Approaching Paragraph 8 from the Perspective of an Engineer

Gregory L. Morris, PE PhD

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Focus of the Presentation

Paragraph 8. provides, *"Except as provided in Paragraph 18, the design of any new Run-of-River Plant (hereinafter in this Part referred to as a Plant) shall conform to the following criteria:"*

- This presentation discusses each of the 7 design parameters that are outlined in Paragraph 8 as required to achieve a Treaty-compliant design for a Run-of-River hydropower plant.
- The design and operation of Hydropower plants throughout the world is constrained by site-specific factors, and no plant is ever constructed and operated in a void. Design and operational limitations include:
  - Physical factors - things such as topography, hydrology, geology, sediment load, access, proximity to markets, the natural environment and the project's impact thereon, etc.
  - Social and legal factors – these include laws and regulations (and in this case the Treaty), displacement of people, laws for environmental protection, cultural resources, etc.
  - Financial factors - not only the project's anticipated costs and rate of return on investment, but also the availability of both equity and credit financing.
- Each of the 7 Para 8 constraints is discussed from the standpoint of engineering design and operational constraints, and how a plant can be designed to be compliant with Treaty limitations.

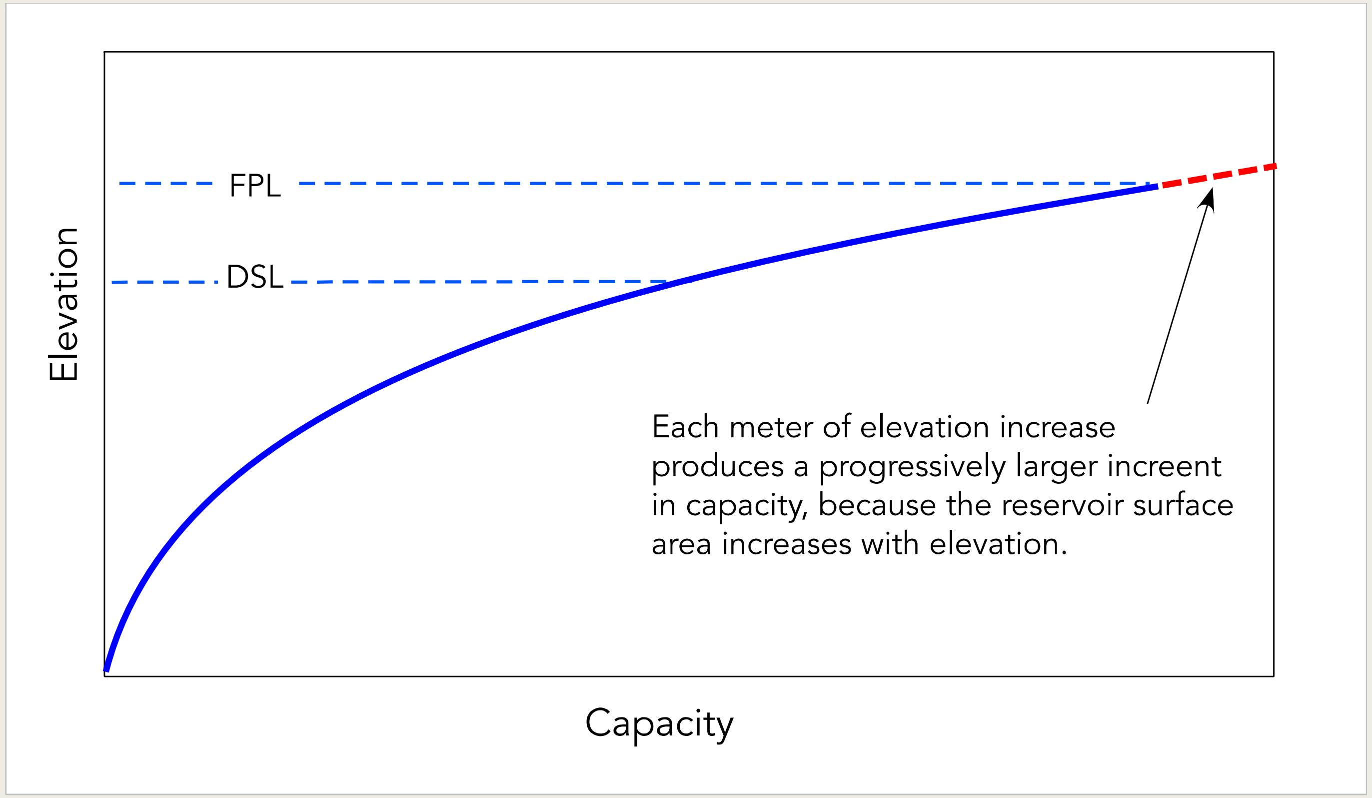
8(a) Limitation of Maximum Water Level

The works themselves shall not be capable of raising artificially the water level in the Operating Pool above the Full Pondage Level specified in the design.

- Most dams can be structurally modified to increase the water level, though this is infrequently done because of cost, upstream flooding, and other factors. It is evident that, once constructed as Treaty-compliant, the works should not be structurally modified to provide additional height and water storage.
- However, the key concept here is that the **operator should not be capable** of artificially raising the water level, for instance, by manipulating gate operation.
- It is similarly important to limit the freeboard, and this is especially so if the freeboard can be converted into controllable storage.

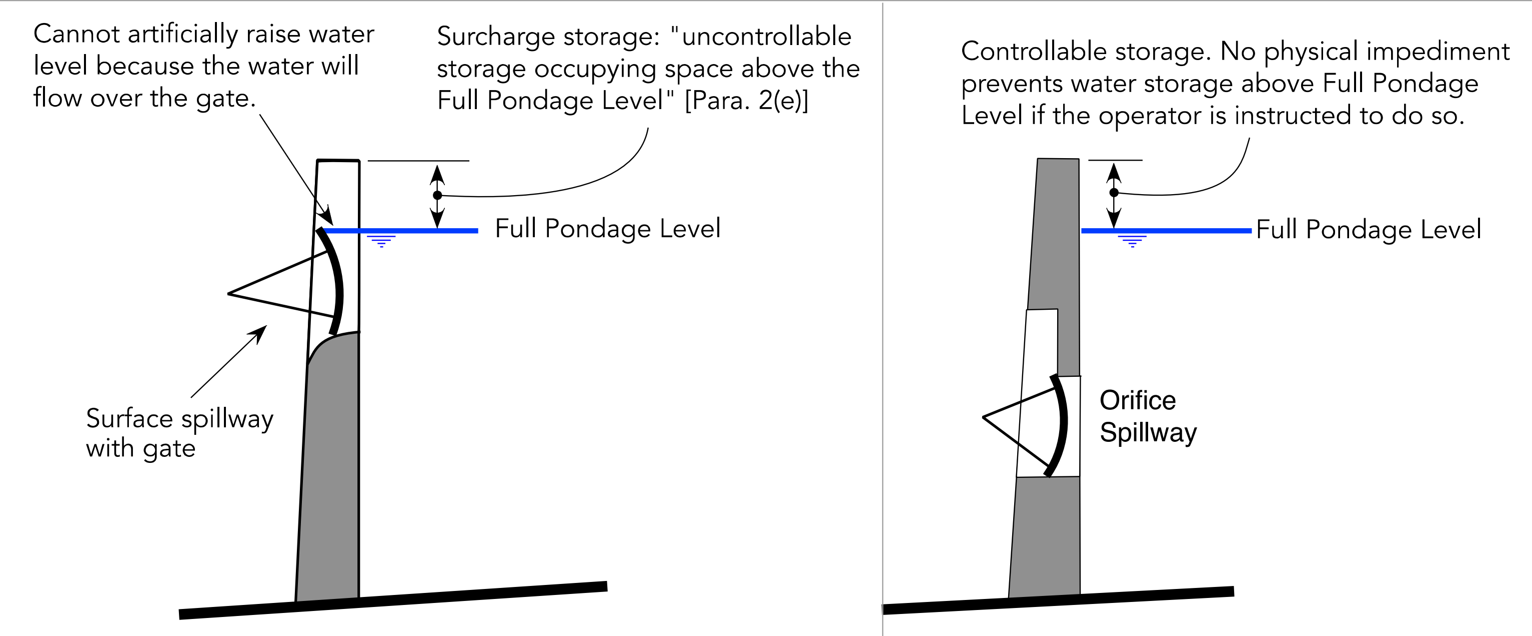
Elevation-Capacity Curve

Increases in reservoir level above Full Pondage Level (FPL) produce large increments in storage capacity.



- The storage capacity in a reservoir is highly sensitive to the maximum water level.
- This occurs because the reservoir surface area becomes larger with increasing water level.
- The elevation-capacity curve expresses storage capacity vs. water level.
- Each meter of water level increase above FPL produces an increasingly large volume of additional storage capacity, as seen by the flatter trajectory of the curve at the maximum elevation.
- This makes it especially important to eliminate the capability to artificially increase the water level.

Outlet Configuration and the Ability to Raise Water Level



(a) Surface Spillway **(b) Orifice Spillway**

(a) When a crest spillway is installed, the maximum water level cannot be increased without structurally altering the spillway or the gates. Without structural modification, water will simply overflow the top of the ungated spillway or the installed crest gates.

(b) However, with an orifice spillway the operator is capable of raising the water level into the freeboard zone by simply keeping the gates closed.

CONCLUSION: If an orifice spillway is used, it must be complemented with a crest spillway, thereby eliminating the capability of the operator to artificially raise the water level through gate operations.

8(b) Surcharge and Secondary Power

The design of the works shall take due account of the requirements of Surcharge Storage and of Secondary Power.

- "Surcharge Storage" is defined as uncontrollable storage occupying space above the Full Pondage Level (para 2e).
- Para 8(b) simply states that the reservoir may incorporate the volume required for flood surcharge.
  - Surcharge above FPL is absolutely required in the case of an ungated spillway.
  - Surcharge above FPL may be optionally incorporated in the case of a gated spillway.
- The reference to Secondary Power simply states that India is allowed to size the plant beyond firm power. Restated, the Treaty cannot be mis-read to imply that India's installed power is limited to Firm Power.
- Because the design power will normally be significantly greater than Firm Power, this implies that a larger (but not necessarily deeper) intake will be allowed.
  - A larger but not deeper intake would be achieved by extending the intake horizontally, rather than extending it vertically to a greater depth.

8(c) Pondage

The maximum Pondage in the Operating Pool shall not exceed twice the Pondage required for Firm Power.

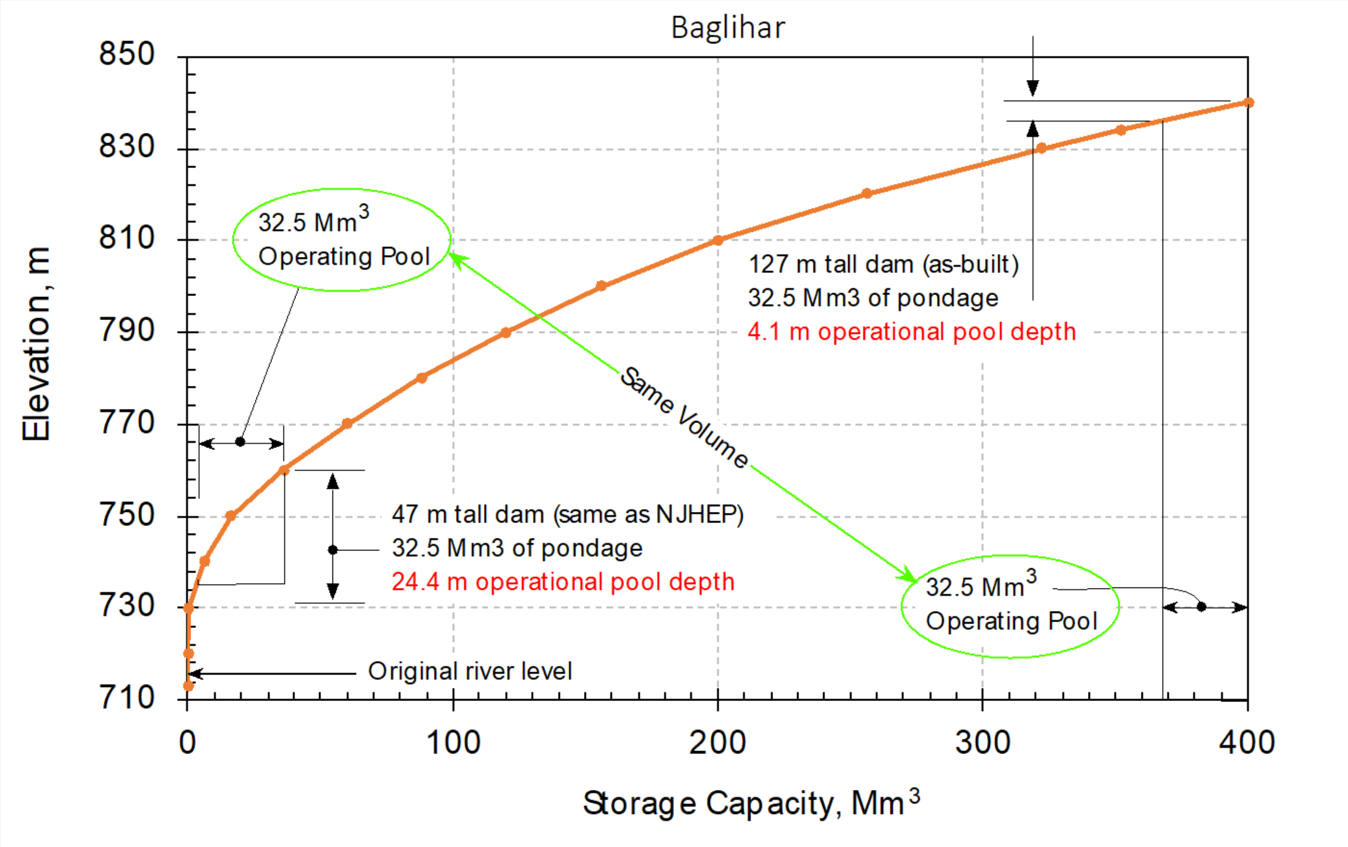
- The Treaty defines the allowable Pondage based on Firm Power, which is firmly rooted in the **hydrology of the site**. **It is NOT based on** the design capacity of the turbines or any other feature of the works.
- This is entirely logical because the Treaty provisions seek to preserve the natural hydrology of flows entering Pakistan against upstream interference. This makes it appropriate that the storage capacity should be defined based on the natural river flows (hydrology), and not on a parameter under the control of the designer (e.g. the design generating capacity).
- Thus, the maximum allowable Pondage capacity is a pre-determined design parameter that defines the **STARTING POINT** in the design process.
- Furthermore, since Pondage capacity is based solely on site hydrology, which is the first and most basic data which are collected and analyzed to initiate the design of any dam, it should be the first criteria that is known to the designer.

8(c) Pondage

The maximum Pondage in the Operating Pool shall not exceed twice the Pondage required for Firm Power.

- The Treaty limits drawdown to the bottom of the pondage pool, i.e. there should be no drawdown below the Dead Storage Level (DSL).
- It should be recalled that in the Himalaya, with high sediment loads, sluicing can be expected to require some degree of drawdown, while maintaining the level variation used for sluicing WITHIN the limits of the operating pool.
- Flushing also requires drawdown (or, more accurately, emptying below DSL). Because flushing requires drawdown below DSL, it is not Treaty-compliant.
- Assuming a Treaty-compliant design, with sluicing drawdown limited to DSL, the height of the dam will determine the amount of drawdown that can occur. The amount of drawdown will be limited to the difference between the Full Pondage Level and the Dead Storage Level, respectively, i.e. the upper and lower limits of the operating pool (the pondage pool).

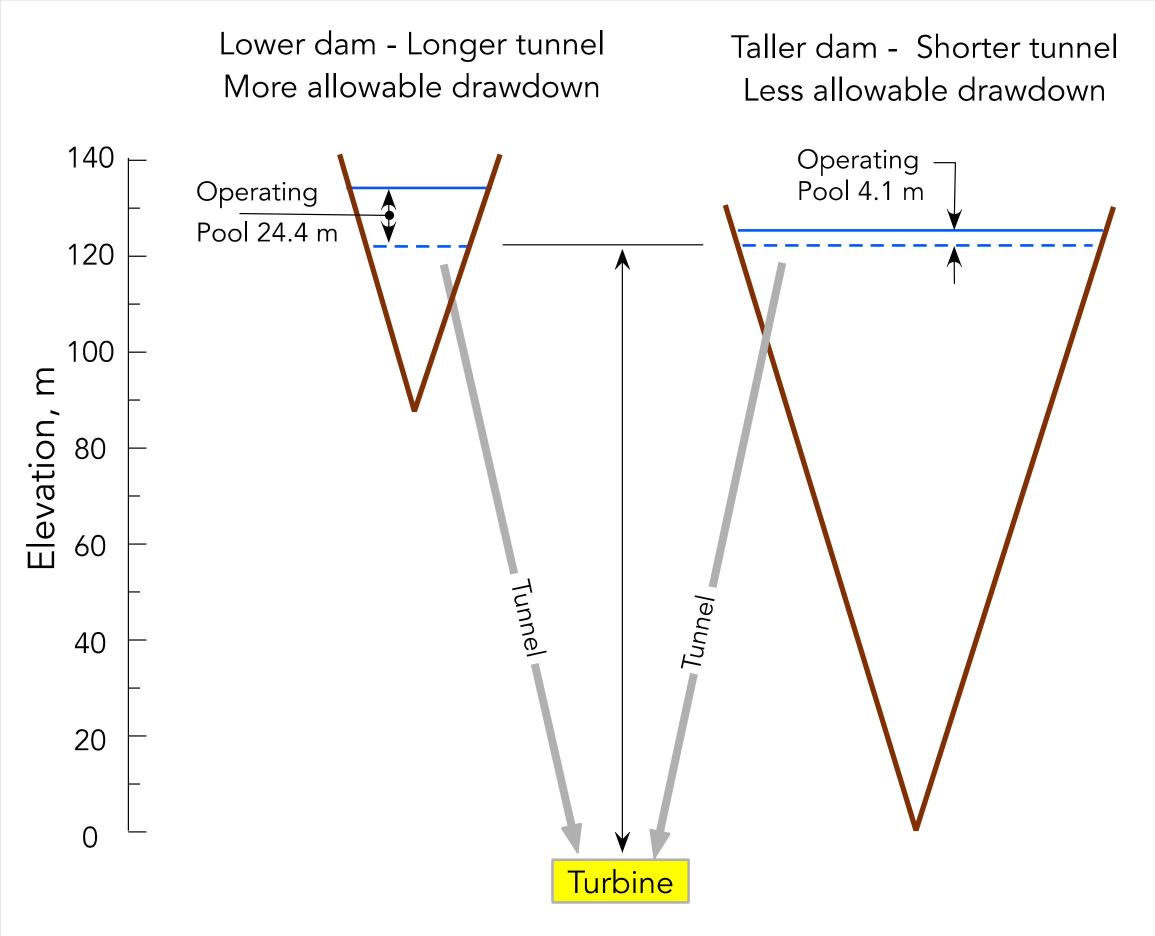
Treaty-Compliant Operating Range Depends on the Selected Dam Height



Elevation-storage curve constructed from Table 3 of Annexure 1.1 “Design Flood” in India’s Counter Memorial of September 2005 in the Baglihar proceedings.

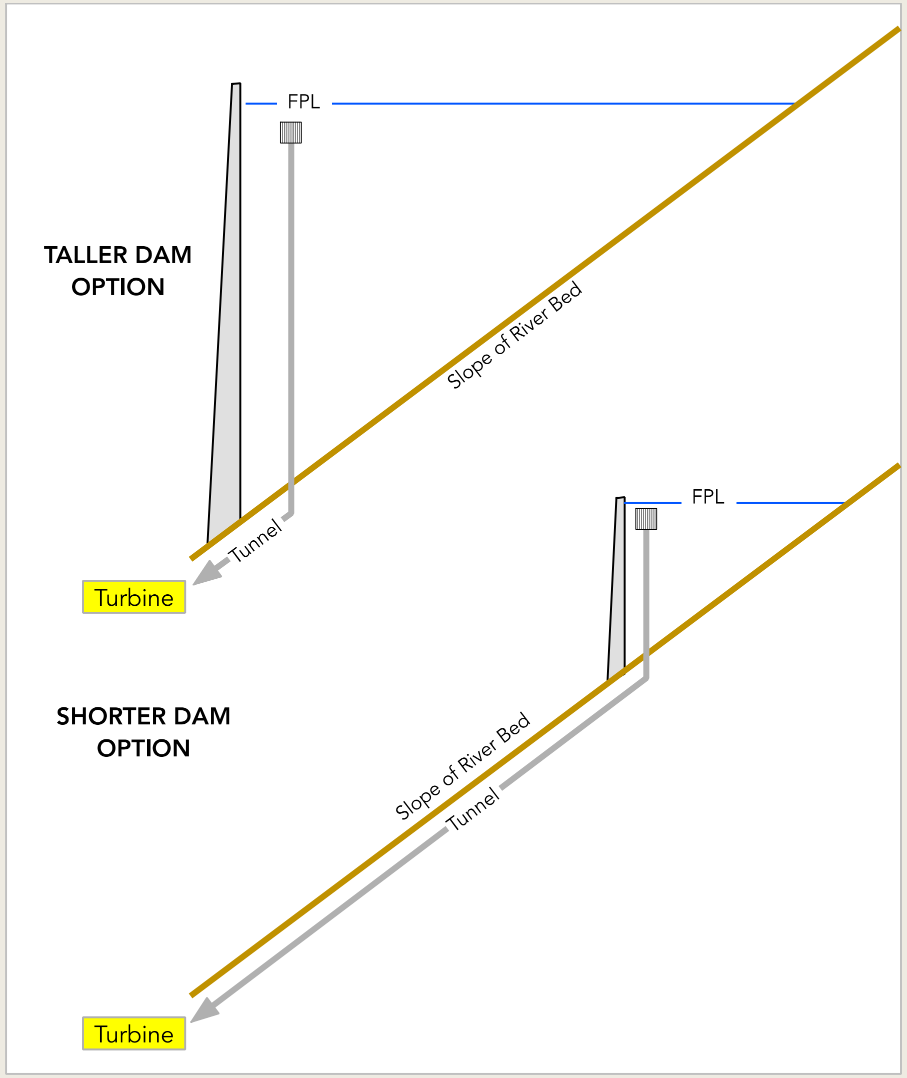
- Using the elevation-storage curve for Baglihar, constructed using data presented by India, as shown on the left, and using Prof. Lafitte’s computed pondage of 32.56 Mm3, it may be seen that:
  - For a 127 m tall dam (Baglihar as-built), the 32.56 Mm^3 pondage pool is only 4.1 m deep.
  - However, if a smaller dam is built, say only 47 m tall – the same height as NJHEP – the depth of the pondage pool will now be 24.4 m, providing greatly increased operational flexibility for sediment management.
- By electing to build a tall dam, India automatically limits the operating pool depth, thereby complicating sediment management.

Treaty-Compliant Operating Range Depends on the Selected Dam Height



- The trade-offs for developing hydropower on a river segment are:
  - o Design a taller dam with a shorter tunnel (the approach used at Baglihar & Ratle), or
  - o Design a lower dam with a longer tunnel (similar to India's Dul Hasti dam, or Pakistan's Neelum-Jhelum).
- The graphic on the left vertically scales the two pondage pools having the same volume shown in the graph on the prior slide.
- In essence, selection of the dam height determines the depth of the Treaty-compliant drawdown.
- Selection of a tall dam automatically reduces the depth of the operating pool which, in turn, complicates sediment management. This leads to the artificially-created "need" to circumvent the Treaty's limitations as an inevitable result of the selected design.

Dam Site Selection



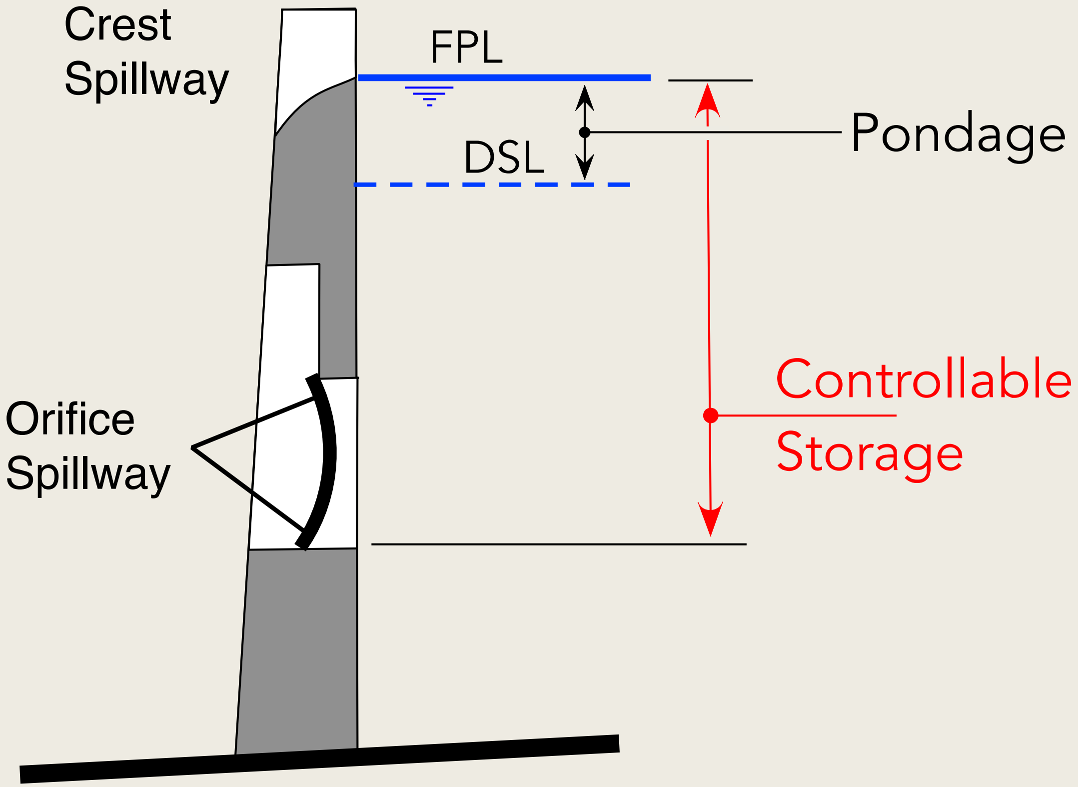
- The choice between the taller and shorter dam is again schematically represented here, comparing them on a longitudinal profile.
- The taller dam serves as a huge sediment trap, and with its limited allowable operating range (e.g. 4.1 m), this complicates sediment management as a result of a conscious design choice.
- The shorter dam has a much deeper Treaty-compliant operating range (e.g. 24.4 m) and is much more amenable to Treaty-compliant sediment management.

8(d) Outlets Below Dead Storage Level

There shall be no outlets below the Dead Storage Level, unless necessary for sediment control or any other technical purpose; any such outlet shall be of the minimum size, and located at the highest level, consistent with sound and economical design and with satisfactory operation of the works.

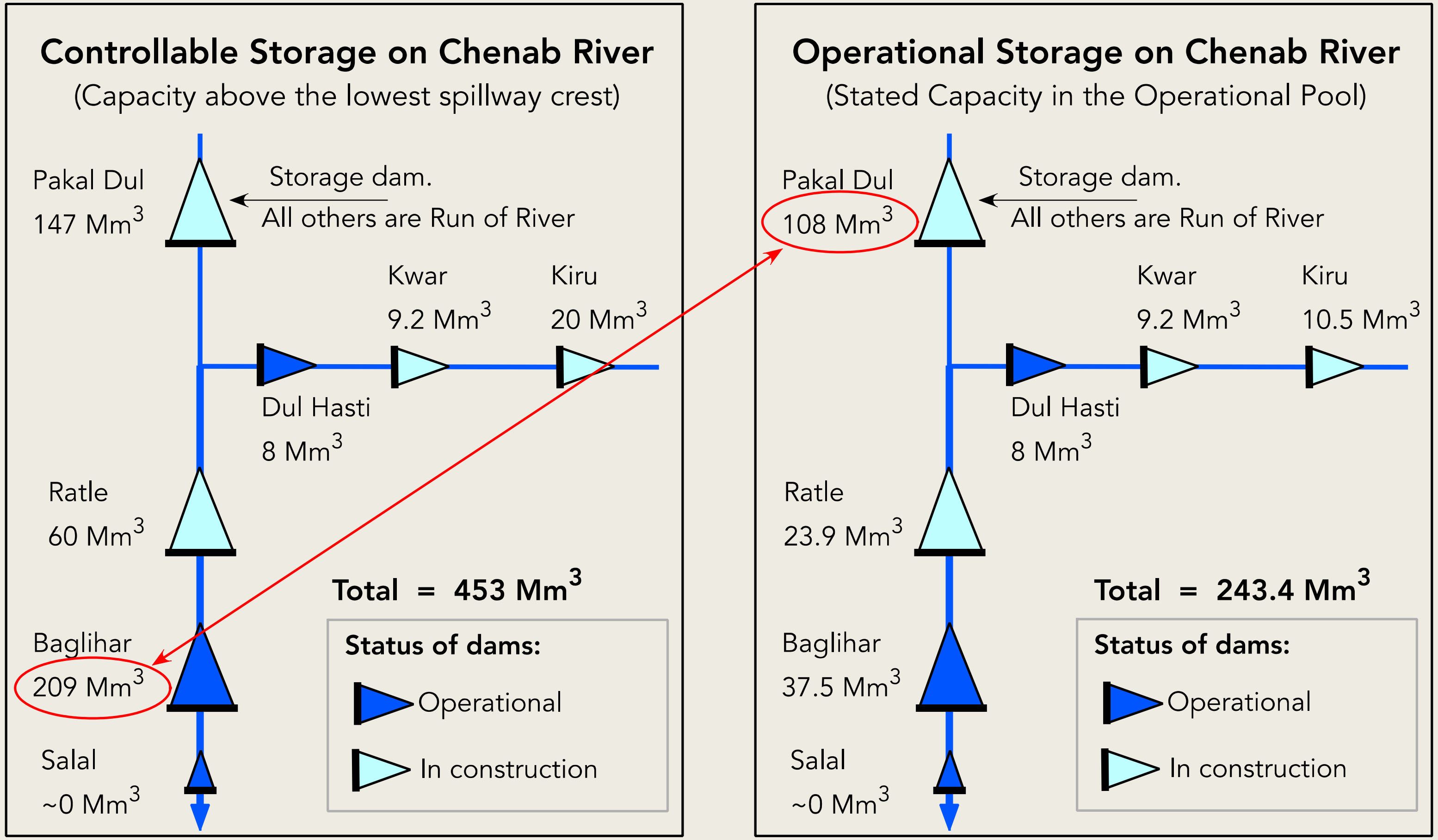
- The focus here is on the concept of "necessity". It will be considered necessary if a practical alternative does not exist, independent of least-cost considerations.
- It is not unusual to face "necessity" requirements in design. For example, many jurisdictions require the installation of an additional gate for added reliability, despite the added cost (the so-called n-1 criteria).
- Power outlets (intakes) must have an invert elevation below the DSL to utilize the full operating pool.
- The spillway crest must be below DSL for sediment sluicing at DSL. However, further lowering will not influence sluicing behavior.
- As outlined in the previous slides, by selecting a Treaty-inappropriate design strategy based on tall dams, the designer can artificially create the appearance of "necessity", when it was in fact created the the designer's selection of a poor design strategy.
- This artificially-created "necessity" can lead to designs which, to "correct" the problem created at the onset of the design process, produces absurd results which violate the very heart of the Treaty's intent to limit controllable storage.

Controllable Storage



- You will remember the concept of controllable storage, being the storage that lies above, and thus be controlled by, the low level outlets.
- The controllable storage is important because it can be SIX TIMES larger than the Pondage. At Baglihar:
    - Pondage =32.56 Mm^3
    - Controllable Storage = 209 Mm^3
- Thus, controllable storage has the potential to have a much greater impact on the manipulation of downstream hydrology than Pondage.

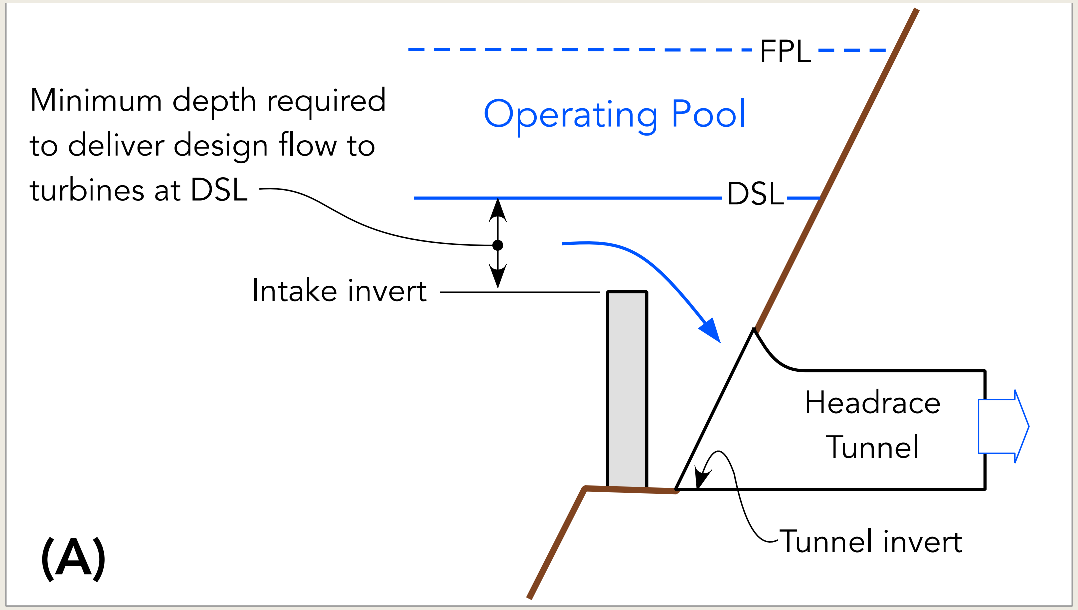
The Problem of Controllable Storage



- These graphics indicate the storage capacities of existing and in-construction dams on the Chenab River.
- Notice that the Baglihar Run of River controllable capacity is approximately **DOUBLE** India's announced live storage at Pakal Dul, which is a **Storage Dam.**
- **It cannot be right** that the Treaty could be interpreted to allow substantially more controllable storage at a Run of River plant than at a Storage facility.
- How does this happen?

Controllable storage has been calculated as the volume above the crest of the low level spillway, except at Kwar and Dul Hasti where the live storage is shown.

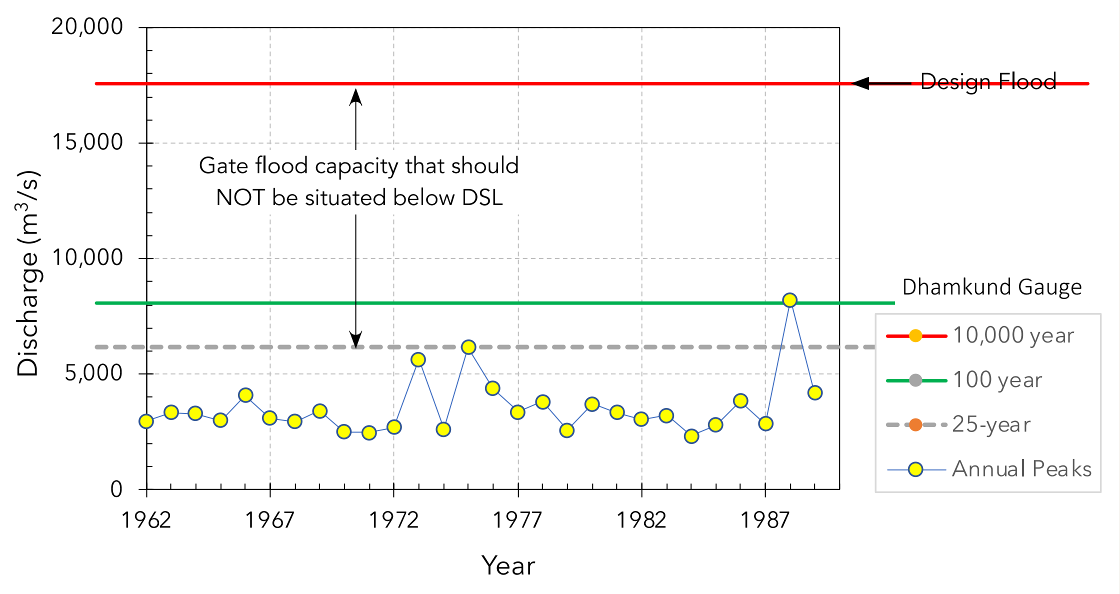
Intake Invert in Relation to DSL



- Use of a deep intake instead of a surface intake drives the need for even deeper spillways and, in the end, results in huge volumes of controllable storage.
- This problem can be minimized using a high-level intake.
- The intake is used to divert water out of the reservoir, and can easily be separated from the headrace tunnel.
- Thus, a high level intake can easily be combined with a deeper headrace tunnel, set at the required submergence to prevent vortexing.
- A desander will typically be located between the intake and the headrace tunnel, as seen at Neelum-Jehlum.

Spillway Crest in Relation to DSL

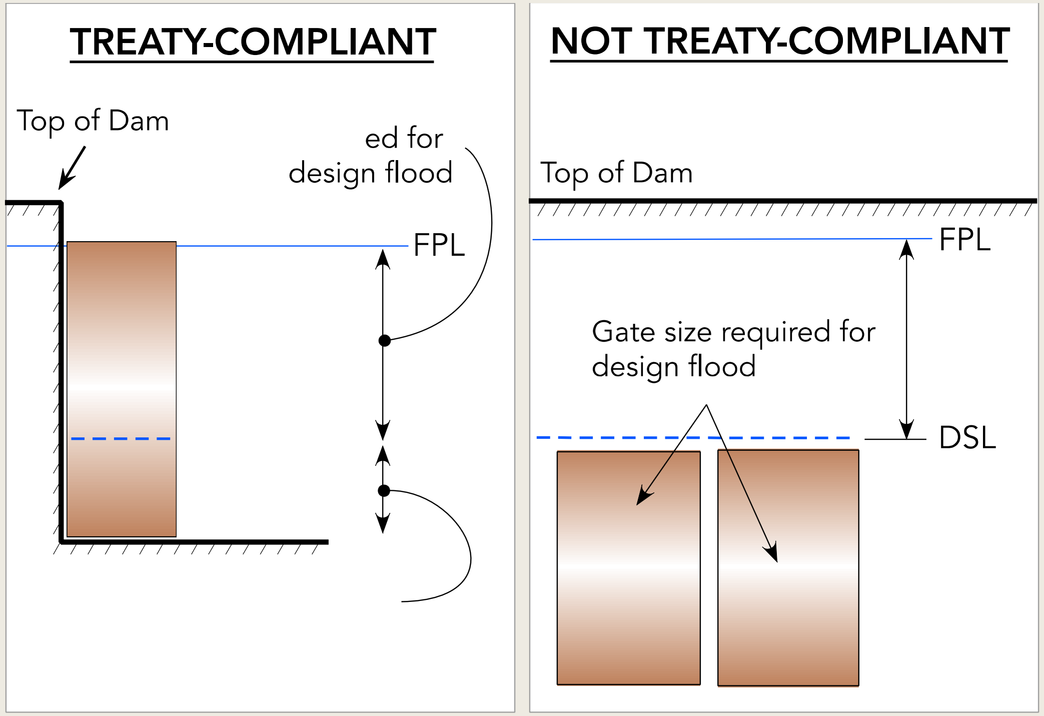
- Spillways must be sized to discharge the maximum design flood.
- The design flood is MUCH larger than the normal annual peak flows, or the even-lower flows typically used to release sediment each year. The large discrepancy between the magnitude of annual peak flows and the design flood is evident in the graphic below.
- Whereas the crest elevation of sediment-release outlets must be situated at an elevation lower than the intake and DSL, this is not generally a requirement of flood release outlets.



Data extracted from Table 1 of Annexure 1.1 “Design Flood” in India’s Counter Memorial of September 2005 in the Baglihar proceedings.

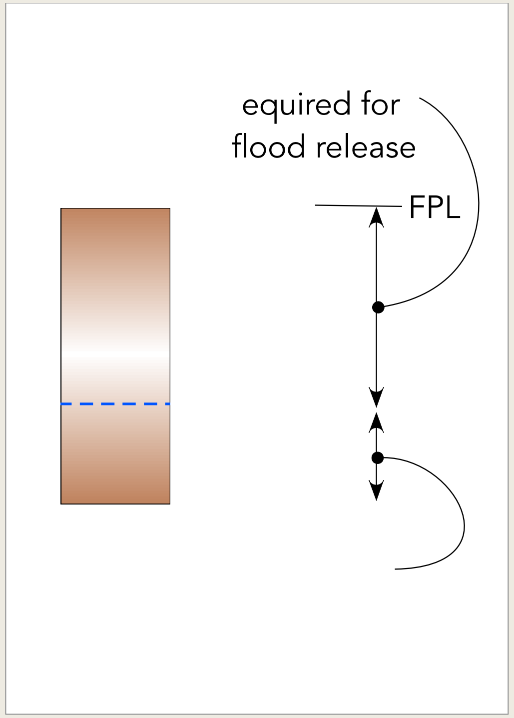
- The relative magnitude of the daily flow data compared to the floods of different return intervals is compared in the graphic.
- If the spillway below the DSL is sized for the design flood, rather than limited to the size required for sediment release purposes only, then it will be over-sized and will not conform to the criteria of “minimum size” and “highest level’.
- Data from Dhamkund gauge below Baglihar dam.

Spillway Crest in Relation to DSL



- Thus, the only “necessary” spillway capacity that can be located below DSL is limited to that associated with **sediment management**.
- Treaty-compliant outlets would allow passage of sediment-release flows. They might be sized to pass, approximately, the 10-year event at DSL when fully open. Larger events would produce flood levels higher than DSL. Events smaller than the sediment-release flow would discharge through partial gate openings to maintain the water level at or above DSL.
- Modeling would be used to select the gate configuration and operating rule that comply with the minimum-size and highest-level criteria.
- Intermittent sluicing may also be adequate, to be determined by modeling plus operational experience.
- CONCLUSION: the Para. 8d design constraint can be accommodated by providing the spillway capacity necessary for sediment management below DSL, while the balance of the capacity required to manage the design flood is accommodated using spillway capacity located ABOVE DSL.

8(e) Gated Spillway



- The analysis sequence for gate sizing is as follows:
    1. Establish a preliminary estimate of the gate size and crest elevation required to pass normal high flows through the reservoir at DSL.
    2. Also size the spillway capacity above DSL. (This may consist of large radial gates which can pass ordinary floods at DSL and larger floods at higher water levels, as illustrated on the left).
    3. Develop the elevation-discharge relationship for the selected gates configuration and incorporate this into the reservoir operational rule for testing.
    4. Use a sediment transport model to simulate many years of reservoir operation for the selected gate configuration and operating rule, noting the capacity of each configuration to preserve long-term capacity.
    5. Through multiple iterations of gate configurations and operating rules, select the configuration that provides the highest level crest of the gated spillway, with the minimum size below DSL.
- This general procedure represents a standard approach for sizing gates in dams.

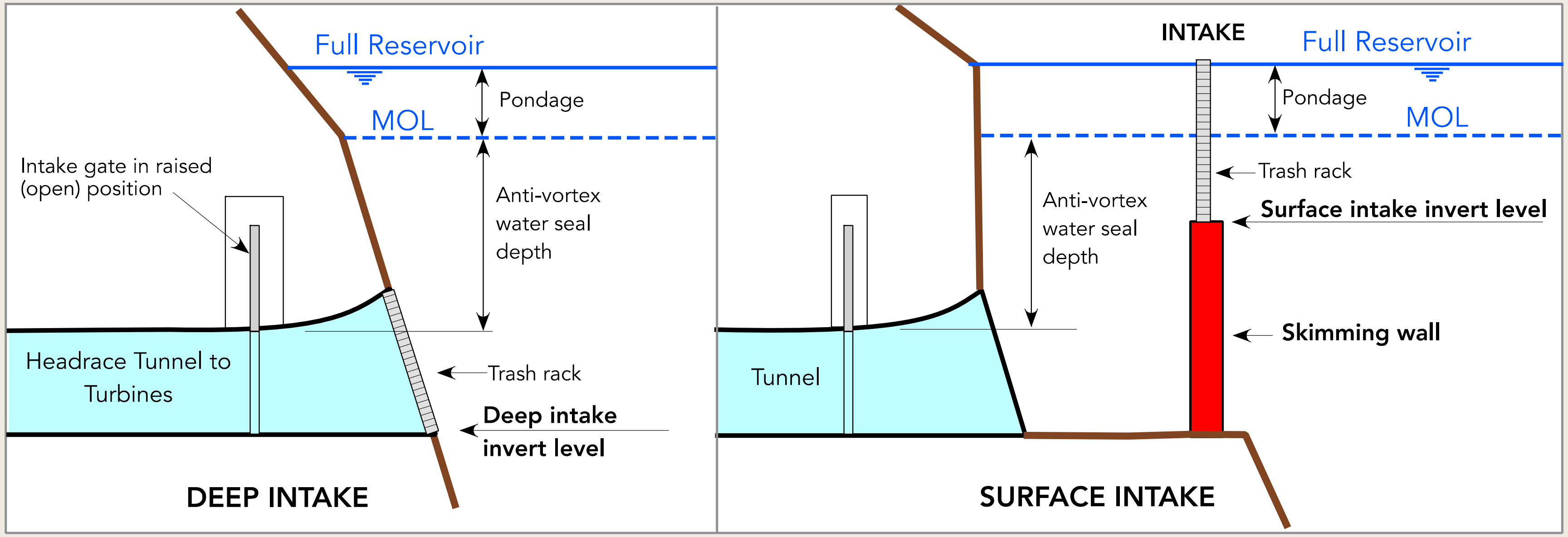
8(f) Intake Placement

The intakes for the turbines shall be located at the highest level consistent with satisfactory and economical construction and operation of the Plant as a Run-of-River Plant and with customary and accepted practice of design for the designated range of the Plant's operation.

- Due to the settling velocity of coarse sediment, the suspended sediment concentration will typically be lower near the top of the water column as compared to near the bottom of the river or reservoir.
- In a Run-of-River plant the exclusion of sediment from the turbines is always a primary concern, and one of the accepted practices to minimize the entrainment of coarse sediment into the intake is by setting the intake at the highest level possible. This Treaty requirement presents nothing out of the ordinary for run-of-river intake design.
- In contrast, intakes at storage reservoirs are typically placed at considerable depth simply because the water level in the storage reservoir may itself vary considerably, by tens of meters over the course of the year.
- If a deep intake is installed in a run-of-river reservoir, then it will be necessary to continuously maintain the required depth in front of the intake. Since the intake invert must be set below DSL, this design choice favors a sediment management strategy based on empty flushing through an even deeper outlet, which is NOT Treaty-compliant and greatly increases controllable storage.

Highest Level Intake Strategy

- The entrance to a headrace tunnel requires a certain submergence depth to minimize vortexing.
- On the other hand, to minimize sediment entrainment the intake level should be set as high as possible.
- These two apparently contradictory requirements can be easily met by using a high level surface intake configuration incorporating a skimming wall, as illustrated below.
  - Features such as a barrier to exclude floating debris and the trash rack would be configured based on local site conditions.



8(g) Regulating Basin

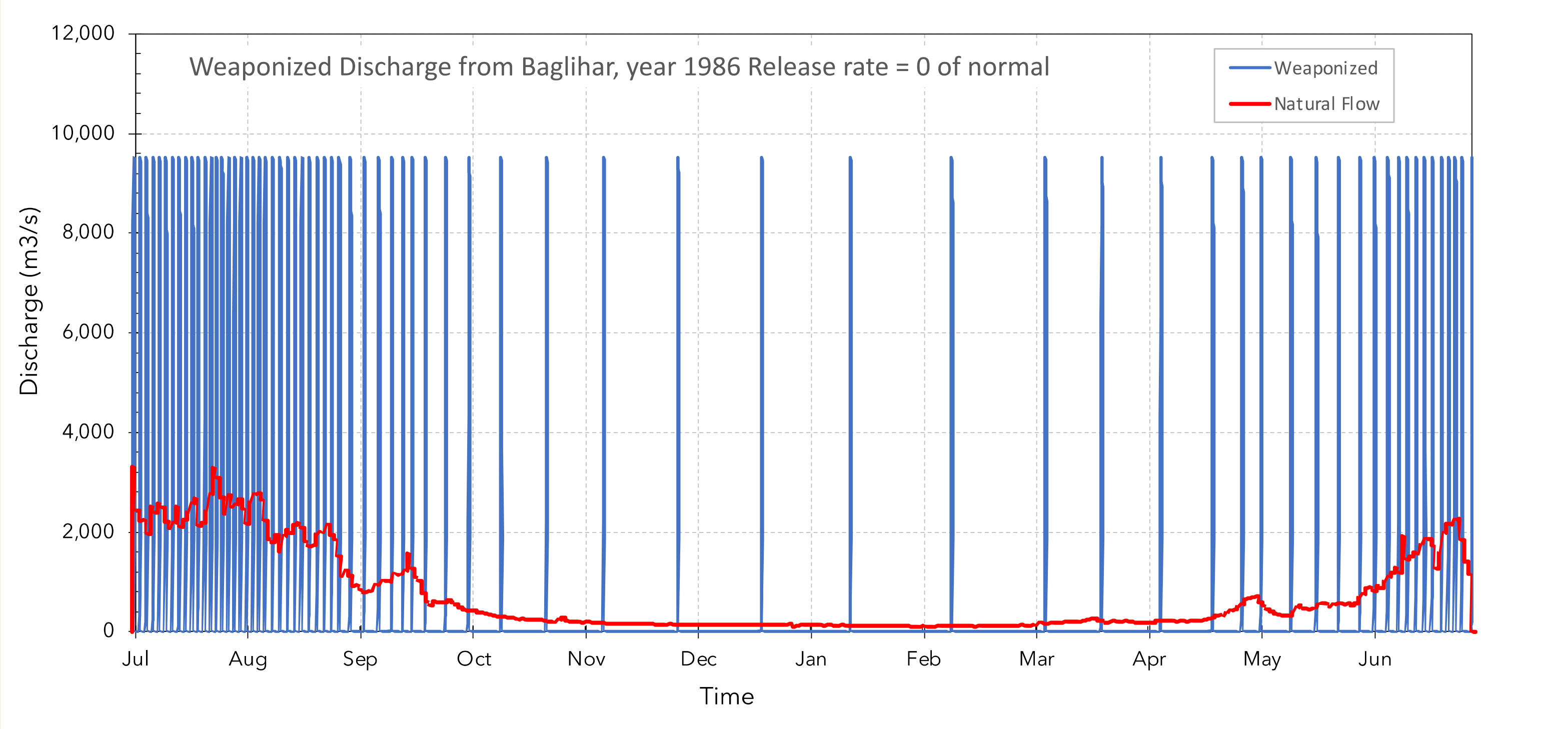
If any Plant is constructed on the Chenab Main at a site below Kotru (Longitude 74° - 59′ East and Latitude 33° - 09′ North), a Regulating Basin shall be incorporated.

- During peaking operations, the discharge from a hydropower plant can vary from zero to the design capacity of the turbines.
- This ON-OFF flow can be highly detrimental to downstream users:
  - It is incompatible with the delivery of irrigation water into a canal system.
  - It will accelerate streambank erosion, which can affect streamside infrastructure.
  - It is damaging to aquatic life.
- A regulating basin accumulates water during peaking discharges, and releases it downstream at an even flow rate, thereby converting ON-OFF inflow into a nearly CONSTANT outflow.
- This is not an item under controversy and will not be discussed further.

Weaponization

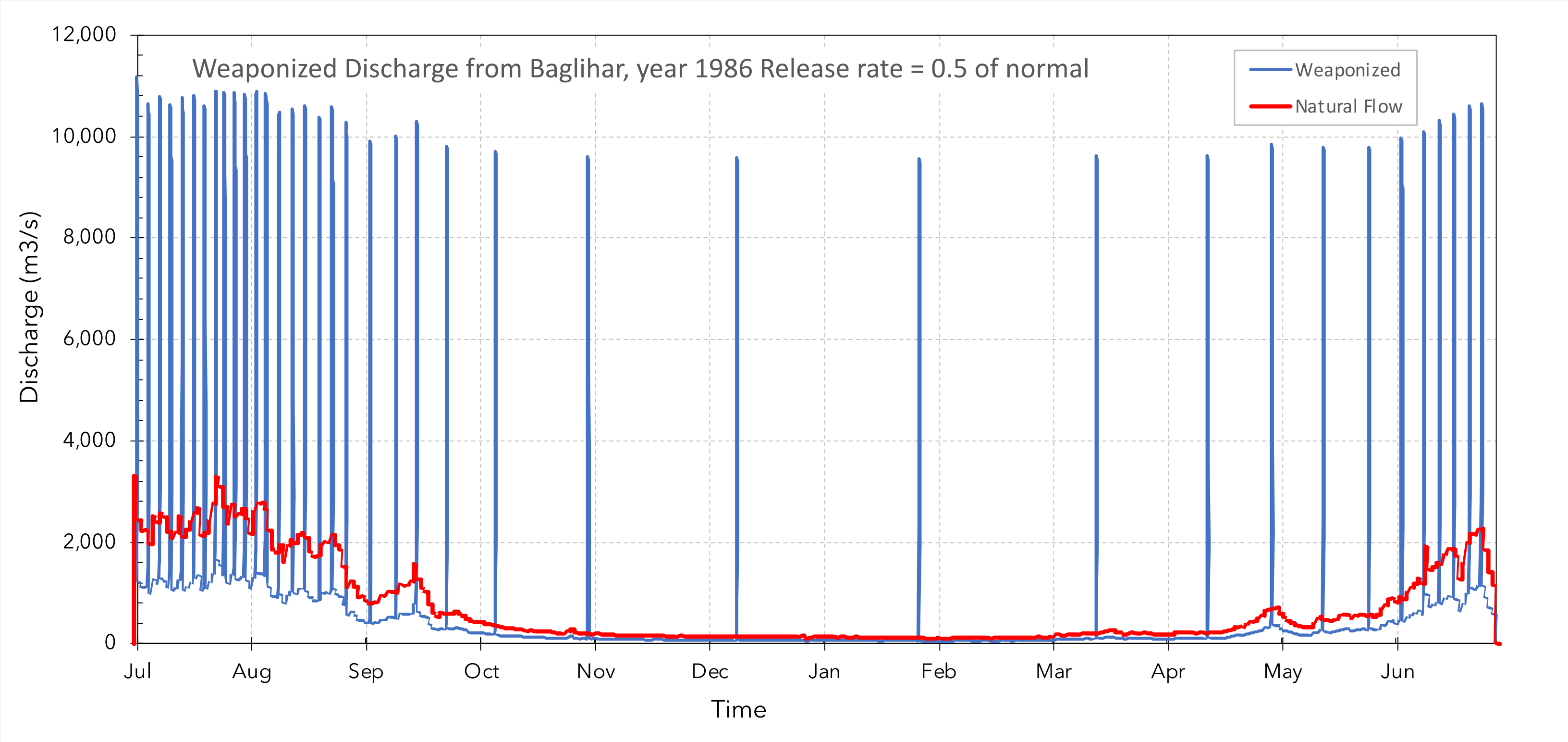
- A prime concern to Pakistan is the potential for India to manipulate the storage capacity in its dams to materially alter flows, essentially weaponizing the dams.
- The weaponization of dams is neither a trivial nor an abstract concept. We need look no more than 13 months into the past, when the Kakhovka dam on the Dnieper River in Ukraine, then under Russian control, was explosively breached, releasing a massive flood.
- In the case of Pakistan, the principal concern revolves around the interruption of water supply for irrigation, particularly in the critical spring kharif planting season.
- A simple conceptual model was created to simulate the accumulation of runoff in dams having a cumulative controllable storage of 400 Mm^3, releasing this flow through the gated outlets at Baglihar. This simplified model does not incorporate operational details for upstream dams and flow routing, but assumes that the upstream dams will be operated to deliver their storage to Baglihar in a timely manner to sustain the simulated Baglihar discharge.
- Scenario #1 is an extreme case, operating gates in an ON/OFF manner, with downstream releases being either:
  - ZERO (empty reservoirs are accumulating water), or
  - FULL OPEN (Baglihar gates open fully to make downstream releases at full gate capacity until the accumulated water is released).

Weaponization: Conceptual Scenario #1



- The first scenario Simulates release at full gate capacity at Baglihar, followed by a period of reservoir refilling with zero releases, followed by another release at full gate opening.
- The simulation shows a repeating cycle of filling and emptying.
- This ON/OFF water delivery schedule would present a catastrophic level of flow interruption to irrigation canals.
- In the wet season the reservoirs refill more quickly, but intermittent ON/OFF flows are still possible.
- This graph simulates 1986, the year having the median annual flow.

Weaponization: Conceptual Scenario #2



- The second scenario is more nuanced and perhaps less obvious to the downstream party.
- In this scenario the emptied reservoirs only capture half of the natural inflow while the other half is released downstream of Baglihar.
- During the spring kharif planting season, this scenario converts “average” spring flows into “drought” flows.

Final Thought on the Treaty's Limitations

The Treaty's limitations are clearly designed to protect Pakistan's hydrology.

They are not designed to satisfy India's desire to build high dams and maximize storage.

India does have Treaty-compliant design options, but has chosen to ignore them.

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