technical Characteristics

Axis	2		5		6	
Dam Type	RCC	CFRD	RCC	CFRD	RCC	CFRD
Maximum Height (m)	239	239	225	225	219	219
Crest Length (m)	532	532	485	485	560	560
Diversion Tunnels (12mx20m, D-shaped Concrete Lined)						
Average Length (m)	1,064	1,365	1,059	1,398	1,132	1,219

Upstream Cofferdam						
Maximum Height (m)	28	46	31	50	29	47
Crest Length (m)	159	236	131	154	207	234
Downstream Cofferdam						
Maximum Length(m)	16	21	17	21	15	19
Crest Length (m)	111	191	171	137	108	118
Spillway (Crest El. 930m)						
Number of Gates	6	7	6	7	6	7
Size of Gates (m)	17.7x20	18.8x20	17.7x20	18.8x20	17.7x20	18.8x20
Powerhouse (8 Generating Units, Maximum Flow 2,516 m³/s)						
Total Installed Capacity (MW)	4,320	4,320	4,069	4,069	4,000	4,000
Unit Size (MW)	540	540	508	508	500	500
Rated Net Head (m)	189	189`	178	178	175	175
Average Total Energy (GWh/y)	20,613	20,613	19,381	19,381	19,044	19,044
Comparative Base Cost (Million US\$)	2,963	3,422	2,821	3,525	3,036	3,810
Annual Net Benefits (Million US\$)	454	454	427	427	419	419
Benefit/Cost Ratio	2.15	1.86	2.12	1.70	1.94	1.55

Project benefits were assessed on the basis of energy production output only, assuming identical benefits for the RCC and the CFRD solutions at each axis.

The main environmental consideration was the flooding of Seo village, located on a terrace on the right bank of Indus river between Axes 2 and 5, that will be caused by building a dam at Axis 2. From environmental point of view, this was the main difference between Axes 5 and 6 on one side, and Axis 2 on the other. From monetary point of view, the actual environmental impact was minor and included in the cost estimate and the economic ranking. However, the social impact on the population of Seo village cannot be measured on monetary terms only.

3.5 Conclusions on Dam Type and Axis Selection

3.5.1 Dam Type

Topography and geology at all the three axes are suitable for Concrete-Faced Rockfill Dam (CFRD) and for Roller Compacted Concrete (RCC) Gravity Dam. Cost-wise, at all the three axes studied, RCC dams are definitely more economic than CFRD, mainly because of the huge costs estimated for construction of the required large spillway on the abutment in case of CFRD. The difference in cost is in the order of 15% for the Axis 2 and 25% for the Axes 5 and 6.

In addition to the cost difference, the following technical aspects also weighed against the CFRD solution.

- With a CFRD, extremely high permanent excavation slopes were required to locate the spillway in the abutment, posing very serious slope stability concerns, particularly in view of the high seismicity of the area.
- Against the required 230 m height of the Dasu dam, the highest CFRD dams built to date barely reach 200 m height and serious problems to the upstream concrete facing have been reported in various CFRD dams built in narrow valleys (Campos Novos and Barra Grande in Brazil; Mohale in Lesotho). From this point of view, it was considered that a CFRD dam of 230 m height carries more technical risks than an RCC dam of the same height.

Taking into account both the difference in costs and technical aspects, RCC gravity dam type was selected for the Dasu hydropower development.

3.5.2 Axis Selection

In terms of construction cost, the cheapest dam axis location with an RCC dam was assessed to be Axis 5, with Axis 2 about 5% and Axis 6 about 7.6% more expensive. Taking into account the different energy production benefits, the benefit/cost ratio was the best (2.15) for Axis 2, second (2.12) for Axis 5 and third (1.94) for Axis 6.

Further aspects considered in relation to selection of a preferred dam axis were:

- Axes 5 and 6 had practically identical manageable environmental and resettlement impacts, while Axis 2 raised the opposition of the local population because of the required flooding of the Seo village located

between Axis 2 and Axis 5. While the differences in the environmental and resettlement costs were minor, and anyway accounted for in the cost estimates, it was feared that local opposition might delay construction of the project or jeopardize it all together.

- From technical point of view, no decisive factors were identified favouring or disfavouring a particular axis, it was noted that Axis 2 requires a dam 20 m higher than Axis 6 and 14 m higher than Axis 5. Given a choice, lesser height of a dam would be favoured.

Based on the above observation, it was concluded to have an RCC gravity dam at Axis 5, having a benefit/cost ratio better than Axis 6 and free of the socio-environmental issues, which were associated with Axis 2. The project layouts developed for the comparative study at Axis 5 with surface powerhouse and underground powerhouse, discharging shortly downstream of the dam are shown in Exhibits 6, 7 and 8.

4. DESIGN CONCEPTS IN PROJECT PLANS

Having selected the type of dam (RCC Gravity) and location of the dam axis (Axis 5), the project planning studies were carried further in the light of design considerations, culminating into the project layout plan shown in Exhibit 9. Photographs of the dam model constructed at the Hydraulic Research Institute, Nandipur is shown in Exhibits 10 and 11. The more important features of the project layout plan finalized in the feasibility study include the following.

- (i) A curved dam axis has been adopted.
- (ii) Powerhouse has been placed underground.
- (iii) The power system is located on the left bank with long tailrace tunnels.
- (iv) The low level outlets are equipped for safe operations under high head.
- (v) The spillway is arranged to suit the river morphology.

The design concepts introduced in the development of these features are briefly described in the following.

4.1 Curved Dam Axis

The RCC gravity dam proposed at Dasu was provided with a curved axis in plan rather than a straight one, as shown in Exhibit 12. The curved axis offered the following advantages.

- It directs the jets from the spillway buckets towards middle of the river channel, minimizing or even eliminating the need to excavate the abutments downstream of the dam to achieve the necessary width of the plunge pool;
- It provides extra safety to the stability of the dam, particularly under seismic conditions; and
- It adds to the aesthetics of the mega dam structure.

4.2 Location of Powerhouse

Dasu dam will be built in a narrow valley having a width of less than 100 m at the river bed level. There is, therefore not enough space available to place over 4000 MW capacity powerhouse at the foot of the dam. Also due to steeply sloping high mountains, the Dasu site is almost devoid of any suitable natural site for locating a surface powerhouse on the river bank, except for a terrace on the right bank located at 550 m downstream of the dam axis. The layout developed for this site with the surface powerhouse discharging directly into the river is shown in Exhibit 6. The surface powerhouse in this layout encountered technical constraints including the following.

- (i) Location of the tail race works just downstream of the spillway plunge pool is a critical issue. Even with some prior excavation of the pool, the tail race outfall will be susceptible to partial blockage from debris. At time of flood discharge, any turbines in such a location could be affected by transient downstream back fluctuations.
- (ii) Due to narrow width of the river valley, the medium to high flood discharge from the spillway would cause a sharp increase in the tail water level, resulting in flooding of the powerhouse.

Both these disadvantages associated with the surface powerhouse at Dasu were overcome by adopting an underground powerhouse, discharging sufficiently away from the plunge pool location. Moreover, an underground powerhouse would be much safer in seismic conditions and security concerns would be lesser. All these advantages led to the choice of an underground powerhouse at Dasu.

4.3 Power Facilities Layout

The morphology of the river and characteristics of the rock mass were the two main considerations in comparative study of location of the power facilities on the two banks at the Dasu site. The initially developed alternative project layouts comprising RCC gravity dam and underground powerhouse located in the right and left abutment are shown in Exhibits 7 and 8 respectively.

At about 600 m downstream of the dam axis, the river takes a sharp left turn, which supports a favourable hydraulic layout for the powerhouse tail race outlet on the right bank (Exhibit 7). But as stated earlier, nearness of the plunge pool to the tail race outlet is undesirable. This situation was remedied by locating the powerhouse on the left bank taking benefit of the sharp turn in the river, which also facilitates a compact layout (Exhibit 8). Moreover the rock slopes in the intake area are steeper on the right abutment compared to the left abutment requiring lesser quantities of surface excavations for the intake structure. Therefore, both in terms of cost and long-term stability of the cut slopes, locating the power intakes on the left bank was preferred.

The investigations through boreholes and geotechnical studies of the jointing system showed that the rock mass quality and orientation of the major joints sets on both the abutments at the dam site is not much different and the power system may be located on either of the banks.

The conceptual planning of the power transmission lines from Diamer Basha and Dasu to the load centers in the country suggest a transmission line corridor on the left bank of Indus river. Thus locating the power generating system also on the left bank offered an economic advantage.

With the above technical and cost considerations, locating the power facilities on the left bank was considered as the appropriate choice for the site. Cross section of the power caverns including the powerhouse, transformers gallery and surge chamber is shown in Exhibit 13.

4.4 Arrangement of Power Waterways

The design considerations in respect of the power water ways are described below.

4.4.1 Headrace Tunnels

Initially one headrace tunnel was considered for two units each. In this case, it was considered to foresee unit valves downstream of the bifurcation so as to allow emergency closure or maintenance works of one unit without having to stop also the other one.

For the over 500 MW size of the units, valves arrangement at the elevation of the turbine centerline would have a large diameter in the order of 5.5 m, under a design pressure of some 270 m (including water hammer). Given the design parameters above, the likely choice was expensive spherical valves, which would also require to be housed in their own upstream cavern, as the width of the powerhouse was already near the limits of previous experience.

An alternative possibility would have been to arrange the bifurcation upstream of the high pressure shafts, and to locate butterfly valves or bonneted gates in between (the same concept applied in Diamer Basha Project). However, this would also require the excavation of an additional valve cavern shortly downstream of the intakes and leaving short lengths of tunnels upstream of the bifurcations.

With these considerations, one water way per unit was provided. In this case, emergency closure of one unit for maintenance purposes or in case of malfunctioning of the distributor is achieved by the intake service gate, designed for an emergency fast closing under flow conditions. This is the concept generally applied for all large size powerhouses arranged at the foot of the dam, with intakes in the dam body and penstocks on the dam downstream face.

4.4.2 Tailrace Tunnels

The design of the tailrace tunnels of Dasu power facility was governed by the following aspects.

- (i) In order to achieve stability of the units under small load changes conditions, downstream surge shafts were necessary. The only possible alternative was to design the tailrace tunnels for free flow conditions, and this was ruled out by the large tail water level variation with the flow: about 12 m in the normal range of operation of the powerhouse,

without considering extreme flood events. This meant that the tailrace tunnel would have to be 25 m high minimum.

- (ii) Just to achieve stability under small loads, individual surge shafts (one per unit) would require a diameter of 22 m and their depth from the ground surface would be in the order of 400 m, which is very large. From constructability and cost point of view, the only reasonable option was one single surge chamber for all the eight units.
- (iii) Given the requirement of the downstream surge chamber, it was not reasonable to foresee individual tailrace tunnels for each unit. A larger number of smaller diameter tunnels would mean an increase of the excavation price, particularly for crossing the adverse geological features. Therefore, one tailrace tunnel was provided for two units each. Providing one tailrace tunnel for 3 to 4 units would have required possible tunnel size of up to 14.0 m x 17.0 m, which would be near the limit of technical feasibility. Beside, inspection and maintenance of the tunnel would require taking a large portion of the total installed capacity out of operation.

In conclusion, the proposed arrangement with one single downstream surge chamber and one tailrace tunnel for two units was considered the most appropriate.

The tailrace tunnels were designed to be concrete lined throughout their length. A consideration was given to partial lining or keeping the tunnels unlined. The quality of the rock mass indicated a need for concrete lining support at places where adverse geological conditions would be encountered. It was also considered that hydraulic conductivity of the unlined tunnel would be less requiring larger cross section of tunnel for the same discharge capacity. Also the inspection and maintenance requirements and consequential stoppage of the power units would be more for the unlined tunnels. For the given considerations, concrete lining of the tailrace tunnels was adopted as the appropriate choice.

4.5 Spillway Arrangement

The total length of the spillway is limited by the narrowness of the river downstream of the dam and high excavation slopes that would be required to enlarge the plunge pool. From this point of view, an arched layout of the dam is an advantage. The spillway comprises six radial gates discharging via downstream chutes to multi-level flip buckets, which direct flows to a downstream plunge pool. The geometry is such as to direct the jet impacts towards middle of the river and also spread longitudinally along the river valley. Exhibit 10 shows a photograph of the spillway in operation on hydraulic model constructed for the testing purposes.

4.6 Low Level Outlets Gates Arrangement

In addition to sediment sluicing the low level outlets would be used to supplement the capacity of the spillway in case of extreme flood. To pass the flood discharges, the outlets and their gate equipment need to be designed for the high reservoir head; exceeding 140 m.

Different outlets gates arrangements were studied with respect to hydraulic requirements, operational reliability, structural implications and constructability. Provision of a bonneted regulating gate near the inlet was considered but not found appropriate due to concerns of energy dissipation of the released water within the conduit at partial gate opening. The regulating gate was therefore provided on the outlet releasing water in the open. The selected arrangement shown in Exhibit 14 includes a radial regulating gate at the downstream outlet end together with a bonneted emergency guard gate immediately upstream. Both the regulating gate and the guard gate would be capable of operating up to maximum reservoir level. For routine maintenance and repair of the radial gate, the bonneted guard gate could also operate as service or maintenance gate. Another bonneted gate would be installed in the conduit near the inlet. It would be used as service gate for inspection, maintenance and repair of the downstream conduit as well as the emergency gate further downstream. This gate will always operate under balance head conditions created using bypass filling valves. Normally, the service gate would be kept in closed position so that the full reservoir head is not exerted permanently to the dam body through the conduit.

The outlet conduits would be fully steel lined, which would enhance safety against any leakages and also minimize the maintenance requirements. However, to cater for a rare need of maintenance of the short length of conduit upstream of the service gate, slots would be provided on the inlet to lower stop logs by barges. For this purpose, the reservoir will have to be depleted to lower levels.

4.7 Maximizing Power Potential of Dasu Project

4.7.1 Long Tailrace Tunnels

From initial study of the alternative dam axes, dam at Axis 2 was favoured which yielded maximum head for power generation. However the dam site was shifted upstream to Axis 5 respecting the demand of the affectees and saving the Seo village from inundation located between Axis 2 and Axis 5. Shifting of the dam axis while discharging the powerhouse flows shortly downstream of the dam axis resulted in about 12 m reduction in the gross generation head. Introduction of the long tail race tunnel option was an outcome of this development, to regain the 12 m head and thereby draw the energy benefits of Axis 2 while constructing the dam at Axis 5. Exhibit 9 shows the layout plan with long tailrace tunnels, which are 2625 m long each compared to the 500 m length of the short tailrace tunnels.

A comparison of the long and short tunnels options was made for the additional energy benefit against the additional cost of the long tunnels. The economic analysis showed that the additional cost involved in constructing the long tail race tunnels carried in itself benefits exceeding the additional investment by nearly 50%, which is attractive. In view of the growing power needs of the country and to maximize benefits from the Dasu hydropower resource, the long tunnel option was adopted with a total installed capacity of 4320 MW, comprising eight units of 540 MW each.

4.7.2 Early Commissioning After Construction of Diamer Basha Dam Project

In the development strategy of the Indus hydropower resource, the potential of Dasu is planned to be exploited after commissioning of the Diamer Basha Dam Project located 74 km upstream of the Dasu site. The Dasu project was accordingly designed for “with Diamer Basha” condition in respect of water availability, floods and sediment.

Sediment sluicing from Diamer Basha is planned to start about 40 years after its completion and sluicing from Dasu will have to be started soon thereafter. When started, the sluicing will be undertaken annually in May at Diamer Basha and in July at Dasu. Power generation will be stopped for one month or more at each plant during these times.

With the given sediment sluicing requirements, the benefits from Dasu can be maximized by constructing it as soon as possible after Diamer Basha to maximize sluice-free operation period at Dasu.

5. CONSTRUCTION OF DASU PROJECT WITHOUT DIAMER BASHA PROJECT

In case construction of Dasu Hydropower Project is taken up before or without constructing Diamer Basha project, the functioning of the project in relation to sediment inflow in to Dasu reservoir and its sluicing would be severely affected. The benefit of sediment free inflow for 35 – 40 years in to Dasu reservoir due to trapping of the sediment in Diamer Basha reservoir would be lost and sluicing of sediment from early years of the project operation would be required. While sluicing, power station would be completely shut down for four weeks or more in the summer months, when electricity is in high demand.

It may be noted that because of the site constraints, Dasu Project would be a run of the river hydro power facility with a balancing reservoir having no capacity for seasonal storage. On the other hand, the country is in dire need of a dam project on river Indus with a large reservoir for seasonal storage. Diamer Basha Project would fulfil both the seasonal storage and hydropower generation needs and thus merits priority in implementation over Dasu Project.

6. CONCLUSIONS AND RECOMMENDATIONS

The detailed feasibility study of the hydropower facility at Dasu was carried out to international standard. The RCC gravity dam will be slightly higher than the current RCC dams but no higher than the dams already planned. Apart from the dam height, all components of the project have ample existing precedent.

It is recommended to commission the hydropower facility as soon as possible after construction of the Diamer Basha Dam Project to maximize sluice-free operation period at Dasu.

The principal project data is given in the following pages.

PRINCIPAL PROJECT DATA

Location	7 km upstream of Dasu town and 74 km downstream of Basha Dam site
Hydrology	
- Average Discharge at Dasu	2081 m ³ /s (73,490 cusecs)
- Average Annual Runoff at Dasu	65.63 BCM (53.18 MAF)
- Safety Check Flood (SCF)	36,640 m ³ /s (1,293,929 cusecs)
- Basic Design Flood (BDF)	20,908 m ³ /s (738,359 cusecs)
Reservoir	
- Gross Storage Capacity (El.950m)	1.39 BCM (1.15 MAF)
- Operational Storage Capacity (El. 900 – 950m)	0.82 BCM (0.67 MAF)
Diversion Tunnels	
- Number and Shape	2, D-shaped
- Size and Lining	12m x 20m high, concrete lined
- Average Length	817m/930m
- Discharge (2 tunnels)	7100 m ³ /s at headwater El.805m
Cofferdams	
- Type	Hard Fill
- Crest Length	U/s cofferdam 143m, D/s cofferdam 88m
- Height	U/s cofferdam 40m, D/s cofferdam 17m
Main Dam	
- Type	RCC (Gravity)
- Maximum Height above foundation	233m
- Crest Length	584m
- RCC Volume	4.25 MCM
Spillway	
- Type	Frontal, overflow, gated
- Number of Bays	6
- Type and Size of Gates	Radial, 16.5 m wide x 20m high
- Maximum Discharge Capacity	25,500 m ³ /s
- Plunge Pool	190m from dam toe
Low Level Outlets	
- Number and Size	7 (5.0 wide x 7.2m high)
- Shape and Lining	Rectangular, steel lined
- Discharge Capacity (7 Outlets)	6400 m ³ /s at reservoir El.860m

Power Waterways

- Number and Shape 8, circular
- Size and Lining 8.5m dia, concrete lined
- Maximum Velocity 5.7 m/s
- Average Length 392m

Power Generation

- Installed Capacity 4320 MW
- Generating Units 8, Francis turbines
- Generating Unit Capacity 540 MW
- Powerhouse Location Underground, left bank
- Cavern (L x W x H) 340m x 26m x 68m
- Maximum Gross Head 201m
- Design Head 183.8 m
- Rated Discharge (8 units) 2600 m³/s (92,000 cusecs)
- Rated Voltage 21 kV
- Total Energy 21,300 GWh/annum
- Plant Factor 52%

Tailrace Tunnels

- Number and shape 4, D-shaped
- Size and lining 10m x12.5m concrete lined
- Maximum Velocity 5.6 m/s
- Discharge per Tunnel 650 m³/s
- Average Length 2625m
- Surge Chamber 256m x 20m x 65m

Power Transmission

- Transmission Voltage 765 kV (AC)
- Powerhouse Substation GIS, Underground
- Transmission Substation AIS, Surface
- Transmission Line Dasu – Gujar Khan – Gatti (575 km)

Environmental Impact

- Persons 3700
- Houses and other buildings 350
- Cultivable and forest land 135 acres
- Trees 20,000
- Suspension Bridges 5
- Village roads and tracks 55 km
- KKH relocation 54 km

Cost and Economics

- Base Cost US\$ 5,206 million
- Capital Cost (including IDC etc) US\$ 7,807 million
- Construction Time 8 years
- EIRR 18.6%
- Benefit-Cost ratio 1.89



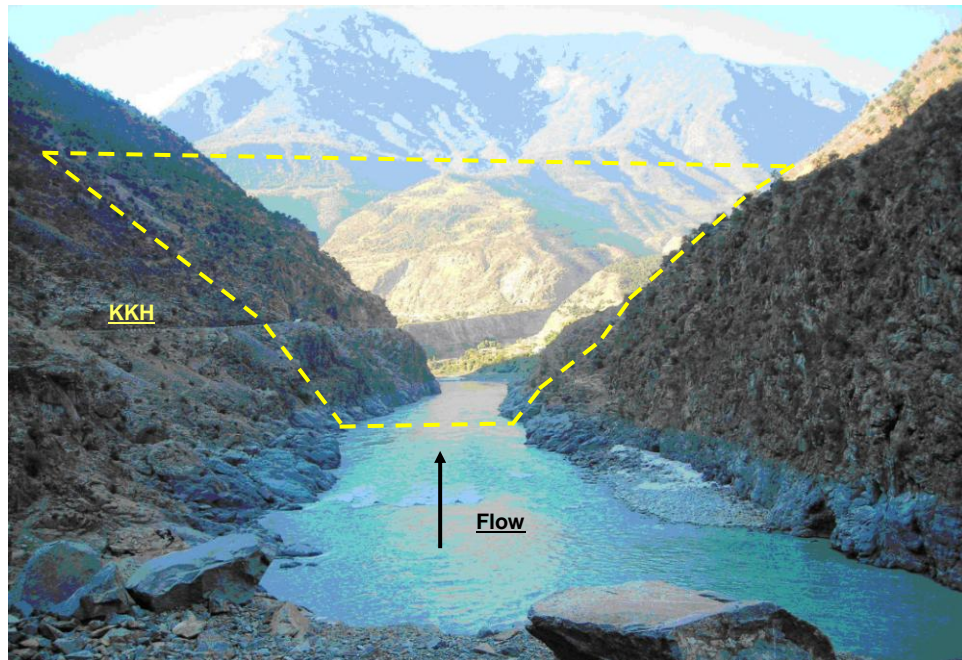


EXHIBIT 3: View of Dam Axis 5

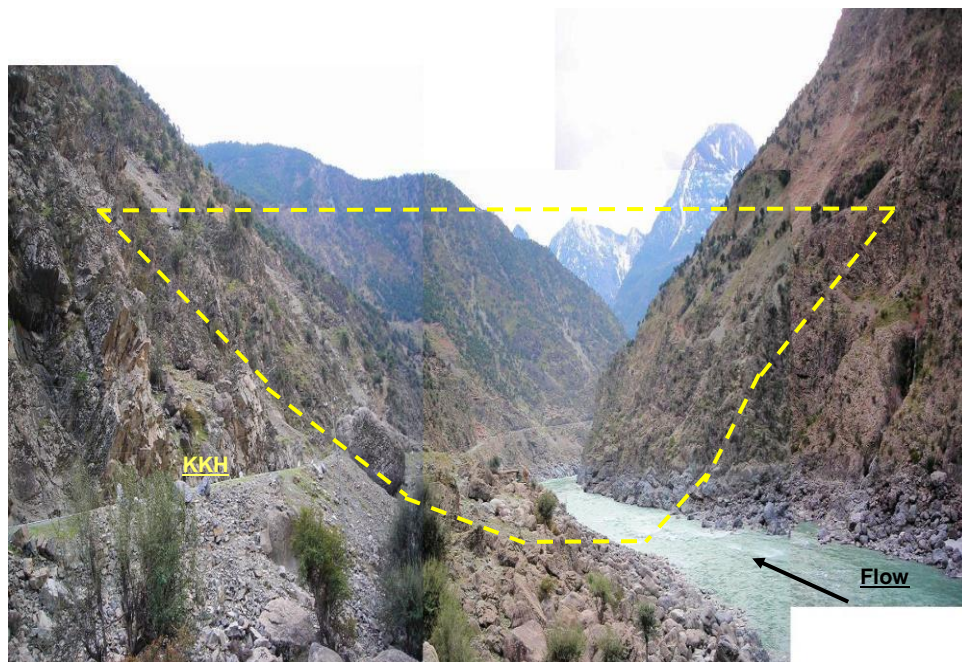


EXHIBIT 4: View of Dam Axis 6

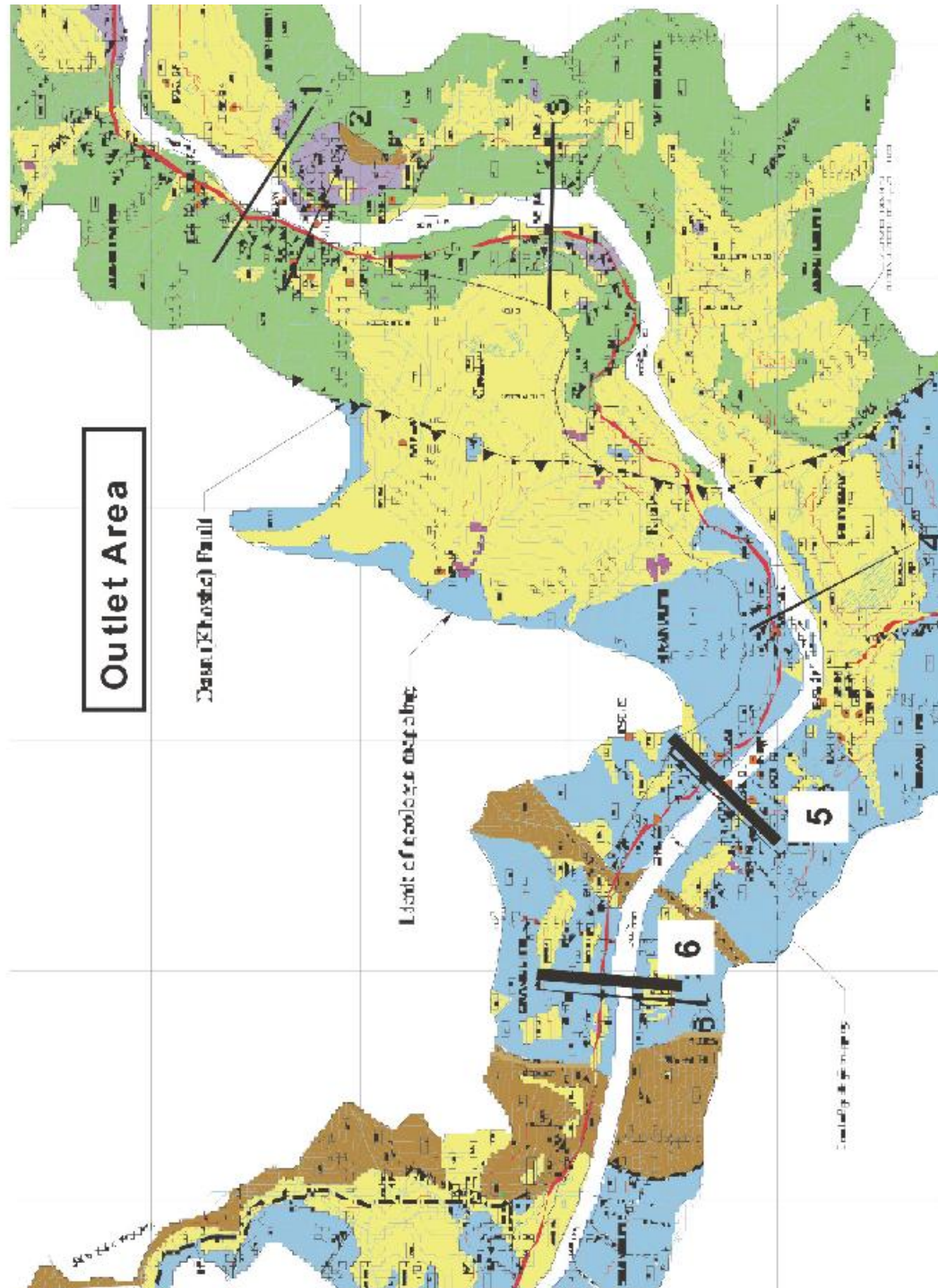


EXHIBIT 5: Site Area Geology

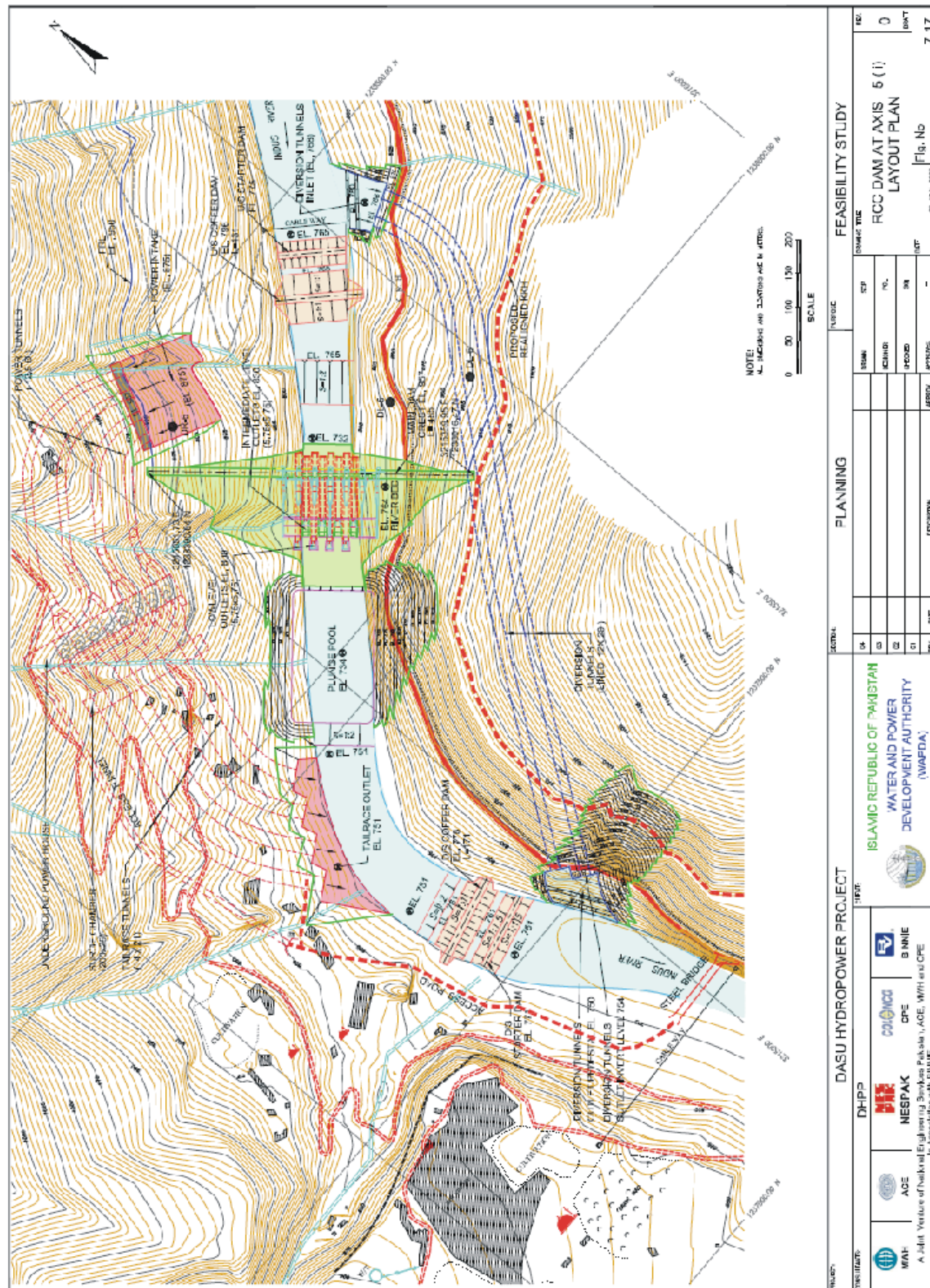


EXHIBIT 7: Project Layout at Axis 5 with Underground Powerhouse on Right Bank

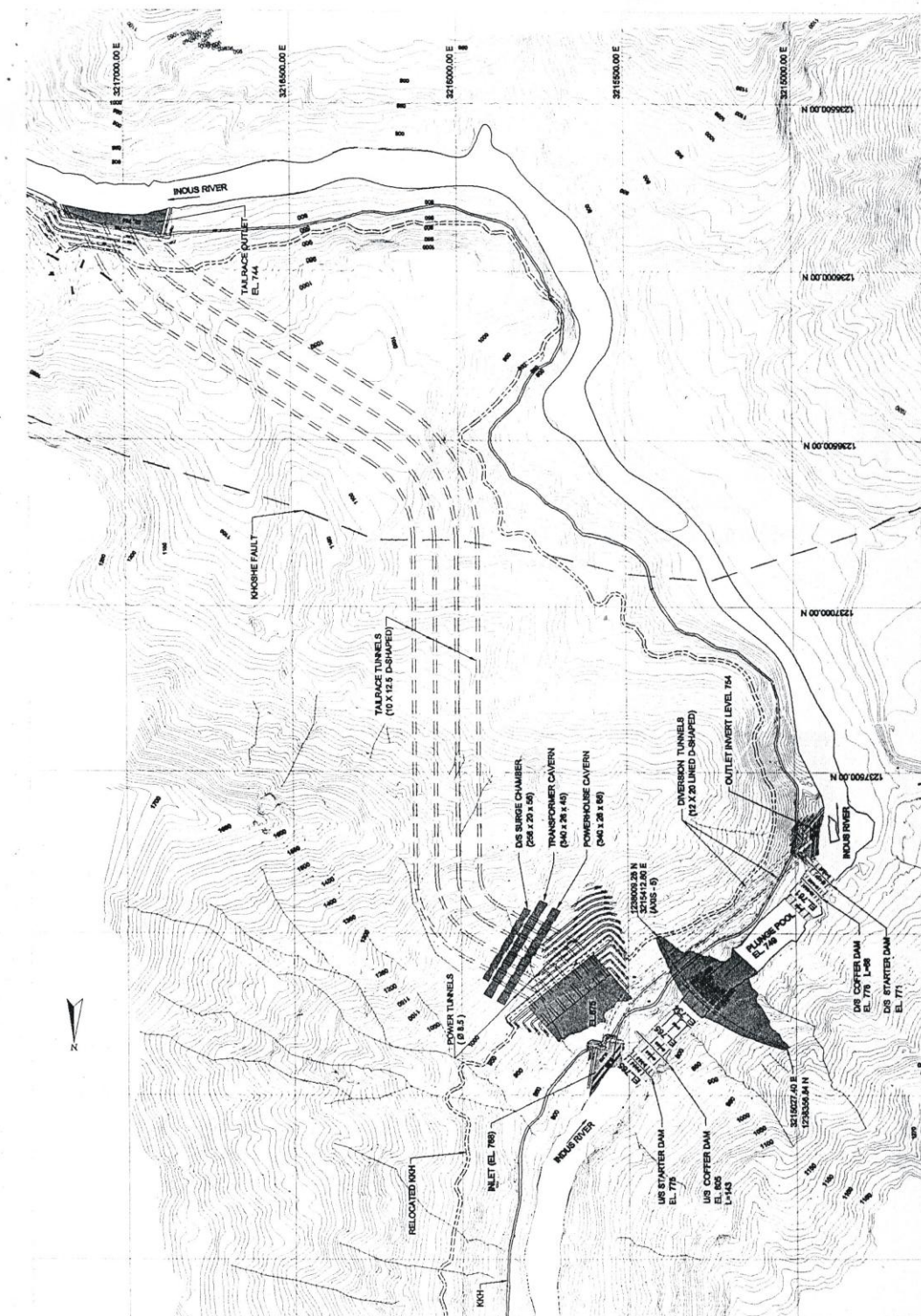


EXHIBIT 9: Selected Project Layout at Axis 5 with Underground Powerhouse on Left Bank and Long ailtrance Tunnels



EXHIBIT 10: Downstream View of Dasu Dam Model



EXHIBIT 11: Upstream View of Dasu Dam Model



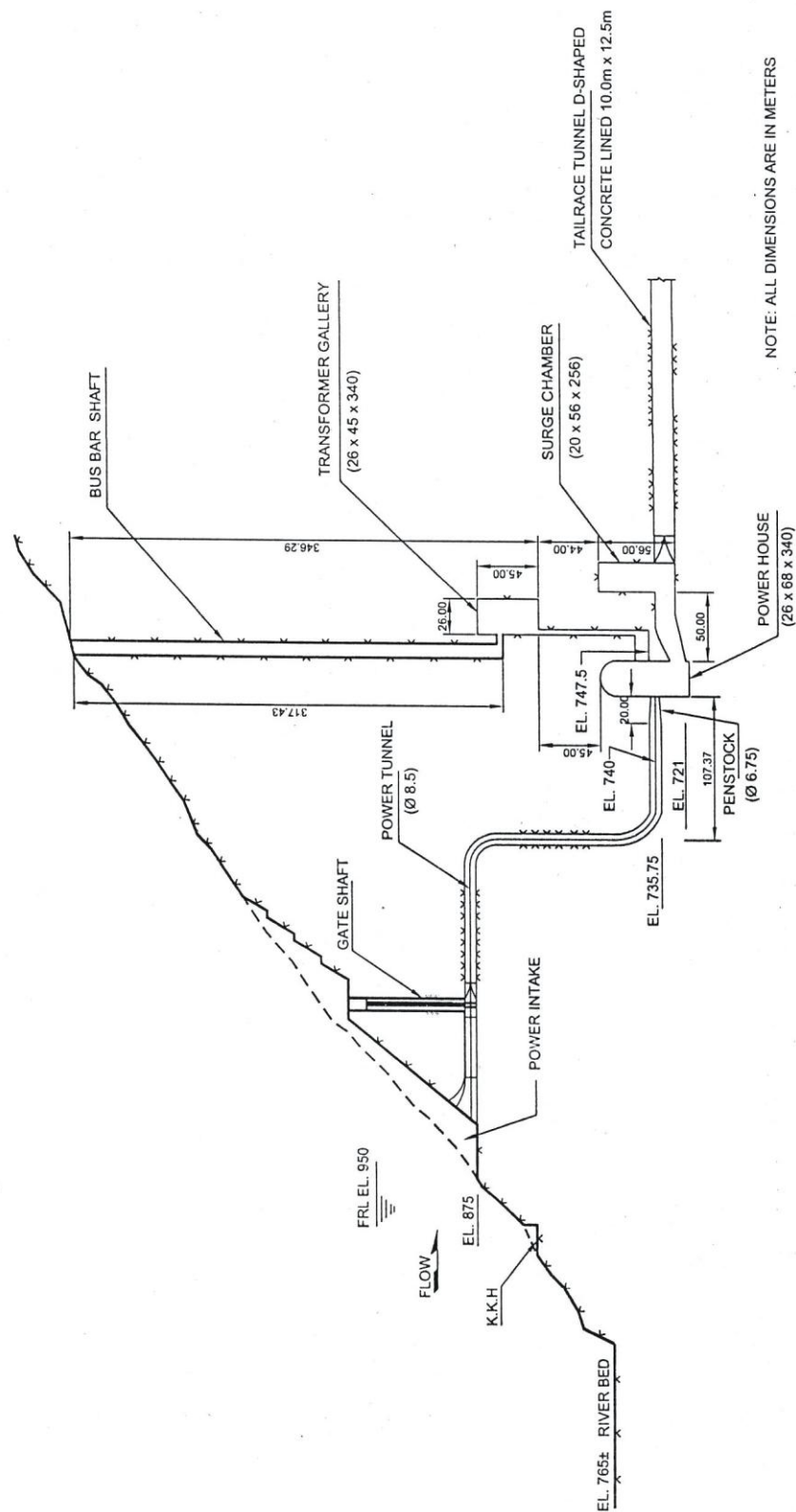


EXHIBIT 14: Underground Power Complex – Cross Section

