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GOVERNMENT
OF PAKISTAN

GOVERNMENT
OF INDIA

THE INDUS WATERS TREATY 1960

BAGLIHAR Hydroelectric Plant

Expert Determination

on points of difference referred by the Government
of Pakistan under the provisions of the Indus Waters Treaty

Prof. Raymond Lafitte
ÉCOLE POLYTECHNIQUE
FÉDÉRALE DE LAUSANNE

Lausanne,
12 February 2007

A philosopher statesman of the late eighteenth century is reputed to have pronounced this *obiter dictum*:

"An international treaty that gives one party all that it wants cannot be a good treaty,"

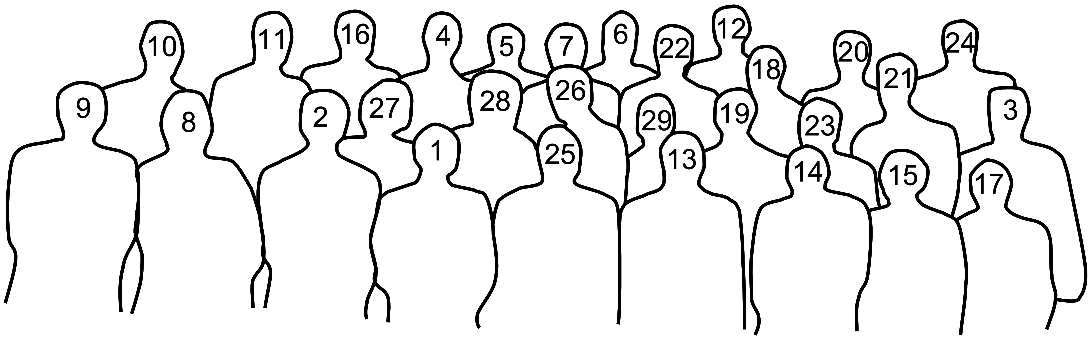
and Sir William Iliff asserts:

"It can, I think, be said of the Indus Waters Treaty, that at least it does not vitiate that criterion."

Foreword by
Sir William Iliff
Former Vice-President of the World Bank

Indus Waters Treaty
An Exercise in International Mediation
Niranjan D. Gulhati
Allied Publishers, 1973

Delegations of Government of Pakistan and of Government of India
Meeting No. 5, Washington, D.C., 9 November 2006



Delegation of Pakistan

1. Mr Ashfaq Mahmood, Secretary, Ministry of Water & Power. Leader of the Delegation
   Mr Abdul Wajid Rana, Minister (Economic), Embassy of Pakistan
2. Mr Jalil Abbas Jillani, Director General (South Asia), Ministry of Foreign Affairs
3. Mr Syed Jamait Ali Shah, Pakistan Commissioner for Indus Waters
4. Mr Syed Feisal Hussain Naqvi, Legal Consultant
5. Mr Bashir Ahmad Qureshi, Vice President (Dams Expert), NESPAK
6. Mr Mirza Asif Baig, General Manager, Hydrology Expert, NESPAK
7. Mr Syed Muhammad Mehar Ali, Senior Engineer, NESPAK
8. Professor James Crawford, SC, Expert in International Water Laws
9. Mr Samuel Wordsworth, Associate of Professor Crawford
10. Dr George Annandale, Technical Expert
11. Mr Peter J. Rae, Technical Expert
12. Mr Muhammad Syrus Sajjad Qazi, Counsellor, Embassy of Pakistan.

Delegation of India

13. Mr J. Hari Narayan, Chief Secretary, Gov. of Andhra Pradesh, Leader of the delegation
14. Mr F.S. Nariman, Senior Advocate, Supreme Court of India
15. Mr R. K. P. Shankardass, Senior Advocate, Supreme Court of India
16. Mr R. Jeyaseelan, Chairman, Central Water Commission
17. Mr V.V.R.K. Rao, Former Chairman, Central Electricity Authority
18. Dr K.G. Ranga Raju, Former Professor, I.I.T. Roorkee
19. Mr Narinder Singh, Joint Secretary (L&T), Ministry of Foreign Affairs
    Mr D.K. Mehta, Commissioner (Indus), Ministry of Water Resources
20. Dr D.V. Thareja, Chief Engineer, Central Water Commission
21. Mr Henrik Garsdal, Senior Hydraulic Engineer, Danish Hydraulic Institute, Denmark
22. Mr Naresh Kumar, Director, Central Water Commission
    Mr G. Aranganathan, Senior Joint Commissioner (Indus), Ministry of Water Resources
23. Mr Subhash C. Sharma, Junior of Mr F.S. Nariman
    Mr Bharat Maurya, Liaison & Protocol Officer, Ministry of Water Resources
24. Mr Anoop Mishra, Minister (Economic), Embassy of India to the USA

25. Professor Raymond Lafitte, Neutral Expert
26. Mr Laurent Mouvet, Senior Assistant
27. Professor Laurence Boisson de Chazournes, Legal Adviser
28. Mrs Eloïse Obadia, Coordinator
29. Mrs Martina Polasek, Coordinator

ACKNOWLEDGEMENTS

The analysis of the Points of Difference referred by the Government of Pakistan, under the provisions of the Indus Waters Treaty 1960, and of the position of the Government of India, to achieve a Determination, was a delicate exercise. It could have not been realized without the fair collaboration of all those involved. So it is for me a real pleasure, jointly with Professor Laurence Boisson de Chazournes, who advised me with respect to legal issues, and with my assistant Mr Laurent Mouvet, to thank all those who contributed to this work.

The Parties made a great effort within a relatively short time, to transmit to me all their information. The best Experts, national and international, were required. The written instruments and the responses to my questions, explaining the points of view of the Parties, with all their arguments and counter-arguments, were very well developed in both content and form. These included a synthesis of the studies made by India during the past years for the design of the Baglihar scheme and its critical assessment by Pakistan, with constructive proposals on some aspects. New developments were implemented by the Parties, model tests and numerical analyses, to support their theses.

The oral presentations by the Parties, on both technical and legal aspects, also documented, were extremely clear and of a very high standard, demonstrating competence and honesty.

The Parties then paid great attention to making their written and oral remarks on the final draft determination of the author, allowing him to complete his report with full knowledge of the case.

The organization of the site visit to Baglihar was excellent and I wish to thank the Indian Government for its hospitality, and in particular Mr D.K. Mehta, Commissioner, Mr Vikrant Sharma, Assistant Director in Jammu, and Mr R.C. Gupta, Vice President of the JP Venture.

I am also grateful to Mr K.D. Sharma, Director of the National Institute of Hydrology (NHI) of Roorkee and to Mr Shiva Datta, Chief Engineer and Director of the Irrigation Research Institute (IRI), for their hospitality during the visits to their respective institutes and the inspection of the hydraulic model of Baglihar.

For all these aspects of efficient cooperation, with a spirit of goodwill and courtesy, but also including clarity and firmness, I wish to express my deep gratitude to the Delegations of the Parties. First to their leaders, for India: Shri J. Hari Narayan, former Secretary, Ministry of Water Resources, and Mrs Gauri Chatterji, Secretary, Ministry of Water Resources and Shri R. Jeyaseelan, Chairman, Central Water Commission; and for Pakistan: Mr Makhdoom Ali Khan, Attorney General for Pakistan, and Mr R. Ashfaq Mahmood, Secretary, Ministry of Water Power. Also, I express thanks to all the members of these Delegations: Lawyers, Commissioners, Experts, Chief Engineers, and Engineers.

It was a great advantage for the author, to have had the support of the World Bank through the International Centre for Settlement of Investment Disputes (ICSID), which assumed the coordination of the process. I wish to thank sincerely Mrs Eloïse Obadia, Senior Counsel, who accomplished this task, with competence, helpfulness and initiative. As she took maternity leave before the end of the mission, she was replaced at that time by Mrs Martina Polasek, Counsel, who is also warmly thanked.

The author is a Professor associated to the Laboratory of Hydraulic Constructions of the “Ecole Polytechnique Fédérale de Lausanne”. He sincerely thanks its Director, Professor

Dr Anton Schleiss, for his welcome in this high level academic environment and for his hospitality during the visit to his laboratory by the Indian and Pakistani Delegations in October 2005. In particular, the author is grateful to Prof. A. Schleiss and to Dr G. de Cesare for their advice on some essential aspects of reservoir sedimentation.

Finally, as I am not particularly expert in some fine points of the English language, it was necessary that this document be reviewed by a native English speaker who was made aware of the confidential nature of the expert determination. This was done by Mrs Alison Bartle, Honorary Member of the International Commission on Large Dams, and Director of Aqua-Media International Ltd. I would like to express my personal deep gratitude to her.

Raymond Lafitte

Lausanne, Switzerland
12 February 2007

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1. INTRODUCTION

1.1 The water resources development of the Indus system of rivers is governed by the Indus Waters Treaty 1960 (referred to hereafter as the "Treaty") signed by the Government of India and the Government of Pakistan.

The Baglihar hydropower plant, a run-of-river plant with a capacity of 450 MW in its first stage, has been under construction since 2002 on the Chenab River, a tributary of the Indus, in the northern Indian state of Jammu & Kashmir.

On 15 January 2005, the Government of Pakistan sent a request to the World Bank (WB) to appoint a Neutral Expert (NE) stating that a "difference" had arisen between India and Pakistan under Article IX (2) of the Treaty, relating to the Baglihar Project.

After consultation with the Parties under the provisions of the Indus Waters Treaty 1960, on 12 May 2005 the Bank appointed the undersigned, Mr Raymond Lafitte, Professor at the Federal Institute of Technology of Lausanne, Switzerland.[1]

The Principal of the NE is the Government of India and the Government of Pakistan.

The proposal of the NE to be assisted by Mr Laurent Mouvet[2], Senior civil engineer, was accepted.

The NE is appointed in his capacity as an "engineer" (*Annexure F, Part 2, Paragraph 4* of the Treaty). However, in view of the necessity to be advised with respect to the legal issues raised in the determination process, he requested the assistance of a lawyer. His proposal, of 28 March 2006, to seek the advice of Dr Laurence Boisson de Chazournes[3], who is Professor and Director of the Department of Public International Law and International Organization at the University of Geneva, was also accepted.

At the request of the NE, the International Centre for Settlement of Investment Disputes (ICSID) assumed the coordination of the process, and in particular has provided its logistical support. Mrs Eloïse Obadia, Senior Counsel, is in charge of this task as coordinator. She left her position to take maternity leave from 24 August 2006 until 8 January 2007, and was replaced during this period by Mrs Martina Polasek, Counsel.

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[1] World Bank letter 15.05.2005, attached in Annex 1.1.

[2] Summarized CV attached in Annex 1.2.

[3] Summarized CV attached in Annex 1.2.

The Governmental Delegations of India and Pakistan were composed of eminent personalities: engineers and lawyers. Their names are given in the minutes of the meetings, attached as Annex 1.3.

We therefore list below only the leading members of these delegations:

- Shri J. Hari Narayan, Secretary, Ministry of Water Resources of India, replaced in the same position since August 2006 by Mrs Gauri Chatterji, and

  Shri R. Jeyaseelan, Chairman, Central Water Commission,

- Mr Makhdoom Ali Khan, Attorney General for Pakistan, and

  Mr Ashfaq Mahmood, Secretary, Ministry of Water Power.

1.2 The mandate of the NE is defined by the letter of the Bank of 12 May 2005, mentioned above, and by the Treaty.

The *Article IX* of the Treaty contains provisions for the settlement of Differences and Disputes, making a clear distinction between these two stages. Any litigious question which arises between the Parties concerning the interpretation or application of the Treaty should be treated with the following gradation: 1) “Agreement” researched by the Permanent Indus Commission, 2) “Difference” dealt with by a NE, 3) “Dispute” resolved either by agreement between Governments, with negotiators and mediators, or by a Court of Arbitration, with arbitrators.

The present case is a Difference, to be dealt with by a NE. According to *Annexure F, Part 2, Paragraph 4* of the Treaty the NE is a “highly qualified engineer”. This indicates that his determination will relate to the technical aspects of the points of difference, based on his knowledge of science, technology and the state of the art in the field concerned, which is in this case the building of a dam and a hydropower station. An additional and cumulative condition is that the design of the scheme should be governed by the provisions of the Treaty (*Annexure F, Part 2, Paragraph 6(b)*). In this context, the NE is bound to apply and give effect to the Treaty, and consideration of questions relating to sound design must be within the framework of the Treaty. The balanced integration of technical and legal aspects in the interpretation of the Treaty is the only means for the NE to preserve the integrity of the Treaty and to achieve his mandate under Annexure F of the Treaty as a “highly qualified engineer”. The taking into account of technical aspects gives effectiveness to the Treaty and contributes to a sound interpretation and application of the Treaty. The Treaty adds that *“[t]he decision of the Neutral Expert on all matters within his competence shall be final and binding, in respect of the particular matter on which the decision is made, upon the Parties and upon any Court of Arbitration established under the provision of Article IX (5)”* (*Annexure F, Part 2, Paragraph 11* of the Treaty).

The neutrality of the NE means that he should not have made up his mind beforehand about the case in favour of one or the other side: he should not be prejudiced. A condition is his total independence from the Parties. His duty is to determine whether or not a concept or structure is technically correct with the condition that the Treaty should be enforced. Naturally the Treaty contains issues which are open to interpretation (this could explain the appearance of litigious questions). Comments will subsequently be made (Chapter 5.1) on the rules and methods of interpretation of the Treaty. At this point, it suffices to say that all matters should be enshrined in the Treaty.

In the view of the NE, neutrality also means transparency. Considering the Principal of the NE is jointly the Governments of India and Pakistan, the NE followed the principle, as mentioned above, that all information given to him by one Party should also be given to the other. No discussion took place separately between the NE and either of the Parties.

1.3 The Treaty prescribes (*Annexure F, Part 2, Paragraph 6*) that the procedure with respect to each reference to the NE shall be determined by him; this relates especially to the procedure used to reach his determination.

On the basis of this perspective, Meeting No. 1 of the Parties and the NE was organized on 9 and 10 June 2005 in Paris at the World Bank Office. Mr Roberto Dañino, Senior Vice President and General Counsel of the Bank, accompanied by Mr David Freestone, Deputy General Counsel, and Mrs Eloïse Obadia, Counsel, ICSID, welcomed the Delegations of the Parties and introduced the NE.

With the agreement of the Parties, the NE's work programme was fixed, based on the following principles. It was important that the NE should produce his determination within the shortest possible time period. The fact that Baglihar power plant was under construction was certainly an important incentive in this regard. It was necessary for the NE to be briefed as fully as possible on the respective positions; but it was also essential, in his view, that each Party should have the possibility to present its arguments comprehensively.

The procedure proposed by the Parties, agreed by the NE, was to proceed to an exchange of written instruments. A programme was defined, which was adapted as it progressed, with the following order of events:

- 15 July 2005: Documents sent by India to Pakistan according to *Appendix II to Annexure D, Paragraph 9* of the Treaty as well as additional and updated documents
- 18 August 2005: Memorial dated 14 August 2005 filed by Pakistan
- 23 September 2005: Counter-Memorial filed by India
- 31 January 2006: Reply dated 25 January 2006 filed by Pakistan
- 20 March 2006: Rejoinder filed by India
- 2 and 3 October 2006: Final Draft Expert Determination
- 26 October 2006: Written comments of the Governments of Pakistan and India on the Final Draft Expert Determination
- 24 November 2006: Written additional comments of the Parties on their respective presentations
- 12 February 2007: Final Determination of the NE

On 2 and 3 October 2005, a visit to the Baglihar site was organised for the NE and the Delegations of India and Pakistan. Then, on 5 and 6 October 2005, the Baglihar hydraulic model was visited at the Irrigation Research Institute (IRI) in Roorkee, India.

The NE and the Delegations were hosted by Mr K.D. Sharma, Director of the National Institute of Hydrology (NHI) and Mr Shiva Datta, Chief Engineer and Director of IRI.

Following Meeting No. 1, in Paris, five subsequent meetings were organized:

- Meeting No. 2, from 19 to 21 October 2005, in Geneva, at the World Meteorological Organisation. This meeting was devoted to additional questions from the NE which had arisen following the site visit to Baglihar.

- Meeting No. 3, from 25 to 29 May 2006, in London, at the International Dispute Resolution Centre Ltd. After the filing of the Rejoinder, this meeting was devoted to oral presentations of the Parties.

- Meeting No. 4, from 2 to 4 October 2006, in Paris, at the World Bank Office. The NE presented his Final Draft Determination.

- Meeting No. 5, from 7 to 9 November 2006, in Washington, D.C. The Parties made their comments on the Final Draft Determination.

On 12 February 2007, in Bern, both Ambassadors of Pakistan and of India received from the hands of the NE hard and soft copies of his Determination.

1.4 Complete records of the meetings were taken, in the form of both written transcripts and audio recordings. Moreover, minutes containing the decisions made were written and agreed by the Parties, for each Meeting and for the visits to the Baglihar site and the hydraulic model in Roorkee. These minutes are attached to this document as Annex 1.3.

The meetings were confidential, to avoid any interference from persons not directly involved at this stage of the development of the procedure. The intention was to inform the media at an appropriate time, and at the end of each meeting a decision was taken concerning the extent of available information to release.

ICSID assumed the task of coordinating the process, under the auspices initially of Mrs Eloise Obadia, and then of Mrs Martina Polasek; all the correspondence between the Parties and the NE, as well as all the documents filed, were addressed to them, as coordinators.

The list of all documents referred to by the NE, his assistant and his legal adviser is given in Annex 1.4.

1.5 An explanation should be given on the procedure proposed by the NE concerning the issuance of his determination.

As is usual in the relationship between engineers, he provided the Parties with his final report in a draft form on the 2 and 3 of October 2006. The objective was to inform the Parties, as a courtesy, of his decisions, and to invite them for possible comments. The NE was conscious that, however much care would be taken to strengthen his opinion, he could not totally preclude the possibility of omitting an important fact and, if this should happen, he could review his opinion so as to give a sound and non contestable determination based on application of the Treaty and the state of the art in the field of technology.

The Parties made their preliminary comments orally on the Final Draft Determination on 4 October 2006, and it was agreed that they would send their final written comments, exclusively to the NE, on 26 October 2006. The Parties would also be given the opportunity to present their comments orally to the NE at Meeting No. 5, to be held in Washington, D.C. on 7 and 8 November 2006. The NE specified clearly, during Meeting No. 4 in Paris that the presentations should not lead to any discussion between the Parties or between the Parties and himself, but that he may ask for clarification on certain specific points. The Parties agreed to this procedure (Annex 1.3.7)

However, Pakistan stated at the end of Meeting No. 5 (Annex 1.3.8) that it was not able to give a positive response to the NE's question to the Parties concerning their acceptance of the procedure followed at the meeting for two reasons: the first was the lack of interchange between Pakistan and the NE, to understand his thinking, the second was that India had submitted new evidence on which Pakistan had been given no opportunity to comment.

Concerning this second reason, Pakistan proposed to present, by 24 November 2006, a brief statement on the new material given by India. For its part, India also proposed to comment on one new element of Pakistan's presentation.

The NE agreed that these additional written comments should be filed by the Parties on 24 November 2006.

Concerning the first reason, Pakistan will find in the present document the answer to its question regarding the views of the NE. The NE has taken into consideration the comments made by Pakistan as well as India's point of view, and has adapted his draft determination of 2 and 3 October 2006 to obtain this clear Final Determination of 12 February 2007.

This present final determination of 12 February 2007 cancels and supersedes the draft determination of 2 and 3 October 2006.

2. POINTS OF DIFFERENCE REFERRED BY PAKISTAN AND INDIA'S POSITION

The Points of Difference were presented during the Meeting No. 1 in Paris by Pakistan. They are repeated in Pakistan's Memorial. We present them below:

a. **Pakistan is of the considered view that the design of the Baglihar Plant on Chenab Main does not conform to criteria (e) and (a) specified in Paragraph 8 of Annexure D to The Indus Waters Treaty 1960 and that the Plant design is not based on correct, rational and realistic estimates of maximum flood discharge at the site.**

   The Indian side does not agree with Pakistan's position.

b. **Pakistan is of the considered view that the Pondage of 37.722 MCM exceeds twice the Pondage required for Firm Power in contravention of Paragraph 8 (c) of Annexure D to the Treaty.**

   The Indian side does not agree with Pakistan's position

c. **Pakistan is of the considered view that the intake for the turbines for the Plant is not located at the highest level consistent with satisfactory and economical construction and operation of the Plant as a Run-of-River Plant and is in contravention of Paragraph 8 (f) of Annexure D to the Treaty.**

   The Indian side does not agree with Pakistan's position.

3. PROVISIONS OF THE TREATY DIRECTLY RELATED TO THE POINTS OF DIFFERENCE

It appears necessary to reproduce below *Paragraph 8 of Part 3 to Annexure D* of the Treaty, which was referred to in Chapter 2, as it is essential for the understanding of the difference.

Throughout the NE's determination, he refers to various provisions of the Treaty and supplies corresponding citations.

- ***Annexure D***
  Part 3 - New Run-of-River Plants

  8. *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:*

     (a) 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.

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

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

     (d) 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.

     (e) If the conditions at the site of a Plant make a gated spillway necessary, the bottom level of the gates in normal closed position shall be located at the highest level consistent with sound and economical design and satisfactory construction and operation of the works.

     (f) 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.

     (g) If any Plant is constructed on the Chenab Main at a site below Kotru[4] *(Longitude 74°-59' East and Latitude 33°-09' North), a Regulating Basin shall be incorporated.*

[4] Annotation of the NE: Located downstream of Baglihar site.

But to understand this *Paragraph 8,* it is necessary to recall Part 1 of the same *Annexure D*; moreover, the provisions of *Paragraphs 15, 16 and 17* complete the application of the *Paragraph 8(c)* mentioned above.

- ***Annexure D***
  Part 1 - Definitions

  2. As used in this Annexure:

  (a) "Dead Storage" means that portion of the storage which is not used for operational purposes and "Dead Storage Level" means the level corresponding to Dead Storage.

  (b) "Live Storage" means all storage above Dead Storage.

  (c) "Pondage" means Live Storage of only sufficient magnitude to meet the fluctuations in the discharge of the turbines arising from variations in the daily and the weekly loads of the plant.

  (d) "Full Pondage Level" means the level corresponding to the maximum Pondage provided in the design in accordance with Paragraph 8 (c).

  (e) "Surcharge Storage" means uncontrollable storage occupying space above the Full Pondage Level.

  (f) "Operating Pool" means the storage capacity between Dead Storage level and Full Pondage Level.

  (g) "Run-of-River Plant" means a hydro-electric plant that develops power without Live Storage as an integral part of the plant, except for Pondage and Surcharge Storage.

  (h) "Regulating Basin" means the basin whose only purpose is to even out fluctuations in the discharge from the turbines arising from variations in the daily and the weekly loads of the plant.

  (i) "Firm Power" means the hydro-electric power corresponding to the minimum mean discharge at the site of a plant, the minimum mean discharge being calculated as follows:

  The average discharge for each 10-day period (1st to 10th, 11th to 20th and 21st to the end of the month) will be worked out for each year for which discharge data, whether observed or estimated, are proposed to be studied for purposes of design. The mean of the yearly values for each 10-day period will then be worked out. The lowest of the mean values thus obtained will be taken as the minimum mean discharge. The studies will be based on data for as long a period as available but may be limited to the latest 5 years in the case of Small Plants (as defined in Paragraph 18) and to the latest 25 years in the case of other Plants (as defined in Paragraph 8).

  (j) "Secondary Power" means the power, other than Firm Power, available only during certain periods of the year.

- ***Annexure D***
  Part 3 – New Run-of-River Plants

  15. Subject to the provisions of Paragraph 17, the works connected with a Plant shall be so operated that (a) the volume of water received in the river upstream of the Plant, during any period of seven consecutive days, shall be delivered into the river below the Plant during the same seven-day period, and (b) in any period of 24 hours within that seven-day period, the volume delivered into the river below the Plant shall be not less than 30%, and no more than 130%, of the volume received in the river above the plant during the same 24-hour period: Providing however that:

  (i) […]

  (ii) where a Plant is located at a site on the Chenab Main above Ramban, the volume of water delivered into the river below the Plant in any one period of 24 hours shall not be less than 50% and not more than 130%, of the volume received above the Plant during the same 24-hour period; and

  (iii) […]

  16. For the purpose of Paragraph 15, the period of 24 hours shall commence at 8 A.M. daily and the period of 7 consecutive days shall commence at 8 A.M. on every Saturday. The time shall be Indian Standard Time.

  17. The provisions of Paragraph 15 shall not apply during the period when the Dead Storage at a Plant is being filled in accordance with the provisions of Paragraph 14. In applying the provisions of Paragraph 15:

  (a) a tolerance of 10% in volume shall be permissible; and

  (b) Surcharge Storage shall be ignored.

4. TECHNICAL DATA CONCERNING THE BAGLIHAR PROJECT

Since the first documents were exchanged between the Parties on the Baglihar project, the project has been subjected to several changes.

For clarification, the main characteristics of the project, as presented during the site visit in October 2005, are repeated below. Corresponding plates are also given in Annex 4.1.

DAM BODY

Type	Concrete Gravity Dam
Height above deepest foundation [m]	144.50
Length of dam crest [m]	317
Crest elevation [m asl]	844.50

RESERVOIR CHARACTERISTICS

Full pondage level FPL [m asl]	840
Dead storage level DSL [m asl]	835
Pondage [M.m^3]	37.50
Dead storage capacity [M.m^3]	358.45
Gross storage capacity [M.m^3]	395.95

HYDROLOGY

Catchment area [km^2]	17,325
Mean annual inflow [M.m^3]	25,000
Mean discharge [m^3/s]	790
Median annual discharge [m^3/s]	450
Peak flood discharge [m^3/s]	
1 year return period	2,300
10 year return period	5,100
100 year return period	8,100
1000 year return period	12,100
PMF	16,500[5]

SPILLWAYS

Type	Sluice spillway with 5 openings, and Chute spillway with 3 bays
Maximum discharge capacity [m^3/s]	16,500 [peak of PMF flood]

a) Sluice Spillway

Type	Submerged orifice with ogee shaped chute
Type of gates	Radial with hydraulic hoists
Number of gates	5
Size of gates	10 m (W) x 10.50 m (H)

[5] Counter-Memorial, Part I, Paragraph 1.3, page 34. It is to be noted that in its Rejoinder, Paragraph 3.6, page 66, India states "The PMF peak of 16,200 m^3/s estimated (…)", and in the Answers to questions posed by the NE during Meeting No. 3, 19 June 2006, Paragraph 3.0, Page 34, the value of 16,195 m^3/s is used in the calculations.

Spillway Sill Elevation [m asl]	808
Head above sill [m]	
Normal conditions	32
Maximum extreme conditions	36.50
Energy dissipation	Splitter and ledge along chute, lined stilling basin
Capacity at FPL [m^3/s] [6]	10,772

b) Chute Spillway

Type of gates	Radial with hydraulic hoists
Size of gates	12 m (W) x 19 m (H)
Number of gates	3
Spillway sill elevation [m asl]	821
Head above sill [m]	
Normal conditions	19.0
Maximum extreme conditions	23.50
Energy dissipation	Flip bucket and lined plunge pool
Capacity at FPL [m^3/s] [7]	5'728

c) Auxiliary Spillway

Purpose	Evacuation of floating debris
Type	surface chute
Size of gate	6 m (W) x 3 m (H)
Spillway sill elevation [m asl]	837
Location	Right side of the dam, close to power intakes
Capacity at FPL [m^3/s]	53

POWER INTAKE

Stages	Stage I: Right intake Stage II: Left intake
Type	Lateral submerged intake
Location	On the right bank, forming an angle of 120° with dam
Sill elevation [m asl]	818
Size of gated section	2 x 10.0 m (W) x 7.5 m (H) for stage I
Size of headrace tunnel	10.15 m diameter circular
Capacity [m^3/s]	430

POWERHOUSE

Location	Underground, on the right bank
Installed capacity [MW]	450
Number of unit	3 (x 150 MW)

[6] Counter-Memorial, Part I, Paragraph 1.8.2, page 42.
[7] Counter-Memorial, Part I, Paragraph 1.8.2, page 42.

5. GENERAL CONSIDERATIONS AS THE FOUNDATION FOR THE EXPERT DETERMINATION

In this chapter, the NE wishes to present the engineering aspects on which his decision will be based. In so doing and in order to preserve the integrity of The Indus Waters Treaty 1960, the NE will identify the scope and the content of the rights and obligations in light of the general rules of treaty interpretation which are described in Chapter 5.1 below.

The decision of the NE is based on the premise that the terms of the Treaty, in accordance with the general rules of treaty interpretation, allow him to have recourse to rules of science and technology and to state-of-the-art practices in his assessment of the concept and design of the Baglihar Dam and Hydroelectric Plant.

5.1. THE TREATY AND ITS INTERPRETATION

5.1.1. Recourse to the usual methods of interpretation of treaties

1. Given the fact that India and Pakistan each refers to specific rules and methods of interpretation of the Treaty, it is necessary first of all to clarify which rules of international law should guide the proper interpretation of the Treaty.

2. Under general international law, Parties to a treaty are supposed to interpret the treaty language with due consideration for ordinary methods of interpretation. To identify the ordinary methods of interpretation, one has to refer to the 1969 Vienna Convention on the Law of Treaties.[8] It is now well established that the provisions on interpretation of treaties contained in Articles 31 and 32 of the Vienna Convention on the Law of Treaties reflect "pre-existing customary international law"[9], and thus may be applied to treaties concluded before the coming into force of the Vienna Convention in 1980 (unless there are particular indications to the contrary). The customary character of Articles 31 and 32 of the Vienna Convention has been recognized by various international courts and tribunals, and especially the International Court of Justice.[10]

3. Articles 31 and 32 of the Vienna Convention on the Law of Treaties read as follows:

> Article 31
> *General rule of interpretation*
> 1. A treaty shall be interpreted in good faith in accordance with the ordinary meaning to be given to the terms of the treaty in their context and in the light of its object and purpose.
> 2. The context for the purpose of the interpretation of a treaty shall comprise, in addition to the text, including its preamble and annexes:
>   (a) any agreement relating to the treaty which was made between all the parties in connection with the conclusion of the treaty;
>   (b) any instrument which was made by one or more parties in connection with the conclusion of the treaty and accepted by the other parties as an instrument related to the treaty.
> 3. There shall be taken into account, together with the context:
>   (a) any subsequent agreement between the parties regarding the interpretation of the treaty or the application of its provisions;
>   (b) any subsequent practice in the application of the treaty which establishes the agreement of the parties regarding its interpretation;
>   (c) any relevant rules of international law applicable in the relations between the parties.
> 4. A special meaning shall be given to a term if it is established that the parties so intended.

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[8] India is not a Party to the Vienna Convention on the Law of Treaties and it has not signed it. Pakistan is not a Party to the Vienna Convention on the Law of Treaties but signed it on 29 April 1970.

[9] See, *PCA, Arbitration regarding the Iron Rhine ("Ijzeren Rijn") Railway*, Award of the Arbitral Tribunal, 24 May 2005, para. 45.

[10] See, *Territorial Dispute (Libyan Arab Jamahiriya/Chad), Judgement, I.C.J. Reports 1994*, pp. 21–22, para. 41 ; *ICJ, Kasikili/Sedudu Island (Botswana/Namibia), Judgement, I.C.J. Reports 1999 (II)*, p. 1059, para. 18 ; *ICJ, Sovereignty over Pulau Ligitan and Pulau Sipadan (Indonesia/Malaysia), Judgement, I.C.J. Reports 2002*, pp. 645–646, paras. 37–38.

Article 32
Supplementary means of interpretation

Recourse may be had to supplementary means of interpretation, including the preparatory work of the treaty and the circumstances of its conclusion, in order to confirm the meaning resulting from the application of article 31, or to determine the meaning when the interpretation according to article 31:

(a) leaves the meaning ambiguous or obscure; or

(b) leads to a result which is manifestly absurd or unreasonable.

4. The clauses contained within Article 31 are not hierarchical. Interpretation is an integrated operation which uses several methods simultaneously.[11] However, there is no doubt that the starting point for interpretation is the ordinary meaning to be given in good faith to the terms of the treaty. The context and object and purpose of the treaty help to confirm or refine and develop the ordinary meaning. It is only when the elements mentioned in Article 31 do not give a clear indication of the rights and obligations of the parties to a treaty that one may have recourse to supplementary means such as *travaux préparatoires* and the circumstances under which the treaty was concluded.

5. The ordinary meaning of the Treaty is to be found in the words of the Treaty. In other words, it is the text of the Treaty which conveys the intention of India and Pakistan. The intention of the parties to a treaty is relevant only to the extent expressed by the text; it is in principle not to be found outside the text. This is not to say that circumstances which led to the conclusion of the Treaty are not relevant to its interpretation. Certainly extrinsic sources (such as "circumstances") may be used, but only if the text is ambiguous or obscure, or if the meaning of the words leads to a conclusion which is obviously absurd or unreasonable.

6. As has been pointed out by both Parties, the Treaty was negotiated and concluded during a period of tension between India and Pakistan. However, in the view of the NE, because of this tension, those who drafted the Treaty aimed for predictability and legal certainty in the drafting of the Treaty so as to ensure its sound implementation. The wish for predictability and legal certainty is well illustrated by the technicalities of the Treaty and particularly of its Annexures. The Treaty contains clear language and wording on how and to which extent India and Pakistan may be allowed to utilize the waters of the Indus system of rivers. The rights and obligations deriving from the Treaty with regard to hydro-electric plants are clearly specified and unambiguous. The Treaty also gives a clear indication of the rights and obligations of both Pakistan and India. Sovereign rights cannot be exercised without consideration of the limits imposed by the Treaty. In this context, it is not appropriate for the NE to qualify the Treaty as, *inter alia*, a "delimitation" or a "boundary" Treaty. The task of the NE with respect to the present difference is not to qualify the Treaty but to decide on a question posed by Pakistan with respect to Annexure D, Part 3 of the Treaty which deals with New Run-of-River Plants.

7. Furthermore and in light of the above elements, the NE stresses that in considering the compatibility of the Baglihar project with the Treaty, he will take into account the principle of international law according to which good faith is to be presumed in the interpretation and implementation of international treaties. On this basis the NE is convinced that both of the Parties are exercising, and will continue to exercise, their rights and obligations

[11] See, *Case concerning the auditing of accounts between the Kingdom of the Netherlands and the French Republic pursuant to the additional Protocol of 25 September 1991 to the Convention of 3 December 1976 on the protection of the Rhine against pollution by Chlorides*, Award of the Arbitral Tribunal, 12 March 2004, paras. 62-63.

under the Treaty and its Annexure D in good faith.[12] The NE is also convinced that both Parties will apply the rules and principles of the Treaty in such a way as not to impair the rights and legitimate interests of the other Party. Respect for good faith in treaty application requires *each* Party to implement the Treaty so as not to cause damage to the rights and interests of the *other*.

5.1.2. The Treaty and the present-day status of scientific and technical knowledge

8. New technical norms may have to be taken into consideration and new standards given proper weight when interpreting the Treaty. In order to clarify the meaning of words agreed upon in 1960, there is nothing that prevents the NE from taking into account the present-day status of scientific and technical knowledge.[13] This need is reflected in the documentary material submitted by the Parties. It is an approach generally adopted by international courts and tribunals.

9. With regard to the Baglihar Hydroelectric Plant and its conformity to Annexure D of the Treaty, the relevant provisions of Part 3 of Annexure D ("New Run-of-River Plants") refer to conceptual or generic notions such as "satisfactory construction and operation of the works", "sound and economical design" and "customary and accepted practice of design". This implies that new technical developments relating to the building and operation of the Baglihar Plant may be taken into account in the interpretation of Annexure D of the Treaty. Such an interpretation (*i.e.* an interpretation of the Treaty which takes into account the evolution of new technologies and new technical standards and practices) illuminates the terms of the Treaty and ensures an application of the Treaty that renders it effective with respect to its meaning and its object(s) and purpose(s).[14]

10. That is to say that both India and Pakistan can use new technologies and new standards and practices of design when exercising their rights under Annexure D of the Treaty. However, the use of such new technologies and standards and practices should remain within the confines of the Treaty and be in conformity with its ordinary meaning. Both States are supposed to use technologies and standards and practices which are consistent with the Treaty and the criteria mentioned in Annexure D. The recourse to present-day scientific and technical knowledge cannot override the rights and obligations foreseen by the Treaty. Recourse to new technical norms and standards is not intended to *rewrite* the Treaty but to *clarify its* scope as well as the content of the rights and obligations under the Treaty.

5.1.3. The Treaty and the principles of integration and effectiveness

11. In addition to the above developments on the rules and methods of interpretation applicable to the Treaty, reference can be made to two principles of treaty interpretation,

[12] See, *ICJ, Nuclear Tests Case (New Zealand v. France), Judgement, ICJ Reports 1974*, p. 473, para. 49: "One of the basic principles governing the creation and performance of legal obligations, whatever their source, is the principle of good faith. Trust and confidence are inherent in international co-operation, in particular in an age when this co-operation in many fields is becoming increasingly essential".

[13] See for example, *ICJ, Kasikili/Sedudu Island, ICJ Reports 1999*, para. 20.

[14] See, *Arbitration regarding the Iron Rhine ("Ijzeren Rijn") Railway, Award of the Arbitral Tribunal, 24 May 2005*, paras. 79-81.

i.e. the principle of integration and the principle of effectiveness that can be inferred from the provisions of the Vienna Convention on the Law of Treaties, 1969.[15]

The principle of integration, with special emphasis on the preamble of the Indus Waters Treaty 1960

12. In their interpretation, treaties should be guided by the principle of integration, i.e. they are to be interpreted as a whole. Unless explicitly stated, no hierarchy exists between the various components of a treaty. The interpretation of the Treaty is guided by the principle of integration. In other words, the provisions of the Treaty and its Annexures constitute a whole, and interpretation of the Treaty must take into account all its parts, provisions and annexures. It is to be noted that the principle of integration is clearly expressed in Article XII of the Treaty which reads as follows: "[t]his Treaty consists of the Preamble, the Articles hereof and Annexures A to H hereto (…)". The words of Article XII of the Treaty are clear and they imply no hierarchy between the various parts of the Treaty.[16] An integrative approach is particularly crucial with regard to the points of differences between Pakistan and India, as the two parties do not agree on the relevance of particular provisions of the Treaty in the interpretation of Annexure D of the Treaty.

13. A debate has arisen between India and Pakistan on whether the Preamble of the Treaty serves as a relevant guide in the interpretation of the Treaty and in the determination of its object and purpose. Therefore, some clarification on the function of the Preamble of the Treaty is necessary. This clarification is aimed at highlighting the role of the Preamble in the interpretation of the substantive provisions of the Treaty. Recourse to the Preamble should not override the substantive provisions of the Treaty.

14. A preamble forms an important context for the operative provisions of a treaty. Thus, when interpreting the operative provisions of a treaty, Article 31 of the Vienna Convention on the Law of Treaties requires taking into account its preamble. A treaty's preamble defines, in general terms, the purposes and considerations that led the parties to conclude the treaty. The preamble of a treaty also normally contains important indications on the object and purpose of the treaty. This has been recognized by various international courts and tribunals.[17] The Preamble of the Indus Waters Treaty 1960 explicitly defines the object(s) and the purpose(s) of that Treaty.

15. According to the Preamble of the Indus Waters Treaty, the object(s) and the purpose(s) of this Treaty is to attain the most complete and satisfactory utilisation of the waters of the Indus systems rivers, to fix and delimit the rights and obligations of each party in relation to the other concerning the use of these waters and to provide for the settlement of questions arising from the application or the interpretation of the Treaty. The objectives set out in the Preamble cannot be read in isolation of each other. They are

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[15] See the scope, the meaning and the relevance of these principles, Sir G. Fitzmaurice, The Law and Procedure of the International Court of Justice: Treaty Interpretation and Other Treaty Points", *British Yearbook of International Law*, 1957, pp. 211-212. See also, H. Lauterpacht, *The Development of International Law by the Permanent Court of International Justice*, Longmans, London, 1934, pp. 67-88.

[16] Such an approach consisting of reading a treaty as a whole has also been emphasized by the Permanent Court of International Justice: "[i]n considering the question before the Court upon the language of the Treaty, it is obvious that the Treaty must be read as a whole, and that its meaning is not to be determined merely upon particular phrases which, if detached from the context, may be interpreted in more than one sense […]", *PCIJ, Competence of the International Labour Organization*, Series B, p. 23.

[17] See, *ICJ, Application of the Convention of 1902 Governing the Guardianship of Infants*, *ICJ Reports 1958*, p. 67. *ICJ, Rights of Nationals of the United States of America in Morocco*, *ICJ Reports 1952*, p. 196. *Beagle Channel Arbitration*, International Law Reports, vol. 52, p. 132.

complementary in the light of the principle of integration and no hierarchy can be deduced from the wording of the Preamble.[18] Thus the Preamble, as it fixes the "common intention" of the parties, should play a role in the interpretation of the rights and obligations under Annexure D of the Treaty.

16. Lastly, pursuant to the principle of integration, there is also no contradiction between the Preamble of the Treaty and the provisions of Annexure D, and therefore there is no objective reason to set aside the Preamble in the interpretation of rights and obligations under the Treaty. Both the Preamble and Annexure D pursue the object(s) and purpose(s) of the Treaty, *i.e.* (i) to attain the most complete and satisfactory utilization of the waters of the Indus systems rivers, (ii) to fix and delimit the rights and obligations of each party in relation to the other concerning the use of these waters *in a spirit of goodwill and friendship* and (iii) to provide for the settlement of questions arising from the application or the interpretation of the Treaty.

The principle of effectiveness and the need to give full effect to the provisions of the Treaty

17. The interpretation of the Treaty should also be guided by the principle of effectiveness. This principle means that treaties are to be interpreted with reference to their declared or apparent object(s) and purpose(s); and provisions are to be interpreted so as to give them their fullest weight and effect. In this context, arguments related to the circumstances of war which accompanied the negotiations and the conclusion of the Treaty should not be used to deprive the Treaty of its object(s) and purpose(s) and to alter the scope and meaning of the rights and obligations provided for by the Treaty.

18. Both India and Pakistan have relied on the circumstances surrounding the conclusion of the Treaty. According to Article 32 of the Vienna Convention on the Law of Treaties, the specific reliance by both States on the circumstances of its conclusion in the interpretation of the Treaty is only necessary as a supplementary means of interpretation to confirm the meaning resulting from the application of Article 31 of the Vienna Convention on the Law of Treaties, or to determine the meaning when the interpretation under Article 31 "(a) leaves the meaning ambiguous or obscure; or (b) leads to a result which is manifestly absurd or unreasonable".[19] The wording of Article 32 of the Vienna Convention is clear. There is no need for the NE to base his determination on circumstances surrounding the conclusion of the Treaty. Indeed, the interpretation of the Treaty under Article 31 does not lead to any kind of ambiguity or uncertainty. Moreover, the circumstances of the conclusion of the Treaty are of no help to confirm the meaning of the rights and obligations under the Treaty.

19. In addition, as explained above, the object(s) and purpose(s) of the Treaty are clearly expressed. It is to be noted that the fixing and the delineating of the rights and obligations of each party "in a spirit of goodwill and friendship" is part of the object(s) and the purpose(s) of the Treaty. The terms of the Treaty are not ambiguous with regard to the "goodwill and [the] friendship" which should govern the application of the Treaty. The Treaty promotes through its provisions and its Annexures the idea of "goodwill and friendship" embodied in the Preamble. There is no need to focus on the circumstances which surrounded the conclusion of the Treaty to interpret the rights and obligations under Annexure D of the Treaty.

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[18] This is confirmed by: "[India and Pakistan] have resolved to conclude a Treaty in furtherance of these *objectives*, and for this *purpose* have named as their plenipotentiaries […]" (Preamble of the Indus Waters Treaty 1960).

[19] See Article 32 of the 1969 Vienna Convention on the Law of Treaties.

20. The Treaty provides for co-operation between India and Pakistan. For instance, co-operation should be sought to achieve the object(s) and purpose(s) of the Treaty and to identify the best design option in the context of Annexure D as foreseen in Article VII of the Treaty: *"[t]he two Parties recognize that they have a common interest in the optimum development of the Rivers, and to that end, they declare their intention to co-operate, by mutual agreement, to the fullest possible extent".* Co-operation is also expressed through Article III read jointly with Article XI (1) of the Treaty, with respect to the flow of the waters of the Western Rivers. Lastly, it should be noted that among the object(s) and purpose(s) of the Treaty there is "the fixing and delimiting" *in a spirit of goodwill and friendship* of "the rights and obligations of each in relation to the other" concerning the use of waters of the Indus system of rivers and the desire to make provision "for the settlement, in a cooperative spirit, of all such questions as may hereafter arise in regard to the interpretation and application" of the provisions of the Treaty.[20]

21. Annexure D cannot be read in isolation from the rest of the Treaty. The Treaty textures and structures the rationale of the rights and obligations contained in Part 3 of Annexure D. These rights and obligations must be interpreted so as to allow for the fulfilling of the object(s) and purpose(s) of the Treaty in "a spirit of goodwill and friendship" and in "a co-operative spirit", taking into account the best and latest practices in the field of construction and operation of hydro-electric plants. In doing so, one cannot focus only on purely grammatical and literal interpretation of the text of the Treaty. One definitely has to seek the interpretation which is in harmony with a natural and reasonable way of reading the text of the Treaty, as an expression of the common intentions of both India and Pakistan.[21] This leads the NE to refer to the Treaty in a purposeful manner, ensuring that it is implemented in a sound and sustainable manner.

5.1.4. **STATEMENT S 1** (related to the interpretation of the Treaty)

By way of summary of the foregoing, one may characterise the approach of the NE as follows: in order to identify the scope and extent of each category of rights and obligations, the NE will have recourse to the ordinary meaning of the Treaty in its context and in light of its object and purpose. In doing so and within the confines of the Treaty, the NE will take into account the present-day status of scientific and technical knowledge. To do so is not the same as refashioning or rewriting the Treaty. He will act in conformity with international practice with respect to treaty interpretation.

The NE also considers that the provisions of the Treaty and its Annexures constitute a whole and that the interpretation of the Treaty must take into account all its parts, provisions and Annexures.

Lastly, the NE considers that a proper interpretation is one which gives full effect to each of the rights and obligations provided for by the Treaty.

[20] See Preamble to The Indus Waters Treaty 1960.

[21] See by analogy, *ICJ, Anglo-Iranian Oil Co. Case, ICJ Reports 1952*, p. 104.

The Treaty is an instrument which deals with the management of a shared natural resource, i.e. the waters of the Indus system of rivers. The development of this resource is necessary for the welfare of the populations of the two countries. This should be achieved in conformity with the Treaty as interpreted in accordance with customary rules of interpretation of public international law.

Science and technology are an important basis for the assessment of appropriate design, construction, operation and maintenance of a particular scheme under the Treaty. Under Annexure F of the Treaty, it is an engineer who is chosen as the NE to deal with the determination, and not a lawyer. The task of an engineer acting as an NE and facing the question of the compatibility of a hydraulic scheme with the Treaty is to make sure that the scheme is technically viable and respectful of the Treaty and of the sound engineering state of art the latter refers to. Engineering state of art is enshrined in the Treaty and cannot be excluded from it.

5.2. SPILLWAY

5.2.1. Points of differences

Paragraph 8 (e) of Annexure D of the Treaty reads as follows:

> *"If the conditions at the site of a Plant make a gated spillway necessary, the bottom level of the gates in normal closed position shall be located at the highest level consistent with sound and economical design and satisfactory construction and operation of the works."*

Pakistan estimates that the design submitted by India does not conform to this criterion.

5.2.2. Design submitted by India

The configuration of the design submitted by India during Meeting No. 1 is a combination of five bays on the sluice spillway located in the river axis, three bays on the chute spillway on the left part of the dam and one auxiliary spillway on the right bank. Copies of the corresponding drawing are provided in Annex 4.1 (pages 3 to 7). Figure 5.2.1 shows on an upstream elevation the layout of the devices as proposed by India.[22]

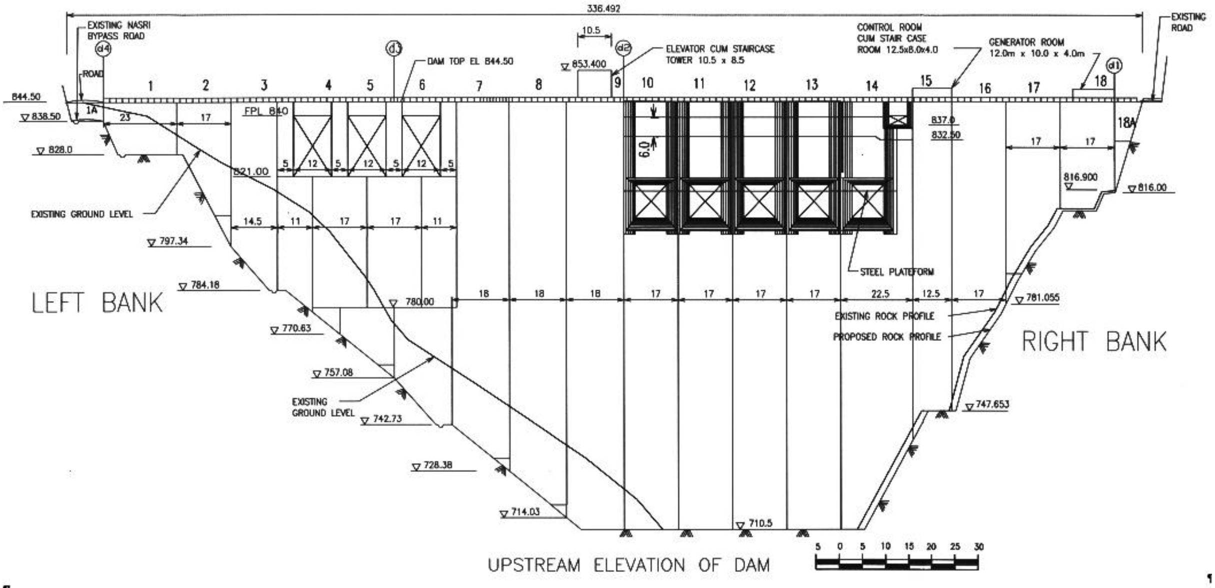


Figure 5.2.1: Upstream elevation of the dam, India's design

The spillway outlets have been designed to allow for the release of the Probable Maximum Flood (PMF), which has a peak discharge of 16,500 m^3/s.

[22] Extract from: Updated Information, Volume 3, page 123, provided by India.

The main characteristics are as follows:

a) Sluice Spillway

Type	Submerged orifice with ogee shaped chute
Type of gates	Radial with hydraulic hoists
Number of gates	5
Size of gates	10 m (W) x 10.50 m (H)
Spillway sill elevation [m asl]	808
Head above sill [m]	
Normal conditions	32
Maximum extreme conditions	36.50
Energy dissipation	Splitter and ledge along chute, lined stilling basin
Capacity at FPL [m^3/s]	10,772

b) Chute Spillway

Type of gates	Radial with hydraulic hoists
Size of gates	12 m (W) x 19 m (H)
Number of gates	3
Spillway sill elevation [m asl]	821
Head above sill [m]	
Normal conditions	19.0
Maximum extreme conditions	23.50
Energy dissipation	Flip bucket and lined plunge pool
Capacity at FPL [m^3/s]	5,728

c) Auxiliary Spillway

Purpose	Evacuation of floating debris
Type	surface chute
Size of gate	6 m (W) x 3 m (H)
Spillway sill elevation [m]	837
Location	Right side of the dam, close to the power intakes
Capacity at FPL [m^3/s]	53

5.2.3. Design proposed by Pakistan

Pakistan has developed and proposed in its Memorial several new designs for the spillway arrangement.[23] Options A-1 and A-2 have only an ungated spillway while options B-1 and B-2 have only a free surface gated spillway.

Option A-1 maintains the Maximum Flood Level at el. 840 and lowers the Full Pondage Level, while option A-2 maintains the Full Pondage Level at el. 840 and increases the Maximum Flood Level. Pakistan proposes in its Memorial to have only surface gates. In

[23] Memorial of Pakistan, Chapter E, pp. 12-28 and Exhibit 1 to 4.

order to maintain the power production at the same level as in India's alternative, the NE will take Option A-2 for the comparison.

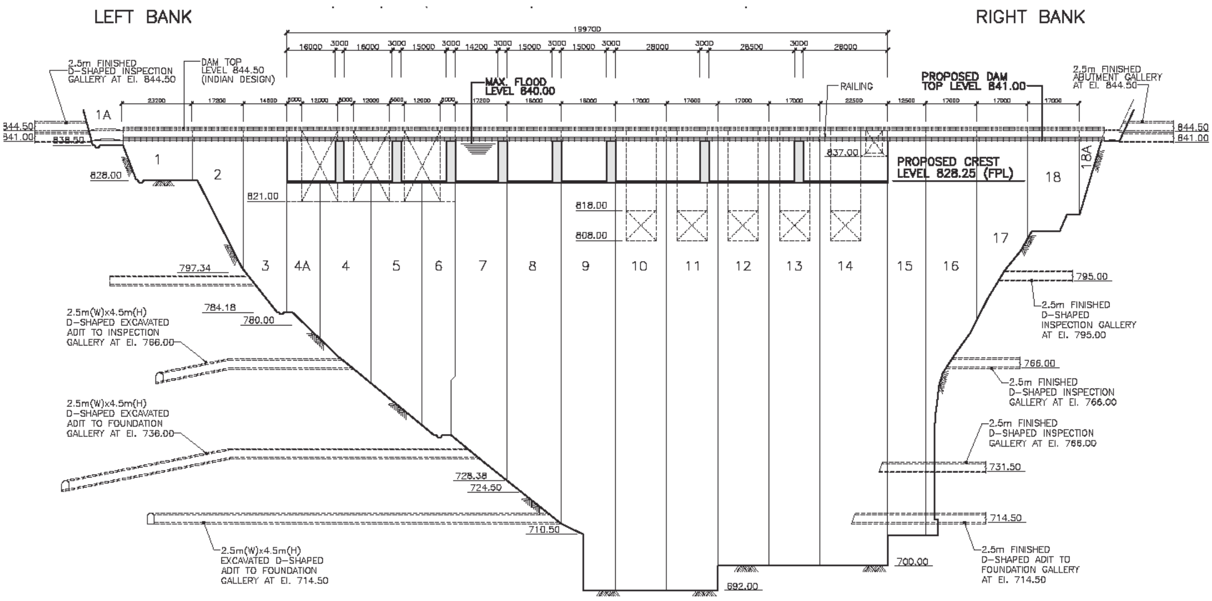


Figure 5.2.2: Upstream elevation of dam, Option A-2 proposed by Pakistan

Drawings describing this option are provided in Annex 5.2.1.

The main characteristics are as follows:

Ungated Spillway

Number of bays	9
Length of each bay crest	from 14.2 to 28.8 m
Total length of crest	175.7 m
Spillway crest elevation [m asl]	840.0
Maximum head above crest	11.76 m
Energy dissipation	Stilling basin for central bays, Flip bucket and lined plunge pool for left side bays
Maximum flood level [m asl]	851.76
Capacity at maximum flood level	16,500 m^3/s

5.2.4. Principle of design

The spillway is an essential safety device. Based on that statement, safety considerations are the most important criteria for determining the type of spillway and its design.

The determination of the possible arrangement of spillways must be driven by the general conditions of the site, which can be classified in the following four categories:

- hydrology and sediment yield,
- topography,
- geology, and
- seismicity.

These general conditions of the site also determine the selection of the type of dam (along with other criteria).

Then, for a given level of safety and taking into account the site conditions, the economics of the project lead to the selection of the optimum arrangement of the spillway devices.

a) Regarding the safety issues:

It should be pointed out that about one-third of dam failures in the last decades were caused by overtopping during a flood event. The two main reasons were the inadequate assessment of the design flood discharge and the malfunctioning of one or more gates.

1. It should be possible to discharge the established design flood without any difficulty. The energy of the flow must be dissipated at the dam toe without endangering the stability of the dam. It should be noted that the power to be dissipated is considerable. For 16,000 m^3/s and a drop of 100 m, the power is equivalent to 13,000,000 kW, corresponding to the power produced by ten modern nuclear plants of 1,300 MW.

2. Hydrology is not an exact science. The determination of design flood peak discharge is governed by the quality and quantity of available data and some statistical and deterministic rules, which are certainly a rough simplification of nature's reality. In addition, some uncertainty remains concerning climate change and its effect on the determination of low frequency floods.

3. The probability of a mechanical device malfunctioning is certainly never zero. Only ungated spillways are able to avoid mechanical malfunctioning. At the present time the experience of maintenance programmes and the education of operators make it possible to maintain this risk at an acceptable and controlled level. This is certainly the case in India, which has great experience in this respect. It should be pointed out that in seismic zones, the risk of damage to the gates is higher. These days the seismic design of mechanical devices such as gates and gantry cranes is well established.

b) Regarding the economics of the project:

1. Maximization of production. The purpose of a run-of-river plant is to concentrate the head difference along a river reach at a particular point, where this head can be used for power generation. The available head is determined by heightening the pool level at the dam location. This level is normally limited by the general conditions of the site previously mentioned in this Chapter. Maximization of production means utilisation of the maximum available head. In the case of an ungated spillway, the flood release requires a raising of the water level above the maximum operating level. As the general conditions of the site limit the maximum level, this creates a limitation of the maximum operating level and thus of the production. On the other hand, a gated spillway allows for the evacuation of the flood discharge without a significant change in the pool level.

2. Minimization of construction costs. For a given maximum operating level, an optimum has to be found for the combination of the costs of the dam body and the spillway devices, considering the general conditions of the site while not affecting the project's safety.

   Without gates, the dam height would need to be higher, and the costs of this additional volume of concrete must be compared with the comprehensive costs of the gates including construction costs and maintenance costs. A brief and simplified economic analysis is provided in Annex 5.2.2.

In the International Commission on Large Dams (ICOLD) Bulletin 58, it states: "[t]he ungated spillway is said to be preferable in particular if the rate of rise [of the reservoir level] is more than 1 to 2 meters per hour."[24]

<u>c) Regarding the sediment issue:</u>

Chapters 5.3 to 5.6 deal specifically with this problem.

5.2.5. Characteristics of Baglihar Project

Relevant to the selection of the spillway type, the Baglihar site is characterized by the following parameters:

1. The valley is very narrow:
   about 70 m at the river elevation, and
   about 300 m at the dam crest elevation.
2. The flood discharge is high:
   16,500 m^3/s as the peak discharge of the design flood and
   17,325 km^2 for the catchment area.
   There is a high energy dissipation requirement in a narrow valley; 16,000 MW in a narrow valley, leading to a total specific energy to be dissipated of about 200 MW/m.
3. The sediment yield is high.
4. The geology in the vicinity of the dam location is generally poor, as could be observed during the site visit.
5. The site is in an area of high seismicity.
6. The reservoir size is small in comparison with the flood volume:
   the flood routing effect would be very limited, whichever design is adopted.

The selection of a single 144.5 m high dam, creating a reservoir of 400 $M.m^3$, appears surprising, at first sight, for a run-of-river plant as the storage volume is not used for power generation. An alternative could have been the implementation of a cascade of three lower head plants along the river. Even without looking at the general site conditions, it seems evident that the cost of three low head projects, each of them being equipped with a 16,500 m^3/s capacity spillway and a 150 MW low head power plant would be higher than the cost of a single higher dam (even without taking into account the possible doubling of the installed capacity).

5.2.6. Historical review of large spillways

A statistical analysis of dams equipped with large size spillways has been carried out, based on the ICOLD's World Register of Dams (WRD).[25] On this particular matter, the NE received the very valuable advice of Mr André Bergeret, former Secretary-General of ICOLD. The

[24] ICOLD Bulletin N° 58, 1987, Paragraph 3.2.1, page 25.

[25] World Register of Dams, Edition 2003, International Commission on Large Dams, Paris.

version of the WRD used for this analysis was the 2003 update. The WRD consists of a database containing data collected since 2001 in 139 countries throughout the world. It contains 33,105 sheets.[26]

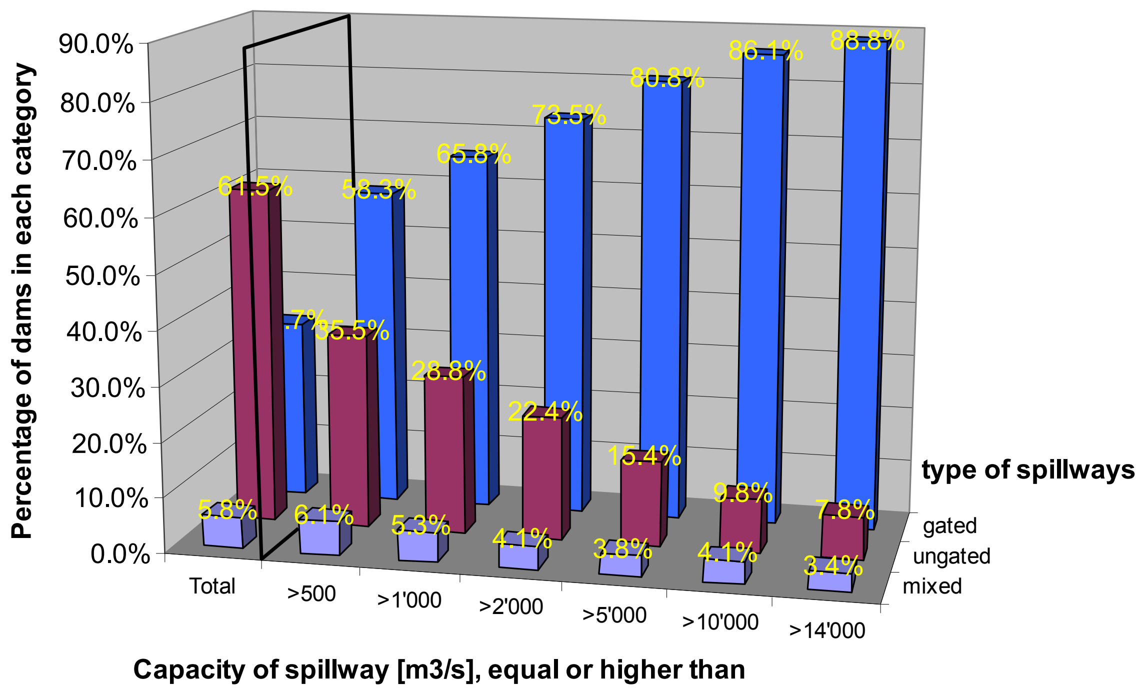
A statistical analysis has been carried out based on that database. The scope of this study was to analyse only the type of spillway, gated or ungated, considering the year of completion of the dam and the spillway capacity.

Only dam sheets containing pertinent information have been selected for the analysis, leading to a total number of 13,039 dams. Annex 5.2.3 gives a breakdown of these dams by year of completion, capacity and spillway type.

The spillways are classified in two categories: gated and ungated.

Dams are classified in three categories: the two mentioned above and a “mixed” category of dams containing both gated and ungated spillways.

The gate type (surface gates or pressure orifice gates) has not been distinguished. For ungated spillways, all types of spillway which do not require the operation of gates or valves have been considered. Most of the cases are free overflow spillways. Some other types, such as siphon type spillways are also included in the study, but there are only a few of these types, and their discharge capacities are quite small.



	Total		>500		>1'000		>2'000		>5'000		>10'000		>14'000	
mixed	759	*5.8%*	292	*6.1%*	169	*5.3%*	78	*4.1%*	31	*3.8%*	15	*4.1%*	7	*3.4%*
ungated	8'034	*61.5%*	1'691	*35.5%*	912	*28.8%*	422	*22.4%*	125	*15.4%*	36	*9.8%*	16	*7.8%*
gated	4'276	*32.7%*	2'777	*58.3%*	2'082	*65.8%*	1'385	*73.5%*	656	*80.8%*	316	*86.1%*	182	*88.8%*
Total	13'069	*100.0%*	4'760	*100.0%*	3'163	*100.0%*	1'885	*100.0%*	812	*100.0%*	367	*100.0%*	205	*100.0%*

Figure 5.2.3: Distribution of dams per type of spillways

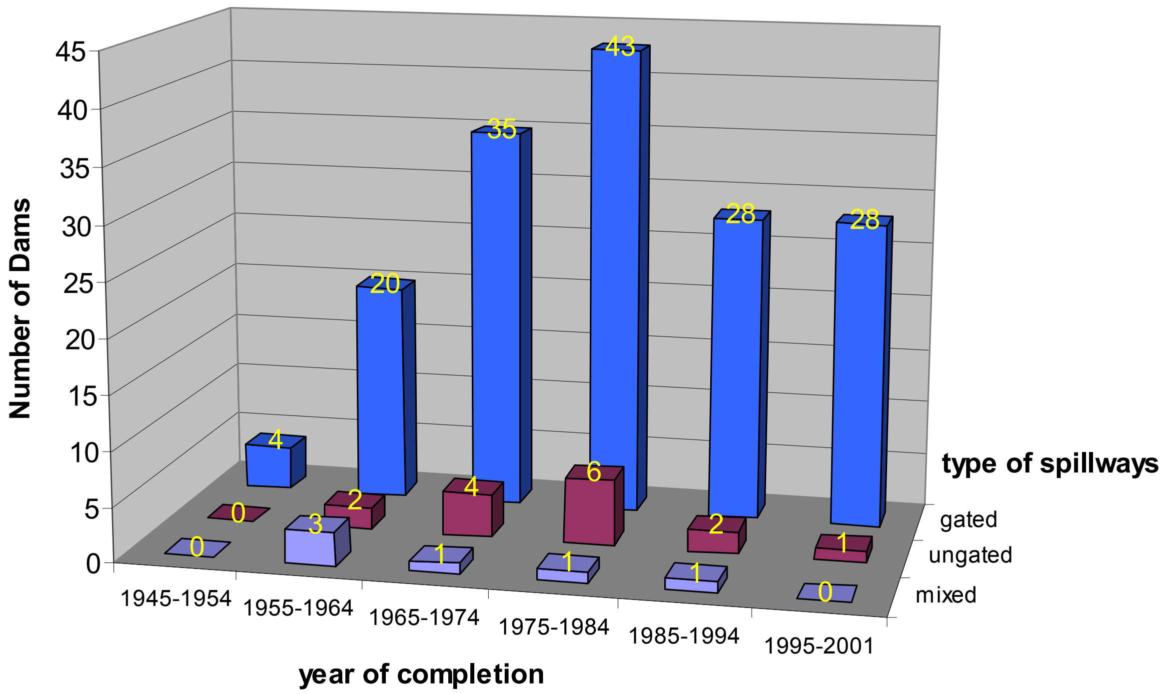
[26] The Register includes all dams not less than 15 m high from the lowest point of the main foundation. Countries having more than 1000 dams may seek special arrangements. For China, only dams high er than 30 m are registered.

It appears in the graph of Figure 5.2.3 that 61.5% of the total number of spillways are ungated, but this percentage decreases rapidly with increased discharge. For discharges of more than 14,000 m^3/s, the percentage decreases to 7.8%, whereas 88.8% have a gated spillway.

Only 179 have spillways releasing a discharge of more than 15,000 m^3/s. Figure 5.2.4 shows the breakdown of these 179 dams with the three spillway types – gated, ungated and mixed – and the year of completion. Only dams built since 1945 have been considered.

It appears very clearly that most of the dams with high flood discharges are equipped with gated spillways.

The 15 dams in which the total spillway capacity is higher than 15,000 m^3/s and recorded as being only equipped with ungated overflow spillways, are listed in Table 5.2.1. After investigation, it was found that four cases are errors in the database (dams No. 4, 9, 12 and 15 have gated spillways). No detailed data on the spillway has been found on four other cases (dams No. 2, 3, 5 and 7). Two dams have spillways which are totally separated from the dam body (dams No. 6 and 8) and two dams have a low height less than 20 m (dams No. 11 and 13), making a comparison with Baglihar irrelevant.



	1945-1954	1955-1964	1965-1974	1975-1984	1985-1994	1995-2001	Total
mixed	0	3	1	1	1	0	6
ungated	0	2	4	6	2	1	15
gated	4	20	35	43	28	28	158
Total	4	25	40	50	31	29	179

Figure 5.2.4: Distribution of the dams with spillway capacity higher than 15'000 m^3/s, per type of spillways.

Finally, only three cases could be compared with the Baglihar case: the Burdekin Falls, Tallowa and Fairbairn dams. All three dams are located in Australia. A key characteristic of these three dams is that their sites are in wide valleys. Also, the area around the reservoir allows for a raising of the water level in the case of a flood, with no danger of flooding important infrastructure. Two of them have particularly strong rock foundations that are suitable for energy dissipation at the dam toe. These situations are not comparable with the Baglihar dam site.

The discussion on the type of spillway could also take advantage of what is known to be common practice in the field of low head run-of-river plants. Protection of the intake structure from sedimentation and pond desilting are key issues for these plants. The solution generally implemented is a gated spillway across the river, which allows for the passage of high floods – both water and sediments - without significant restriction of the riverbed width and depth.

	Dam name	Country	Year of completion	Dam Height [m]	Spillway discharge [m^3/s]	Comments
1	**Burdekin Falls**	Australia	1987	55	64,600	RCC gravity dam 830 m wide overflow spillway, q=78 $m^3/s/m$ stilling basin
2	Hongjiang	China	2000	56	28,275	No data found
3	Mashi	China	1973	31	25,000	No data found
4 *	Oshun	Nigeria	1977	11	23,800	Earthfill dam "mechanical spillway for occasional use", certainly gated
5	Tagwai	Nigeria	1978	25	22,500	No data found
6	Harding	Australia	1985	45	21,'500	Separate overflow spillway with unlined chute
7	Gandhi Sagar	India	1960	62	21,238	No data found
8	Pindari	Australia	1969	85	20,650	CFRD type dam Separate ungated spillway Energy dissipation in unlined quarry
9 *	Vanderkloof	South Africa	1977	108	20,400	Mixed spillway, with a 4 bays gated spillway on left bank
10	**Tallowa**	Australia	1976	43	20,200	Gravity dam 518 m wide overflow spillway, q=39 $m^3/s/m$ stilling basin
11	Kangimi	Nigeria	1977	19	20,000	Earthfill dam 121 m wide overflow spillway,
12*	Mosul	Iraq	1983	131	17,000	Gated spillway on right bank
13	Oba	Nigeria	1964	13	16,000	Low head earthfill dam
14	**Fairbairn**	Australia	1972	49	15,580	823 m wide overflow spillway, q=19 $m^3/s/m$ stilling basin
15*	Dantiwada	India	1965	61	15,290	Equipped with 11 12.5 mx8.2 m radial gates

* Error in the database

Table 5.2.1: List of dams recorded in WRD, with only ungated spillways with capacities higher than 15,000 m^3/s

This limited analysis of existing dams with large spillways demonstrates that it is certainly not common practice to design a dam such as Baglihar with only ungated overflow spillways. On the contrary, the statistical analysis shows that the common solution is a gated spillway when the flood discharge is high.

5.2.7. Historical review of the development of large orifice outlets

The history of construction of large orifice spillways was the topic of question Qrs2 posed by the NE to the Parties for Meeting No. 3. Responses to this question were presented on 25 May 2006.

The problem is twofold as the key parameters of orifice outlets are both the head and the size (or gate surface).

High-head bottom outlets have been implemented for a long time in high storage dams. They are only considered as safety devices, allowing for a preventive lowering of the reservoir level in the case of an emergency. They were also frequently used during first impounding to control the rise in the reservoir level. They are generally not used for releasing flood waters.

Large gates have also been common as surface spillways since the early 1900s.

The conjunction of these two characteristics in the same device required several technological developments, which were only accomplished in the second part of the 20th Century.

Both Parties established a list of submerged segment gates with dimensions and head comparable with what is planned for the Baglihar project.[27] The list is limited to cases built or planned before 1960, the date of implementation of the Treaty. The number of cases is limited, and it appears clearly that it has increased significantly since 1970. Table 5.2.2 gives a list of dams including large orifice spillways implemented before 1970.

The reasons for implementation of submerged outlets should be addressed case by case, and the success of such an arrangement should also be discussed.

It appears that implementation of high pressure submerged gates was only limited to some specific cases and was not common practice before 1970.

Since 1970, the number of cases increased rapidly, as a result of significant technical progress in gate technology. The most significant are listed below:

- The development of self-lubricating bearings, which allows for significantly higher thrust on the bearings of segment gates,
- Sealing materials, such as Teflon coated seals,
- High pressure hoist cylinders,
- Pre-stressed anchors, and
- Steel quality and coatings, which increase the abrasion resistance of steel linings.

[27] Planned Gate area is 105 m^2 and the design head is about 30 m.

	Dam name	Country	Year of completion	Gate area [m^2]	Head [m]	Comments
1	Owen Falls	Uganda	1954	76		Operated on very long periods Sliding gates Outlet of Lake Victoria.
2	Kariba	Zambia Zimbabwe	1959	77	33	6 gates
3	Khashm el Girba	Sudan	1964	49	32	7 radial gates. Total sediment yield is 20 M.tons and concentration during floods is 50-200 g/l[28]
3	Roseires	Sudan	1965	68	35	6 radial gates. Almost same sediment yield as Khashm el Girba
4 *	Mangla	Pakistan	1967	134	49	
6	Pandoh	India	1974	132	24	
6	Castelo de Bode	Portugal	1949	119	30	

Remark: numerical values may vary depending on the source and are to be considered as indicative.

Table 5.2.2: List of dams with large orifice spillways referred by the Parties and completed before 1970.

This technical progress is also attested by ICOLD in its Bulletin No. 58 (1987)[29] stating: “[r]ecent progress, with gates in particular, now makes it possible to have very large bottom sluices under very high heads for river flood discharge.”

In fact, orifice spillways are frequently used today as sluice spillways in relation to sediment management. This function requires very strong abrasion resistance of the linings, gate sealings and gate bodies. They require higher maintenance costs than surface gated spillways.

The NE concludes that the implementation of high-head submerged spillways was not common practice before the drafting of the Treaty. Some experience was acquired with mixed feed back.

The use of such spillways in the context of high sediment yield was certainly discussed at that time in research and development institutes, but their implementation on rivers with high sediment loads did not yield any clear conclusions at that time.

[28] French Committee on Large Dams, *“Contrôle de l’alluvionnement des retenues, quelques exemples types”*, Proceedings of XIVth Congress of ICOLD, Rio de Janeiro, 1982, Volume III, Question 54 Report 34, pp. 537-562.

[29] ICOLD Bulletin No. 58, 1987, Paragraph 4.1, page 95.

5.2.8. **STATEMENT S 2** relating to the issue of gated or ungated spillway [point (a) of the difference referred by Pakistan]

The determination of the possible arrangement of spillways must be driven by the general conditions of the site, i.e. hydrology and sediment yield, topography, geology and seismicity.

Based on the statistical analysis given in Chapter 5.2.6, it has been demonstrated that the provision of gates on large spillways is a frequent practice. Furthermore, it has been demonstrated that the sole use of ungated free overflow spillways is marginal when the required capacity for flood releases is higher than 15,000 m^3/s.

Free overflow spillways require a higher dam to be able to release the design flood than is the case with gated spillways. The cost of this dam heightening has been compared with the cost of a corresponding gated spillway. A simplified calculation has demonstrated that, with dam type and size comparable with Baglihar dam, and considering the same discharge requirements, a purely economic comparison always favours a gated spillway.

With very large reservoirs, the routing effect in the reservoir is more significant with overflow spillways than with gated spillways because of the higher flood storage volume. This allows for a reduction in the spillway design discharge. This routing effect is very limited in the Baglihar reservoir, the area of the reservoir being limited compared with the flood volume.

Finally, a brief historical review of the development of large submerged gates has been carried out. Although there was some experience before 1960 with large submerged spillways, the review indicated that this practice became increasingly common after 1970, as a result of several technical improvements in the field of gate technology.

5.3. EVOLUTION OF TECHNOLOGY CONCERNING RESERVOIR SEDIMENTATION

5.3.1. The necessity for an analysis of the evolution of knowledge in the field of reservoir sedimentation

Pakistan is of the considered opinion, according to its Memorial,[30] that the Baglihar Plant does not conform to *Annexure D, Part 3 - New Run-of-River Plants, Paragraph 8 (e)* of the Treaty which states:

> *"If the conditions at the site of a Plant make a gated spillway necessary, the bottom level of the gates in normal closed position shall be located at the highest level consistent with sound and economical design and satisfactory construction and operation of the works".*

The position of Pakistan[31] is that a gated spillway is not necessary, and that India should have specified an ungated spillway. Furthermore, even if it can be assumed (without conceding) that a gated spillway is necessary, the bottom level of the gates proposed by India is not located at the highest level.

In its Counter-Memorial,[32] India declares:

> "a configuration of three bays of chute spillways, an auxiliary spillway and five bays of sluice spillways at different crest/sill levels has been provided, keeping in view the limited width available in the narrow and steep gorge at the site, the relative techno-economics of various possible configuration, the fragile Himalayan geology, submergence issues that have local implications, the need to ensure safe passing of the design flood and also the need to ensure a silt-free environment near the intakes for trouble-free operation by transport of sediments along with flood discharges through the sluice spillways. By considering all these factors, the spillway with chosen configuration is at the highest possible level consistent with sound and economical design and satisfactory construction and operation of the works".

The important element is that the concept of the spillways and of the power intakes should take into consideration the exceptional level of sediment in the Chenab river, which is a general problem for Himalayan rivers. The risks are: sedimentation of the reservoir, bringing into question the sustainability of the operating pool (the pondage); the sedimentation of the power intakes; and suspended sediment, with a high concentration and size, entering the power intake and power tunnel causing erosion of the turbines.

In fact the designer of a spillway is not only faced with the problem of flood control, but also with that of sediment control. Confusion and misunderstandings could arise because these two factors are not independent of each other. The element which links them is the role played by the bottom outlet. Referring to Bulletin 115 of ICOLD, "Dealing with reservoir sedimentation", the state of the art is today, that "[b]ottom outlets may be used for under sluicing of floods, emptying of reservoirs, sluicing of sediments and preventing sediment from entering intakes, etc."[33]

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[30] Memorial, page 12.

[31] Memorial, page 28.

[32] Counter-Memorial, page 30.

[33] ICOLD Bulletin 115. *Dealing with reservoir sedimentation*. 1999.

For its part, the Treaty in *Annexure D Part 3 - New Run-of-River Plants, 8(d)* states:

> *"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".*

It is interesting to point out that Pakistan does not refer to this criterion 8(d) in its written Instruments. However, the question was raised during Meeting No. 3 in London, which was devoted to the oral presentations of the Parties.[34] According to the rules and methods of interpretation applicable to the Treaty, and especially the principle of integration, the NE considers it essential that, beside provisions 8(e) and 8(f), provision 8(d) is also retained.

The above considerations led the NE to undertake an analysis of the evolution of technology concerning reservoir sedimentation, particularly its management. Thus, independently from the problem of Baglihar, an academic investigation was carried out in this field, in April and May 2006, with the advice of Professor Anton Schleiss and his assistant Dr Giovanni de Cesare from *the Laboratoire de constructions hydrauliques (LCH), Ecole Polytechnique Fédérale de Lausanne (EPFL)*. Moreover, during the Meeting No. 3, 25-29 May 2006, the following questions were put to the Parties by the NE[35]:

Qrs1: Since which time could we consider that a general understanding has existed concerning methods of managing reservoir sedimentation, and the science and technology of the design of related hydraulic works: for example, passing and removal of sediments through reservoirs (sluicing, venting of density currents, flushing, dredging) or bypassing the reservoirs?

Qrs2: Since which time have large-scale high pressure spillway gates been built?

It was stated that these questions do not relate to knowledge of scientific theories or solutions for some particular cases, but rather the existence of a well developed science and technology (we could say: as taught in the institutes of technology) generally accepted by designers, contractors and owners concerned by sedimentation problems.

The Parties answered these questions with great care.

The NE sets out below the result of his own analysis concerning the question Qrs1. He will come back later in paragraph 5.3.7 to the conclusions of the May 2006 presentations of Prof. G. Annandale for Pakistan and Prof K.G. Ranga Raju for India.

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[34] Meeting No. 3. Draft transcript, 28 May 2006; Prof. J. Crawford: pages 7, 13, 14; Mr F.S. Nariman: pages 114, 115, 116, 117, 118, 119.

[35] Additional Questions of 12 April 2006 Proposed by the NE to the Parties in Preparation of Meeting No. 3.

5.3.2. The state of the art in the field of reservoir sediment control

As mentioned above, ICOLD Bulletin 115, "Dealing with reservoir sedimentation", 1999, is a major reference for design engineers.

Another important document was published in 2003, reporting on a research project initiated by the World Bank: REServoir CONservation (RESCON).[36] Its purpose was to develop an approach to the assessment and promotion of sustainable management of reservoirs.

The various options for reservoir sedimentation control are as follows:

a) Minimise sediment loads entering a reservoir through:
   - soil and conservation programmes,
   - upstream trapping of sediment (debris dams or vegetation screens),
   - bypassing of high sediment loads, and
   - off-channel storage;

b) Minimise deposition of sedimentation in a reservoir through:
   - sluicing which is the passing of sediment-laden floodwaters through the reservoir by means of drawing the water level down, and
   - density current venting;

c) Remove accumulated sediment deposits through:
   - flushing by means of drawing the water down during the rainy season, and
   - excavation by means of dredging or other mechanical equipment; and

d) Compensating for reservoir sedimentation:
   - maintaining long-term storage capacity by raising the dam, and
   - abandoning/decommissioning the silted reservoir and constructing a new reservoir or introducing water from elsewhere.

As mentioned above, this Bulletin could be considered today as the state of the art. The problems of reservoir sedimentation are clearly set out, and solutions for its management are presented or are in the process of being developed. The present discussion concerning the design of the spillway and power intakes of Baglihar is not only a matter of interpretation of the Treaty, but also a question, less evident, of research of a technically acceptable work from the point of view of operation, maintenance, safety and sustainability. Moreover, the solution of some important problems still requires research and development, such as, sedimentation control of reservoirs with multi-annual regulation of river flow.

[36] The RESCON Approach, Volume 1 and 2. A. Palmieri; F. Shah; G. W. Annandale; A. Dinar. The World Bank. 2003

5.3.3. Statistical analysis of the publications on reservoir sedimentation

Even if statistics may be somewhat lacking in sensitivity (especially in a field where humans are concerned), they can provide a good perspective of the history, giving less weight to some examples which influence the mind but could be an exception, and, in this way, separate more clearly the general from the particular.

A statistical analysis of the publications on reservoir sedimentation was carried out on the basis of 370 publications covering more than 70 years.[37] Figure 5.3.1 shows the evolution of the number of publications before 1950, then over the decades, and since 1990. It appears that less than 3% of the papers were published before 1950 and 10% before 1960. A very major increase occurred after 1980.

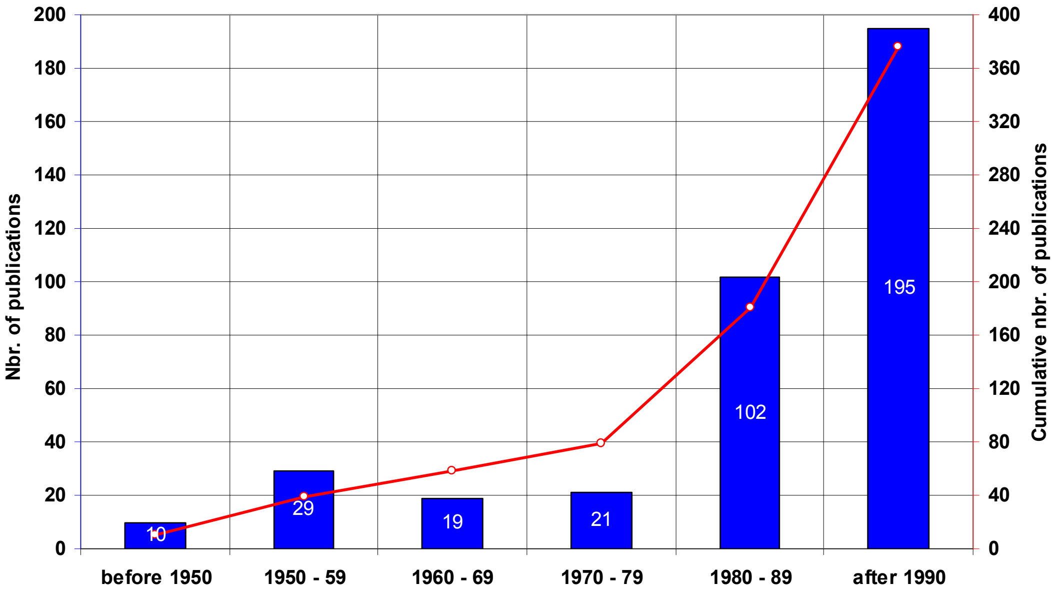

Figure 5.3.1: Number of publications related to sedimentation

In order to have a more detailed overview, the themes of the papers have been divided into 5 categories, represented in Figure 5.3.2. It can be observed that in some cases the classification is somewhat subjective.

Category 1 (erosion, sediment yield from watershed, sediment transport) is covered by 47 papers of which only 4 were published before 1960 while the majority were published during the 1980s and subsequently.

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[37] The publications are from the following books, journals, proceedings and transactions: American Geophysical Union; Annales de l'institut technique du bâtiment et des travaux publiques; Annandale G., Reservoir sedimentation; ASCE: Journal of the Hydraulic Engineering, Journal of the Hydraulics Division, Journal of Water Resources Planning and Management, Transactions; Bureau of Reclamation; Canadian Journal of Civil Engineering; Central Board of Irrigation and Power; The International Journal on Hydropower & Dams; Hydro Review Worldwide; IAHR: Congresses and Symposiums, Journal of Hydraulic Research; ICOLD Congresses on Large Dams; Journal of Fluid Mechanics; Journal of Geology; Journal of Sedimentary Research; Marine Geology; Morris G. and Fan J., Reservoir sedimentation handbook; ONU; Journal Soil and Water Conservation; Scienta Sinica; US Dept. of Agriculture; Water Resources Research; Ven Te Chow, Handbook of applied hydrology; Water Conservation; Water Power & Dam Construction, The World Bank.

In total, 97 papers for **category 2** (turbidity currents, observations, physical and numerical modelling) have been identified, with some nine being published before 1960. The number of in situ observations has not significantly increased since these times, very probably because of the cost and scale of the methods required for the observation and measurements of the turbidity currents.

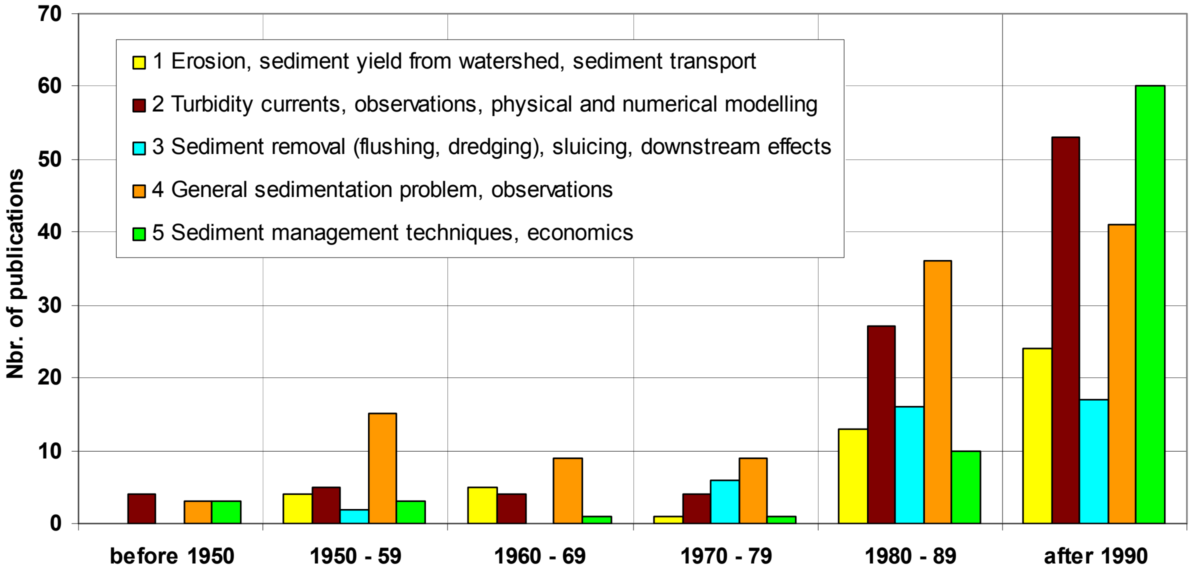

Figure 5.3.2: Number of publications distributed by themes

Thirty-nine papers are related to **category 3** (sediment removal: flushing, dredging, sluicing, downstream effects), with only two papers before 1960. Flushing through bottom outlets was mentioned at the 2nd ICOLD Congress in 1936, and described in detail at the 4th ICOLD Congress in 1951. A real case was described only in 1971 in the journal of *Water Power & Dam Construction*, even though such operations had been carried out earlier. But globally, reports on sediment removal techniques appear in a fairly insignificant number of papers and the theme is still under investigation and on site tests.

As for **category 4** (general sedimentation problems, observations) 113 papers are reported with some 18 before 1960. The United Nations Report[38] in 1954 is among the first overall presentations of the problem, only preceded by contributions at the 2nd and 4th ICOLD Congresses in Washington, (1936), and New Delhi (1951).[39]

[38] UNITED NATIONS (1954). *"Le Problème de la sédimentation"*. Commission Economique pour l'Asie et l'Extreme Orient, New York

[39] LEWIS, M. A. (1936). *"Silting of four large reservoirs in South Africa"*. Communication 5. "The silting of reservoirs formed by large dams; its measurements and prevention", 2nd Congress on Large Dams, Vol. 5, Washington.

VISENTINI, M. (1936). *"Alluvial deposits in reservoirs, their importance and the means to lessen or prevent them"*. Communication 5 "The silting of reservoirs formed by large dams; its measurements and prevention" 2nd Congress on Large Dams, Vol. 5, Washington.

NIZERY, A, and ROUSSELIER, M. (1951). *"Economical aspect of the sedimentation in reservoirs"*. 4th ICOLD Congress. Question 14. New Delhi.

Of the total of 79 publications concerning **category 5** (sediment management techniques, economics) a significant number were published since 1980; only six papers existed before 1960, including the earliest papers[40] by Hill and another by Visentini both in 1936, and a third by Brown in 1943, and three articles were published in 1951 during the 4th ICOLD Congress in New Delhi. The increase after 1990 is spectacular with a jump from 18 to 61 papers. This clearly indicates the greater awareness of the necessity to master reservoir sedimentation and to develop the required expertise in this field.

Another approach can also be made by considering only the references given in the above mentioned ICOLD Bulletin 115. From the 129 documents referenced, only 10 were published before 1960 and 5 before 1950. This is approximately the same result as that obtained from the statistical analysis of 370 publications.

5.3.4. Lessons from dam construction

For all large civil or mechanical works, beyond the necessary theoretical developments, their implementation, the action of construction itself, is the deciding factor for dam construction. Experience comes from construction, and so it follows that a major role of a professional association, such as ICOLD, is for its members to exchange their experiences, whether good or bad.[41]

For this reason it is interesting to look at the evolution of the number of large dams[42] built since the middle of the last century,[43] in the world (Figure 5.2.3) and in some characteristic countries (Table 5.3.1), where about 90% of all the large dams registered in the world are represented. We can make the following observations:

- In 1950, about 5,200 large dams existed in the world, including 80% in North America and in Europe.
- Then during the next 50 years, until the year 2000, the construction continued strongly with a mean value of 630 large dams per year reaching 33,100, i.e. about 4 times the number in 1960 (8,000), but for Asia the coefficient was about 9 times.
- The large dams in North Africa and South Africa are especially noted in Table 5.3.1 because they were generally facing sedimentation problems before 1950.

Since the Second World War, and especially between 1950 and 1960, the pace of dam construction in the world suddenly increased to a considerable extent, with this rate being sustained up to the present. This was possible because of the experience gained during the first part of 20th Century, generally on medium-sized dams. But it appeared that some

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[40] HILL, R.A. (1936). *"Silting of reservoirs formed by large dams. Its measurement and prevention"*. Communication 5 The silting of reservoirs formed by large dams; its measurements and preven tion, Proceedings of 2nd Congress on Large Dams, Vol. 5, Washington.

BROWN, C. B. (1943). *"The control of reservoir silting"*. US Dept of Agriculture. Misc. Publication. No. 521, Washington DC, USA.

[41] "We learn from our mistakes, but, as Bernard Shaw remarked, 'one must not take it too far." José Toran, President of ICOLD. "Lessons from dam incidents". ICOLD. 1974.

[42] ICOLD's definition of a large dam: dam with a height above foundation not less than 15 m, but not less than 30 m for China (about 17 000 dams), or with an impounding more than 3 hm^3.

[43] ICOLD, World Register of Dams, 2003.

aspects of technology were not well controlled or known across the engineering profession, and this led to incidents which were sometimes catastrophic.[44]

This important evolution of construction meant that more and more engineers became involved, and this is reflected by the number of their technical publications presenting their experiences. This was particularly the case in the field of reservoir sedimentation, as can be seen in Chapter 5.3.3.

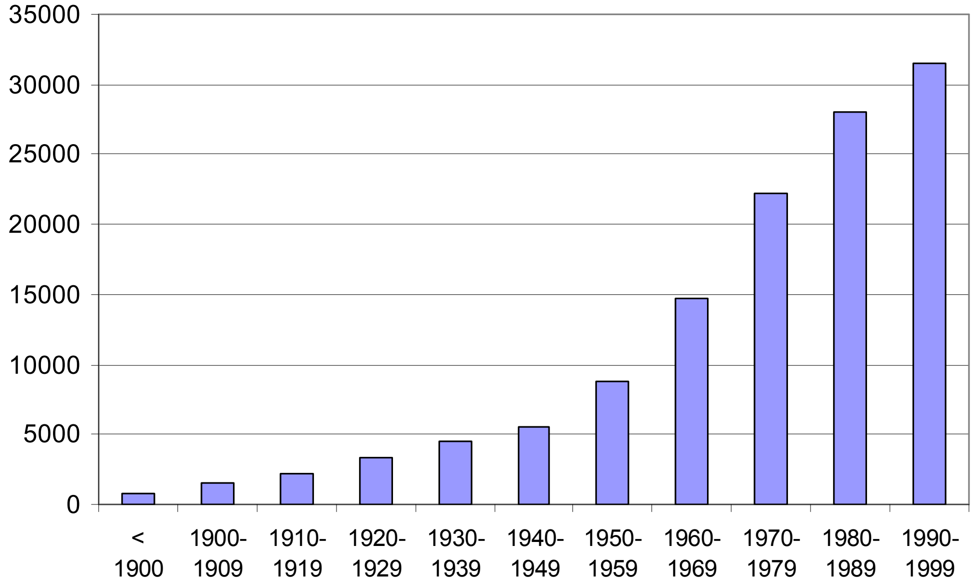

Figure 5.3.3: Number of large dams registered in the world

Years		**1950**	**1960**	**2000**
Entire World		5,200	8,000	33,100
North America	USA	2,600	3,700	9,250
	Canada	240	387	793
Europe		1,300	2,000	6,300
Asia	China	9	260	4,593
	Japan	108	241	1,038
	Korea	155	280	1,198
	India	312	533	4,613
	Pakistan	2	2	71
Africa	Algeria	18	21	111
	Egypt	4	4	6
	Morocco	7	13	101
	Tunisia	1	6	109
	South Africa	100	179	912
Australia		129	181	501

China: 1950 and 1960: only dams higher than 60 m are recorded; 2000: higher than 30 m

Table 5.3.1: Number of large dams registered in the world and in some specific countries

[44] ICOLD. Bulletin 99: *Dam failures, Statistical analysis*, 1995. Between the years 1950 and 1986, about 12,100 large dams were built (excluding China), 59 of them failed, which gives a rate of failure of 0.5%. This represented a progress, because during the first part of the 20th century, 117 dam failures occurred for 5,200 dams built; the rate was 2.2%.

5.3.5. ICOLD literature on sedimentation

ICOLD, which is an international association with 83 member countries, was founded in 1928. It organizes triennial congresses where four technical questions, chosen with great care, by the general assembly of the members, are discussed. Since its foundation, 22 congresses have taken place, and 87 Questions have been discussed with the subsequent publication of the proceedings. Moreover, 22 Technical Committees, in various fields of dam technology, including social and environmental aspects, prepare Bulletins which are published by the Commission (128 to date). All these publications constitute an exceptional documentation which is available for the engineering profession.

A safe way to approach the evolution of reservoir sedimentation technology is to refer to these publications. In the question Qrs1 put to the Parties (Chapter 5.3.1) it was stated that the problem does not refer to the evolution of the knowledge of scientific theories or solutions for some particular cases, but to the existence of a well developed science and technology, generally accepted by engineers.

The following Congresses on Large Dams included, among other questions, sedimentation:

- 1936. Second Congress. Washington. Communication 5. “Silting of reservoirs”. 4 individual reports.
- 1951. Fourth Congress. New Delhi. Question 14. “Sedimentation in reservoirs and related problems”. 1 General report. 16 individual reports
- 1973. Eleventh Congress. Madrid. Question 40. “The consequences on the environment of building dams.” 1 General report. 5 individual reports.
- 1976. Twelfth Congress. Mexico. Question 47. “The effect on dams and reservoirs of some environmental factors.” 1 General report. 14 individual reports.
- 1982. Fourteenth Congress. Rio de Janeiro. Question 56. “Reservoir sedimentation and slope stability. Technical and environmental effects.” 1 General report. 38 individual reports.
- 1997. Nineteenth Congress. Florence. Question 74, “Performance of reservoirs; a) Sedimentation including effects on structures, equipment, water quality and river downstream.” 1 General report. 41 individual reports.

After two congresses in 1936 and 1951, where sedimentation problems were identified, engineers decided that it was necessary to continue to exchange knowledge on their investigations and on the applied solutions at four subsequent congresses, especially of note are the congresses held in 1982 and 1997.

Two ICOLD Bulletins on sedimentation were published in 1989 and 1999.[45] They are coherent documents essentially on the integrated management of reservoir sedimentation.

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[45] ICOLD Bulletin 67. Sediment control of reservoirs, 1989; and ICOLD Bulletin 115. Dealing with reservoir sedimentation, 1999.

5.3.6. Periods of evolution of sedimentation technology

Consultation of the various documents enables some key points to be determined concerning the evolution of the knowledge on reservoir sedimentation:

- Measures to control erosion in the watershed were quite well developed in some affected countries before 1950.
- Methods to estimate sediment yield from watersheds were developed during the 1960s and 1970s.
- Sediment transport mechanisms for bed load and suspended load were known in 1950, but suspended transport was studied during the following decade and some research studies were undertaken up to the 1970s.
- Observations were made on turbidity currents before 1950, but the theory was not developed before the 1980s.
- Processes for the removal of deposited sediment by flushing and dredging have been applied in some cases since the beginning of the 20th Century.
- Methods of passing incoming sediments through reservoirs by sluicing or venting were also sometimes applied at the beginning of the 20th Century; there have been more applications since 1970.
- Numerical modeling of sediment transport appeared in the 1980s.
- Integrated reservoir sedimentation management began to be disseminated around 1980. We note that China joined ICOLD in 1974, and in 1976 at the 12th ICOLD Congress presented its important experience.

5.3.7. The point of view of the Parties

Answering question Qrs1 of the NE, on the evolution of the technology concerning reservoir sedimentation, during Meeting No. 3, 25-29 May 2006, a good review of the history in this field was made by both Parties.

The conclusion of Prof. K.G. Ranga Raju from India was clear, and similar to that of the NE, stating:

> "A rational approach to management of reservoir sedimentation and design of related hydraulic works may be said to have emerged after 1970's with the advent of Mathematical Modeling of Morphological Processes and the awareness of the need for integrated sediment and water management in case of alluvial streams carrying heavy sediment loads."[46]

The conclusion of Prof. G.W. Annandale, Expert for Pakistan, was that today the current generally accepted techniques to manage reservoir sedimentation (pressure flushing, drawdown flushing, sluicing)[47] were already known and implemented in 1936. This is not

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[46] Prof. K.G. Ranga Raju. Oral presentation and PowerPoint slideshow, Meeting No. 3, May 25, 2006.

[47] Prof. G.W. Annandale. Oral presentation and PowerPoint slideshow, Meeting No. 3, May 25, 2006.

incorrect but incomplete and the NE thinks it is necessary to recall what was written by Pakistan in its Reply[48] of 25 January 2006 (i.e. before that the NE asked his question Qrs1):

> “Precedents for the management of reservoirs have evolved over the past few decades as more attention as been paid to the effect of sedimentation on the loss of project benefits. The evolving state of the art is summarized in a number of reference texts and numerous conference papers.
>
> (…)
>
> The history of reservoir sedimentation management is recent and the technology is still to be fully mastered.
>
> (…)
>
> However, apart from a few “special cases”, during the mid-20th Century, the concept of active operation within the reservoir to manage sediment was largely ignored. Such processes include: sediment bypass, pass-through (also known as routing) and drawdown flushing.”

So, all being well considered, a consensus, although not expressed, appears between each Party and the NE. His point of view is presented Statement S 3 in Paragraph 5.3.9.

5.3.8. Citations of authorities and international experts

Finally, some citations can illuminate the landscape with a horizon going back to the middle of the last century:

JOHNSON, Ian. *“Reservoir Conservation. The Rescon Aproach”*. The World Bank 2003 (Foreword):

> “Whereas the last century was concerned with reservoir development, the 21st Century will need to focus on sediment management; the objective will be to convert today’s inventory of non-sustainable reservoirs into sustainable infrastructures for future generations.
>
> The scientific community at large should work to create solutions for conserving existing water storage facilities in order to enable their function to be delivered for as long as possible, possibly in perpetuity.”

MORRIS, Gregory, FAN, L. Jiahua. *“Reservoir sedimentation handbook”.* McGraw-Hill. 1997 (page 2.13):

> “Reservoir sedimentation has been methodically studied since the 1930s (Eakin and Brown, 1939), but dam engineering has historically focused on structural issues, giving relatively little attention to the problem of sediment accumulation. The three volume treatise Engineering for Dams, authored in 1945 by Creager, Justin, and Hinds, fails to mention sedimentation, and the 1960 version of the Bureau of Reclamation's publication Design of Small Dams[49] covers the topics in a single page. However, the 1987 version expended this topic to an entire Annex.

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[48] Reply. Part I. ANNEX I-D. Commentary on India’s report on “Sedimentation of the reservoir and sediment management” Vol 5 (ii). Pages 5 and 6.

[49] As it is mentioned in the preface of the 3rd edition in 1987, some of the information relates to large dams, and many of the theoretical concepts presented can be applied to large or small structures.

With reasonable levels of maintenance, the structural life of dams is virtually unlimited, and most reservoirs are designed and operated on the concept of finite life which will ultimately be terminated by sediment accumulation rather than structural obsolescence."

ANNANDALE, George. *"Reservoir sedimentation".* Elsevier. 1987. (Preface):

"Books on the subject of reservoir sedimentation are generally lacking. There is however a need for collecting, documenting and evaluating the knowledge available in this field of engineering. Research on reservoir sedimentation in recent years was aimed mainly at water resources projects in developing countries. These countries, especially in Africa, often have to cope with long droughts, flash floods and severe erosion problems. Large reservoir capacities are required to capture water provided by flash floods so as to ensure the supply of water in period of drought. The problem arising however is that these floods, due to their tremendous stream power, carry enormous volumes of sediment which, due to the size of reservoirs, are virtually deposited in the reservoir basin, leading to fast deterioration of a costly investment. Accurate forecasting of reservoir behaviour is therefore of the utmost importance"

ZHANG, Hao; et al. *"Regulation of sedimentation in some medium and small size reservoirs on heavily silt-laden streams in China".* 12th ICOLD Congress. Q47-R32. (pages 1232, 1242, 1243), 1976:

"In order to preserve a certain storage capacity of a reservoir on a sediment laden stream for a considerable long period, it is necessary to make simultaneous regulation of sediment and river-runoff; otherwise runoff regulation itself may fail because the reservoir might have been rapidly filled with sediment. Moreover, it would also be a loss of fertile sediments containing much humus should all be captured in the reservoir. Therefore, it is necessary to make regulation of both runoff and sediment, in order to maintain capacity and to make good use of the sediments…[E]xperience has indicated a mode of reservoir operation summarized as storing the clear water and discharging the muddy water, and diverting the muddy water for irrigation and warping (…)"[50]

DROUHIN, George. *"Silting of reservoirs and related problems".* 4th ICOLD Congress. Q 14 (page 9), 1951:

"Engineers have hitherto been somewhat at a loss in dealing with the phenomena which cause reservoirs to fill up." So it is true that in many cases all that is done is to provide a capacity which leaves a margin for filling up, sufficient for some decades, or in favourable circumstances, for some centuries. This amounts to adopting the hypothesis that when the time is reached that the storage becomes inadequate, a new structure can be built; or, the hope that one's successors helped by technical progress in the meantime will then be able to apply effective and economically justified methods in combating or in removing accumulations of silt.

Anyhow most of the means to be contemplated avail only for extending the life of such works, without amounting to an absolute remedy."

[50] The underlining is by the NE.

LEWIS, A.D. *"Silting of four large reservoirs in South Africa"*. 2nd ICOLD Congress Communication 5 (page 193), 1936:

> "Bottom-flow tapping by means of relatively small opening at deep levels does carry through some of the worst kind of silt during floods. Mechanical stirring might assist.
>
> Deep spillway gates have the advantage of carrying through finer suspensions early in big floods, but chiefly when the capacity of the reservoir bears a small relation to the run-off. They are expensive to install and to operate."

5.3.9. STATEMENT S 3 relating to the level of the spillway gates [point (a) of the difference referred by Pakistan]

Considering the evolution of technology concerning reservoir sedimentation during the 20th Century, the situation appears as follows to the NE:

- Before 1960, the theoretical aspects of sediment transport were generally known, with the exception of the turbidity currents. The removal processes of deposited sediment by flushing and dredging, and the routing by sluicing and venting were also known and applied, but only in some cases. It was after 1970 that these processes of flushing, sluicing and venting became more generally developed.
- In 1960 the phenomenon of reservoir sedimentation was not recognized everywhere to its full degree of significance. Moreover, it was only 20 years later, in 1980, that the concept of an integrated reservoir sedimentation management began to be clear and coherent. This simple principle was announced succinctly by the engineers of China stating: "[s]tore the clear water and discharge the muddy water."

5.4. OPERATION AND MAINTENANCE

5.4.1. Necessity to clarify the meaning of the term "operation"

Some provisions of Annexure D to the Treaty contain the following terms or expressions concerning the issue of "**operation**". These are, *inter alia*, *"storage which is not used for **operational purposes**"* (ANNEXURE D. Part 1. Paragraph 2(a)); *"**Operating Pool**"* (Paragraph 2(f)); *"**operation** of the following hydro-electric plant"* (Part 2. Paragraph 3) and *"**operation** by India, of the following hydro-electric plants"* and *"**partial operation**"* (Paragraph 4); *"**Operating Pool**"*, *"**sediment control**"* and *"**operation of the works**"*, *"**operation of the Plant**"* (Part 3. Paragraphs (a), (d), (e) and (f)) etc.

Moreover, the term "**maintenance**", which is often associated in the industry with the word "operation" (O&M), does not appear explicitly in the Treaty. This appears due to the fact that it did not seem necessary at the time of the negotiation of the Treaty to insert a provision for this obvious matter that civil works and electro-mechanical equipment should be maintained.

In the course of the previous chapters of this Determination we referred in some places to "**reservoir sedimentation control**" and "**technically acceptable work from the point of view of operation, maintenance, safety and sustainability**" (Chapter 5.3.2); "**integrated management of reservoir sedimentation**" (Chapter 5.3.5), etc.

To avoid any misinterpretation of the provisions of the Treaty dealing with the question of "operation" it appears necessary to give some clear explanations in this respect.

5.4.2. Operation and maintenance of the reservoir

The development of a power plant contains the following processes: Planning, Design, Construction and Implementation, Operation and Maintenance, Replacement and Decommissioning.

These processes should satisfy various conditions: technical, economic, social and environmental, each of these including considerations of reliability, safety and sustainability.

This applies to each component of a power plant, and for a hydroelectric plant, these are as follows:

- Power plant itself (civil works and machines);
- Dam and its appurtenants works (civil works and equipments, such as spillway gates);
- Reservoir; and
- River bed up and downstream.

The NE outlines the processes of operation and of maintenance specially for the power plant itself, the dam and the reservoir as follows:

a) As regards the <u>power plant</u>, "operation" concerns exclusively (if it is not a multi-purpose scheme) power generation, with all the necessary activities: technical, economic and financial, administrative, etc.

"Maintenance" of the power plant consists in maintaining each part of the installation in perfect working order, which implies constant checking and repair of defects. In this field, the expression "renewal" is reserved for major and rare processes of replacing equipment.

b) The dam structure and foundations are essentially part of the process of "maintenance", which includes monitoring, safety assessments, repairing when necessary.

The electro-mechanical equipments of a dam's appurtenant works (spillway, bottom outlet) are "operated" and should be "maintained".

c) For the reservoir of a run-of-river plant, we have to make the distinction between two storage zones:

- The Live Storage (Pondage), which is strictly devoted to "operation", i.e. for power generation.
- The Dead Storage, which cannot be used for "operational purposes", i.e. for power generation.

The Dead Storage is kept full at all times, at the Dead Storage Level (DSL)[51], to provide minimum head on the turbines and on the power intake, and consequently it is technically impossible to generate power if the reservoir level is below the DSL.

The Live Storage should be protected against sedimentation because the volume of the pondage is a necessary element in the operating plan of the power plant. In addition, the power intake should be preserved from bed load sediments and the power tunnel preserved from suspended load sediments. Finally, it is imperative to avoid flooding of the land and habitat upstream of the reservoir.

To perform these objectives, a process of "maintenance" is necessary for the Live Storage and for the Dead Storage. This last one, as mentioned above, is not concerned with a process of "operation", but only with a process of "maintenance".

The principle of sustainability is today essential in the design of large infra-structures. This implies for dams the requirement of integrated reservoir sedimentation management, which is in fact a process of reservoir maintenance. It consists especially of the routing of sediments through the reservoir by sluicing and venting, as well as removal processes of deposited sediments in the reservoir by flushing and dredging.

[51] For Baglihar this level is fixed at 835.0 according to the design of India

5.4.3. STATEMENT S 4 relating to the level of spillway [point (a) of the difference referred by Pakistan]

An analysis of the meaning of the word "operation" leads the NE to the following conclusion concerning its interpretation in the case of Baglihar:

- The Live Storage, the Pondage, is strictly devoted to "operation", i.e. for power generation.
- The Dead Storage, cannot be used for "operation", i.e. for power generation.
- For both Live and Dead Storage, "maintenance" is necessary, which means the use of processes of routing of sediments by sluicing and venting, as well as the removal of deposited sediments by flushing and dredging.

5.5. PROVISIONS OF THE TREATY DEALING WITH SEDIMENTATION

5.5.1. Necessity for an analysis of the provisions of the Treaty in the field of sediment transport

The Treaty was signed in 1960.

The analysis of the evolution of technology concerning reservoir sedimentation presented in Chapter 5.3 concluded that:

> "[i]n 1960 the phenomenon of reservoir sedimentation was not widely recognized to its full degree of significance. Moreover it was only 20 years later, in 1980, that the concept of integrated reservoir sedimentation management began to be clear and coherent. This simple principle was announced succinctly by the engineers of China in 1976 stating: "[s]tore the clear water and discharge the muddy water."[52]

Today, we know that the phenomena of reservoir sedimentation are very critical for Himalayan rivers which have a large sediment load. Moreover, the due taking into account of the issue of sedimentation is in line with the *Preamble* of the Treaty which states that one of the object(s) and purpose(s) of the Treaty is the attainment of *"the most complete and satisfactory utilisation of the waters of the Indus system of rivers (…)"*. These are major elements in the design of the Baglihar power plant.

The engineering determination of the NE on the point of difference (a), which concerns the design of the spillway, should be in conformity with the Treaty. It is also essential to understand which are the provisions of the Treaty relating to sedimentation: what is said and what is not said and which are the potential resources of the Treaty in this respect on which a satisfactory design of the dam can be based in accordance with the rules and methods of interpretation applicable to the Treaty.

5.5.2. Provisions in the Treaty concerning (or not concerning) sediment transport

The NE quotes the relevant provisions of the Treaty which concern sediments explicitly or implicitly (they are written in bold below). He also quotes the provisions in which, in his opinion, issues of sediment can be considered as dealt with under the Treaty.

THE INDUS WATERS TREATY 1960

1. *ARTICLE I. Definitions.* There is no definition concerning any item on sedimentation technology.

2. *ARTICLE II. Provisions Regarding Eastern Rivers. Paragraph (1) and (4)* makes no mention of sediment transport, especially concerning the discharge observation stations.

3. *ARTICLE III. Provisions Regarding Western Rivers. Paragraph (4)* reads as follows: *"India shall not store any water of, or construct any storage works on, the Western*

[52] ZHANG, Hao; et al. *"Regulation of sedimentation in some medium and small size reservoirs on heavily silt-laden streams in China"*. 12th ICOLD Congress. Q47-R32. (pages 1232, 1242, 1243), 1976.

Rivers." There is no mention of sediment transport, for example with respect of the obligation to let the sediments flow and not only to let the waters pass.

4. *ARTICLE IV. Provisions Regarding Eastern and Western Rivers.* No mention is made of sediments. *Paragraph (2)* states *"[i]n executing any scheme of flood protection or flood control each Party will avoid, as far as practicable, any material damage to the other Party (…)",* and *Paragraph (9)* provides *"[e]ach Party declares its intention to operate its storage dams, barrages and irrigation canals in such manner, consistent with the normal operation of its hydraulic system, as to avoid, as far as possible, material damage to the other Party."* No mention is made of the storage of sediment in a reservoir which can modify the morphology of the river downstream and cause potential damage.

5. ***Paragraph (11)*** states *"[t]he Parties agree to adopt, as far as feasible, appropriate measures for the recovery, and restoration to owners, of timber and other property floated or floating down the Rivers, subject to appropriate charges being paid by the owners."* The Treaty speaks of floated or floating transport but not of sediment transports, such as bed load or suspended load.

6. ***ARTICLE VI**. Exchange of Data. Paragraph (1)* makes no mention of the exchange of data concerning the sediments, but ***Paragraph (2)*** provides *"[i]f, in addition to the data specified in Paragraph (1) of this Article, either Party requests the supply of any data relating to hydrology of the Rivers, (…), or to any provision of the Treaty, such data shall be supplied by the other Party to the extent that these are available."* This provision could be used with respect to exchange of any data on sediment transports.

7. *ARTICLE VII. Future Co-operation. Paragraph (2)* states *"[i]f either Party plans to construct any engineering work which would cause interference with the waters of any of the Rivers and which, in its opinion, would affect the other Party materially, it shall notify the other Party (…)."* No mention is made of sediment transport, however, as was stated above in Point 4, the storage of sediments in a reservoir by one Party may affect the other Party downstream.

8. ***ARTICLE XI**. General Provisions. Paragraph (1)* provides *"[i]t is expressly understood that (a) this Treaty governs the rights and obligations of each Party in relation to the others with respect only to the use of the waters of the Rivers and matters incidental thereto; and (…)."* It might be possible to consider that the sediment transport is included in the words *"matters incidental thereto"*.

ANNEXURE C. AGRICULTURAL USE BY INDIA FROM THE WESTERN RIVERS

9. ***Paragraph (3)*** reads *"India may withdraw from the Chenab Main such waters as India may need for Agricultural Use on the following canals limited to (…) Provided that (i) The maximum withdrawals shown above shall be exclusive of any withdrawals which may be made through these canals for purposes of silt extraction on condition that the waters withdrawn for silt extraction are returned to the Chenab."*

ANNEXURE D. GENERATION OF HYDRO-ELECTRIC POWER BY INDIA ON THE WESTERN RIVERS

10. ***Part 1. Definitions. Paragraph 2(a)*** provides *"'Dead Storage' means that portion of the storage which is not used for operational purposes and 'Dead Storage Level' means the*

level corresponding to Dead Storage", and Paragraph (2)f states "'Operating Pool' means the storage capacity between Dead Storage Level and Full Pondage Level".[53] The operational purpose of Baglihar is power generation, and so this purpose is not allowed for the Dead Storage. It is admitted that, over the years, the Dead Storage will store sediments. However, with the objective of ensuring Live Storage sustainability, the provision does not exclude a process of maintenance, *i.e.* a sedimentation control of the Live Storage and of the Dead Storage, having recourse to the various known processes, and in particular, drawdown sluicing and flushing.

11. ***Part 3. New Run-of-River Plants. Paragraph 8(d)*** provides *"[t]here 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."*[54] This is the first of the two provisions of the Treaty dealing explicitly with sediment control. The other one concerns the storage of water by India on the western rivers (*ANNEXURE E*).

12. *Paragraph (14)* states *"[t]he filling of the Dead Storage shall be carried out in accordance with the provisions of Paragraph 18 or 19 of Annexure E"*. This concerns the filling with water; it might be considered that the infilling with sediment is implicit. We point out that reference is made to the provision of *Paragraph 19 of ANNEXURE E* related to *storage of waters by India on the western rivers*.

13. In *Paragraph (15),* detailed provisions are made concerning the volume of water received in the river upstream of the plant, which should be discharged in the river downstream. There is no mention of any obligation to deliver the sediment. The principle summarized succinctly by the Chinese engineers in 1976[55] advocating to "[s]tore the clear water and discharge the muddy water" was not yet considered in 1960.

14. *APPENDIX I TO ANNEXURE D* concerns the hydro-electric plants in operation or under construction, on the "effective date". This provision gives the detailed list of information and documents which should be communicated by India to Pakistan for each of the plants specified. No mention is made of sediments, especially in the Hydraulic Data. However, the characteristics of the outlet works are required.

15. *APPENDIX II TO ANNEXURE D* concerns the new run-of-river plants (such as Baglihar). As for the above APPENDIX I, no mention is made of sediments, especially in *(2) Hydrologic Data, (3) Hydraulic Data* and *(4) Particulars of Design*.[56] However, the characteristics of the outlet works are required under *4(g)*.

16. *APPENDIX III TO ANNEXURE D* concerns the small plants and it is similar to the *APPENDIX II* with regard to remarks concerning sediment.

ANNEXURE E- STORAGE OF WATERS BY INDIA ON THE WESTERN RIVERS

[53] The underlining is by the NE.

[54] The underlining is by the NE.

[55] ZHANG, Hao; et al. *"Regulation of sedimentation in some medium and small size reservoirs on heavily silt-laden streams in China"*. 12th ICOLD Congress. Q47-R32. (pages 1232, 1242, 1243), 1976 and JIANG, Naisen & FU, Linyan, *"Problems of Reservoir Sedimentation and Measures for Reducing Sediment Deposition in China"*. Proceedings of the XIXth Congress of ICOLD, Florence, 1997, Volume III, Question 75 Report 5, pp. 71-84.

[56] The underlining is by the NE.

According to *Paragraph 2(a)(iii)* of *Annexure E*, Baglihar Dam is, in principle, not covered by these provisions, with the exception of Paragraphs 18 and 19, as mentioned above under item 12.

17. In *Paragraph 2,* definitions are given but there is no mention of sediment. *Paragraph 2(c)* provides *"'Dead Storage Capacity' means that portion of the Reservoir capacity which is not used for operational purposes (…)",* and *Paragraph 2(j)* states *"'Dead Storage Level' means the level of water in the reservoir corresponding to Dead Storage Capacity, below which level the reservoir does not operate"*. The same comment as in Point 10 above is made. The operational purpose of Baglihar is power generation, and so this purpose is not allowed for the Dead Storage. It is admitted that, over of the years, the Dead Storage will store sediments. However, with the objective of ensuring Live Storage sustainability, the provision does not exclude a process of maintenance, *i.e.* a sedimentation control of the Live Storage and of the Dead Storage, having recourse to the various known processes, and in particular, drawdown sluicing and flushing.

18. *Paragraph 11(e)* states *"[o]utlets or other works of sufficient capacity shall be provided to deliver into the river downstream the flow of the river received upstream of the Storage Work, except during freshets or floods",* and ***Paragraph 11(f)*** provides *"[a]ny outlets below the Dead Storage Level, necessary for sediment control or any other technical purpose shall be of the minimum size, and located at the highest level, consistent with sound and economical design and with satisfactory operation of the Storage Works."*[57] This is the second provision of the Treaty speaking explicitly of sediment control.

19. ***Paragraph 19*** states *"[t]he Dead Storage shall not be depleted except in an unforeseen emergency. If so depleted, it will be refilled in accordance with the conditions of its initial filling."* This provision which allows for depletion of the Dead Storage in the case of an emergency is realistic if we consider, for example, that the dam is in an unsafe situation.

20. ***Paragraph 23*** provides *"[w]hen the Live Storage Capacity of a Storage Work is reduced by sedimentation, India may, in accordance with the provisions of this Annexure, construct new Storage Works or modify existing Storage Works so as to make up the storage capacity lost by sedimentation."*[58] This provision does not preclude the possibility to modify the maintenance process of the existing Storage Works.

21. ***APPENDIX TO ANNEXURE E.*** This provision gives the detailed list of information and documents which should be communicated by India to Pakistan. In this case *"Sediment data"* is included in the list under the item *"Hydrologic Data"*.

[57] The underlining is by the NE.

[58] The underlining is by the NE.

5.5.3. **STATEMENT S 5** relating to the level of the spillway [point (a) of the difference referred by Pakistan]

It appears that the Treaty is not particularly well developed with regard to its provisions on sediment transport. This is not a criticism: the Treaty reflects the status of technology on reservoir sedimentation in the 1950s. The consequence is that the provisions of the Treaty which explicitly mention sediment acquire a special significance, especially those mentioned in Points 11, 18 and 20.

In developing his determination, the NE takes into account the current level of scientific and technical knowledge within the framework of the Treaty. He gives full weight to the rights and obligations provided by the Treaty, and in particular he invokes the provision mentioned in Point 11 which provides: *"[t]here 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 definition of the Dead Storage given in Points 10 and 17 states that it cannot be used for operational purposes, *i.e.* for power generation. This is precisely the purpose of the Live storage. However, the capacity of the Live Storage should be protected against sedimentation. This is an essential matter of sustainability. To meet this objective, maintenance of the Dead Storage should be carried out – this is not excluded by the Treaty – in accordance with the various known processes of sedimentation control, and in particular, drawdown sluicing and flushing.

5.6. MODELLING OF RESERVOIR SEDIMENTATION

5.6.1. Sedimentation problems in the design of the Baglihar dam

Baglihar is a run-of-river plant with a dam of 134 m high above the river bed (the head is created by the dam itself); the volume of the reservoir is 400 $M.m^3$. The Chenab river is subjected to significant sediment transport and it is foreseen by the designer that the reservoir will ultimately be filled with sediment except for a remaining live storage volume of 37.5 $M.m^3$ (according to the Indian design).

Measures should be taken to preserve the live storage from sedimentation, to protect the power intakes from the deposition of bed load sediments, to prevent suspended load sediments from entering in the power tunnel, which would cause erosion of the turbines and to protect the town of Pul Doda, located upstream of the reservoir, from flooding.

In Chapter 5.4.1 the NE pointed out the importance of the problem of reservoir sedimentation in the difference between the Parties concerning the design of the spillway (gated or ungated, as well as size and level of the gates). To justify their point of view, and to answer to the questions of the NE concerning sedimentation management of this reservoir, the Parties developed , between October 2005 and March 2006, important simulations on numerical and physical models. It appears necessary to the NE to comment on these tests. For this task, he took the advice of Professor Dr Anton Schleiss Director of the Laboratory of Hydraulic Constructions at the Ecole Polytechnique Fédérale de Lausanne and of his assistant Dr Giovanni de Cesare.

The evaluation focuses on the three major topics:

a) Filling of the entire reservoir over the years in order to estimate the lifespan of the dead storage, starting from the pre-construction topography and taking into account measured time series of water and sediment inflow.

b) Flow conditions in the near field of the dam, spillways and water intake, mainly performed in purely hydraulic conditions, without sediment transport (bed load and suspension). The geometry adopted assumes the reservoir to be filled-up with sediments up to reaching the sill of the lower level spillway, with a sluicing cone or an average constant upstream slope.

c) Suspended sediment concentration at the power intake, with the reservoir assumed to be full of sediments with a fixed geometry.

5.6.2. Some characteristics of the dam of Baglihar

Summarized below are some characteristic levels of Baglihar dam and reservoir volumes; a vertical cross section of the dam in front of the power intakes is given in Annex 5.6.1.

- Top level of the dam 844.5 m asl
- Full Pondage Level (FPL) 840.0 m asl
- Valley width at FPL 320 m
- Sill level of the gates of the auxiliary spillway 837.0 m asl

- Dead Storage Level (DSL) 835.0 m asl
- Sill level of the gates of the chute spillway 821.0 m asl
- Sill level of the power intake 818.0 m asl
- Sill level of the gates of the sluice spillway 808.0 m asl
- Deepest river bed level 710.0 m asl
- River width 60 m
- Total spillway capacity 16,500 m^3/s
  - 5 orifice spillways 11,200 m^3/s
  - 3 surface spillways and one auxiliary spillway 5,300 m^3/s
- Design discharge of the power plant 430 m^3/s
- Mean annual river inflow 25,000 $M.m^3$
- Mean annual sediment yield 30 $M.m^3$
- Total volume of the reservoir 400 $M.m^3$
- Volume of the live storage, pondage 37.5 $M.m^3$

5.6.3. Numerical analysis of the sedimentation done by India[59]

a) Filling of the entire reservoir

The numerical 1D model used for this case was DHI Mike 11 with the sediment transport module. This is widely used and has been proven for a long time.

Normally this is a numerical flow model for river networks, but by adding special modules taking into account sediment transport with a mobile bed and suspension, the numerical code can be applied for reservoir sedimentation analysis.

As for the boundary conditions downstream, a point is fixed at the sill of the sluice spillway (el. 808 m asl). Upstream, at the entrance of the reservoir, it seems that the bed level is fixed over time at el. 840 m asl, resembling an equilibrium bottom level at a point fixed around 30 km upstream of the dam.[60] The inflow discharge is the series of observed records for the period 1963-2001, extended to 100 years by repeating the historical sequence.

The water level at the dam axis is maintained constant at el. 835 m asl during monsoon time; a process of sluicing without drawdown is applied, and the water head is 27 m (835-808). During the non-monsoon time the water level varies between els. 835 and 840 m asl.

Sediment transport calculations, in the GTS (graded sediment transport model) considered five grain sizes (0.063 to 1.18 mm) and, in the ST (uniform model) only one single grain size

[59] Rejoinder of India, Volumes I and II, March 2006.

[60] Rejoinder of India, Volume II, Report of M/s DHI, Denmark. On Figure 4.1, page 14, this point is at a distance of about 32 km from the dam, and of about 26 km on Figure 4.5.

(0.22 mm) was considered.[61] The calculations are performed according to the Engelund & Fredsoe formula, taking into account total sediment transport, mean bed load and suspended load. The formula seems to be applicable in this particular case (but the possible grain size and slope range are not indicated).

In order to take into account the more rapid approach flow to the sluice gates and its effect on sediment transport, increased bottom shear stress has been introduced in the near field of the 1D model; the shear stress has been multiplied by a factor varying between 2.23 at the sluice spillway to 1 at approximately 300 m upstream, reproducing the sluicing effect. This variation results from the calculations of the shear stresses using the 3D analysis by the DHI NS3 model with respect to the flow conditions in the near field; this question is covered in the next paragraph.

The results of the two models are quite different.

The GTS model forecasts a quite rapid filling within approximately 12 years. This appears rather unlikely as there would not be such a great sediment yield within that time span. The source of this inaccuracy is difficult to identify, the geometry (length of the reservoir is 26 or 32 km) cannot be the main cause, because with the same numerical model utilizing instead a single grain size approach, a much longer filling time has been predicted.

Results from the single grain size ST model show a 30 year filling time, which seems more reasonable.

b) Flow conditions in the near field

The numerical model used is the DHI in-house NS3-3D, which is able to perform a 3D analysis, on a hydraulic model which does not take into account the sediment transport. It has a fixed geometry for the reservoir when it has been filled with sediment. The longitudinal section of this 3D model is represented in Annex 5.6.2. The fixed bed is derived from the sediment calculation done with the 1D model, which itself has been corrected with the variations of the shear stresses calculated using this 3D model with its fixed bed. It is interesting to note that usually the scour cone of sediments which appears near the sluice gates is of relatively small size, about some 10 m; here it has a length at its base of 400 m at el. 813 m asl. The reason for this surprising result should be researched, probably in the looped calculation between the 1D and 3D models.

On 26 October 2006, India presented a new simulation[62] with a 2D sophisticated model (without any looped impact resulting from the 1D-3D coupling) which demonstrates that sluicing without drawdown can maintain a channel towards the spillway at about el. 812 m asl, with a length of 150 m. A critique of this analysis was done by Pakistan, which included some good arguments.[63] This exercise was an admirable effort on the part of the Indian Party and especially its expert, the Danish Hydraulic Institute (DHI), to support its thesis concerning the appearance of a large scour effect. It is also commendable for Pakistan to have developed a detailed critique. The opinion of the NE is that too much evidence results from the experience concerning the relative inefficiency of the sluicing

[61] In the opinion of the NE, for long term calculations, a split into two grai ns sizes, one representative for bed load (for example 2 mm) and one for suspended sediment (for example 0.2 mm) is normally appropriate.

[62] Government of India. Written comments on the Final Draft Expert Determination. 26 October 2006.

[63] Government of Pakistan. Comments of Government of Pakistan on 2D computer simulation presented by India, 24 November 2006.

process without drawdown, to give credit to this latest analysis of India[64]. Numerical simulation is a very powerful tool, but it can only be truly valuable when it is ultimately controlled by sound engineering judgement.

c) Sediment concentration at the power intake

The sediment concentration at the intake level has been assessed using four approaches:

- Physical model studies at Irrigation Research Institute (IRI), Roorkee
- Three-dimensional numerical modelling using SSIIM, considering turbulence and sedimentation in the Baglihar reservoir using the geometry near the intake from the profiles issued from 1D DHI's MIKE 11 calculations.
- 1D and 3D mathematical models of DHI. Analysis using NS3 software giving details of flow and implications on sediment transport in the vicinity of the sluice gates and the intake.
- Considering the reservoir in front of the intake to be functioning as a sediment trap using Camp's formulation to compute the trap efficiency.

All four methods indicate a comparable trend as regards the velocity and sediment concentration field in front of the intake.

These calculations are correct, but it appears to the NE that the hypothesis of a geometry of the model which largely clears the water intakes from bed load sediments at a distance of 300 m from the dam, does not correspond to the physical reality.

5.6.4. Numerical analysis of the sedimentation done by Pakistan[65]

Pakistan proposed a new design for the water intakes which, in its view, avoids the sedimentation risk and, in addition, respects the Treaty. Its characteristics are given below and presented in Annex 5.6.3. The name given to this structure is Sediment Exclusion Trough (SET). The characteristics are as follows:

• Top level of the dam	844.5 m asl
• Full Pondage Level (FPL)	840.0 m asl
• Valley width at FPL	320 m
• Dead Storage Level (DSL)	835.0 m asl
• Sill level of the sediment exclusion wall	826.5 m asl
• Sill level of the sediment dividing wall	825.5 m asl
• Sill of the sill of the chute spillway gates (7 gates)	825.7 m asl
• Sill level of the power intakes	822.0 m asl

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[64] In particular the angle of repose of about 10° of the non-cohesive sediment calculated for the scour cone is abnormally low; a realistic value would be in the order of 30°. Reference: "Propriétés des alluvions récentes dans les retenues alpines". Eau, Energie, Air. Heft 9/10. 1999.

[65] Reply of Pakistan, Volumes I and II, January 2006; see also Pakistan's presentation, 26 May 2006, London.

- Sill level of the sediment sluice gates (2 gates) 808.0 m asl
- Capacity of the 2 sediment sluice gates 1,300 m^3/s

a) Filling of the entire reservoir

The numerical 1D model used is HEC6–KC–1D. This is an integrated 1D numerical flow and sediment transport model with a mobile bed developed specially by the USACE for scour and deposition in rivers and reservoirs. This model has been widely proven.

The upstream bed level condition is not mentioned, but according to the results it seems to be variable over time. This is the origin of the increase in the bed level at the reservoir entrance. Assuming that the sill of the chute spillway gates (el. 825.7 m asl) is the pivotal point of the new equilibrium bed level around which the bed slope can rotate in the upstream direction, this assumption is correct. But in order to assess the new bed level after complete in-filling of the reservoir, the calculations have to be extended a long way upstream, to the point where another fixed bed level (or equilibrium bottom level) could be expected.

The water level at the dam axis is kept constant all time at el. 840 m asl. A process of sluicing without drawdown is applied, with a water head of 14.3 m (840-825.7). The water head is smaller than in the Indian design, because the spillway sill level is located at a higher elevation in the Pakistani design.

Twelve grains size classes were considered in the sediment transport calculation according to the Ackers & White formula (total sediment transport, meaning bed load and suspended load) which seems to be applicable (regarding limits in grain size and bottom, as well as energy slope) in this particular case.

The results confirm the gradual filling of the reservoir over approximately 30 years with the advancing delta of the Chenab River.

It should be noted that an ambiguity appears in the data of this numerical analysis concerning the gate sill level. In Pakistan's Reply[66], page 1 of Annex I-A, the gates sill level is indicated at el. 808 m asl, same as in the Indian design. But in Figure A-14, page 20, the river bed level at the dam axis, after 60 years, is at about 825 m asl, which would be the case for a gate sill level at 825.7 m asl of the chute spillway proposed by Pakistan. The conclusion would be that the reservoir sedimentation calculated by Pakistan concerns the dam based on its own design rather than the Indian one.

An important result of this calculation is that, after 60 years of sedimentation, the river bed level at the entrance to the reservoir will be at el. 858 m asl and that, with a 100 year return period flood, the town of Pul Doda would be inundated.

b) Flow conditions in the near field

The objective of the SET is to exclude sediment in front of the power intake and evacuate it downstream of the reservoir.

The numerical model SMS-RMA2 2D is used to demonstrate that this function is achieved.

[66] Government of Pakistan. Reply to the Counter-Memorial by Government of India. Part I. ANNEX I-A. Sedimentation of reservoir using HEC-6 KC model. 25 January 2006.

Calculations have been carried out using only hydraulic conditions without considering sediment transport. A fixed bed level geometry for the reservoir already filled, with a fixed bottom slope of 2% starting at the dam, has been used. The model is depth averaged (a mean value of the horizontal velocity is considered and no vertical velocity). Potential bed load movement is assessed based on the evaluations of the stream power from these hydrodynamic calculations. SMS-RMA2 2D is a widely proven numerical model, widely available and well tested.

The results confirm the attraction effect of the SET in front of the power intake for bed load, but as the calculation is depth averaged, some uncertainty remains.

c) Sediment concentration at the power intake

The sediment concentration at the power intake was evaluated using numerical and physical modelling.

The flow conditions in the near, intermediate and distant field zones have been used in the calculations.

The near and intermediate fields have been determined by physical hydraulic modelling. This modelling, at a scale of 1:50, was performed at Colorado State University to investigate near field performance of the gated crest, the spillway and the SET, with a focus on in its ability to evacuate sediment from the zone in front of the power intakes, and to ensure good flow conditions at the power intake, with no disturbance caused by the sediment movement.

The results of tests for the sediment evacuation through the SET confirm that 100% of the sediment is trapped. The tests for sediment entrainment by the SET, in all cases tested when sediment movement from the delta towards the power intake was observed, showed that the sediment was trapped in the SET and did not enter the power intakes. The efficiency of the system for sediment evacuation through the sediment ejector sluice seems to be proven.

But an important problem remains: after the complete filling of the dead storage, the reservoir bed in front of the power intakes will stay at a level higher than the sill of the chute spillway, fixed at el. 825.7 m asl and also higher than the crest of the sediment dividing wall, 825.5 m asl. Suspended load will enter the power intakes in a rather high concentration.

A two-dimensional numerical model developed with the SMS-RMA2 was used for the intermediate field. Two bed levels were considered in front of the water intakes one at mid-height of the sediment dividing wall, 818 m asl, and the other at its crest, 825.5 m asl. This model is very effective for visualizing the potential for sediment transport, especially with respect to the approach to the SET and spillways. The analyses show that sediment can only be transported during large floods. The numerical model confirms the potential evacuation of sediment observed in the physical model. The discharge through the spillway gates can still transport sediment through the reservoir so that there will be no accumulation of bed load sediments above the elevation of the SET which could affect the operation of the power intake.

However, this statement seems to be unrealistic, as a new bed level, once the reservoir has been completely filled with sediment, will develop starting at the sill of the chute spillway (825.7 m asl). A limited scour cone will appear, which normally extends horizontally some one to two times the water height above the sill (depending on the lowering of the water level during the release of floods and on the equilibrium slope of the deposits below the water level). Therefore, the bed level may be raised in front of the SET above its sill level; a sluice cone will be formed and bed load sediment will be entrained into the power intake.

5.6.5. Calculations of the reservoir in-filling done by the NE

The NE has performed a simplified estimation using a purely volumetric approach of the reservoir filling with three different sediment trap efficiency curves by Brown,[67] Churchill[68] and Brune.[69] The available data on water and sediment inflow are given in the documents provided by India. The considered time series starts from the first year (1976), for which both data sets (water and sediment) are available.

Figure 5.6.1 shows the evolution over time of the loss of dead storage capacity and Figure 5.6.2 indicates the reduction of the sediment trap efficiency as the reservoir dead storage fills up.

The infilling time lies between 20 and 30 years. It can be seen that Brown and Churchill relationships give similar results (this statement can also be found in literature).

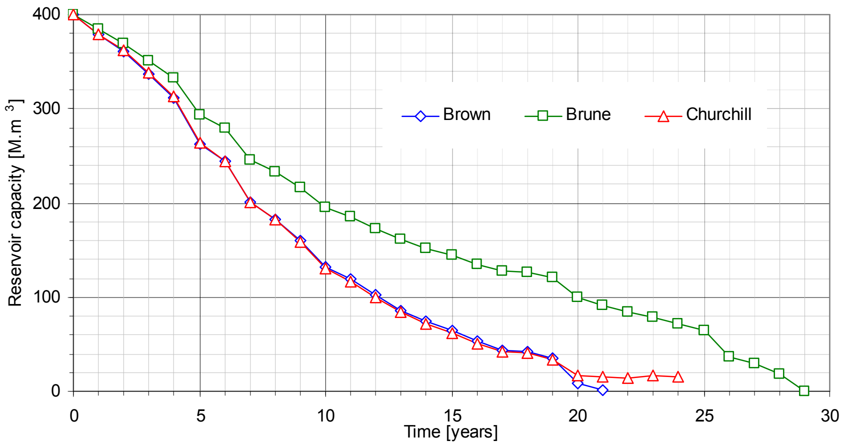

Figure 5.6.1: Sedimentation of the Baglihar reservoir

[67] BROWN, C. B. (1943) Discussion of Sedimentation in Reservoirs, by J. Witzig. Proceedings of the America n Society of Civil Engineers 69, pp. 1493-1500.

[68] CHURCHILL, M. A. (1948) Discussion of Analyses and Use of Reservoir Sedimentation Data by L.C. Gottschalk. In Proc. of the Federal Inter-Agency Sedimentation Conference, Denver, Colorado: US Geological Survey, pp. 139-140.

[69] BRUNE, G. M. (1953) Trap Efficiency of Reservoirs. Transactions of the American Geophysical Union 34, pp. 407-418.

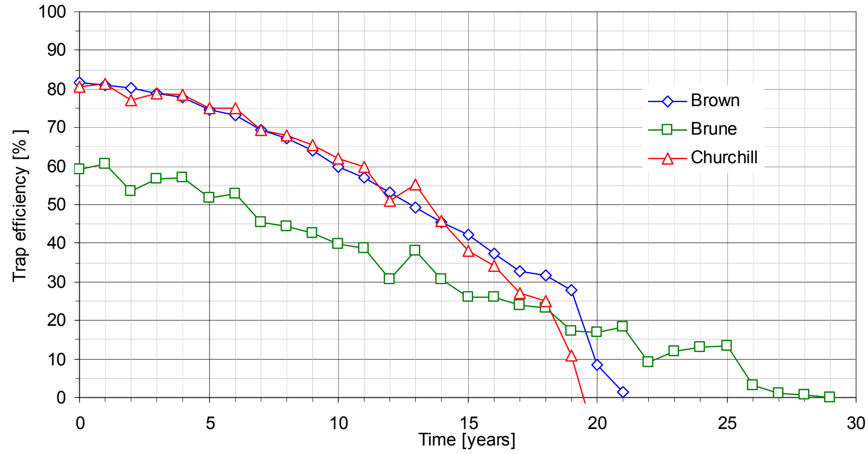

Figure 5.6.2: Sediment trap efficiency of the Baglihar reservoir

By comparison, the results given by the Parties (neglecting the questionable value of 12 years resulting from one calculation done by DHI), based on more developed methods, are some 1 to 9 years longer. We note that the trap efficiency in their calculations remains high at some 70 to 80% over a rather long time, some 30 years, and drops to zero within a few years. This rapid drop seems to be more realistic, as it indicates that the sediment deposits have reached the sill of the lowest level outlet gates; from that moment on, bed load can pass.

5.6.6. Evaluation by the NE of the modelling process of reservoir sedimentation

<u>a) Filling of the entire reservoir</u>

The analysis was done by the Parties admitting that a process of sluicing without drawdown, during the monsoon season, was applied.

Globally, the Parties predict a new stable reservoir bottom after some 30 years (if we neglect the questionable value of 12 years). The differences which appear in the progression of the front of the sediment deposit result from the downstream conditions (outflow, sill level), the grain size distribution and break-up in size classes, and the upstream bottom level conditions.

The NE considers, without trying to obtain illusory accuracy, that filling of the entire reservoir would take about 20 to 30 years.

But it is important to note that the reservoir still has the risk of possible exceptional sediment transport in the Chenab river resulting from major sliding along its course.

The risk of having the town of Pul Doda, upstream of the reservoir, inundated in the event of high flood cannot be excluded.

<u>b) Flow conditions in the near field</u>

The calculations done purely by hydraulic modelling necessitate the definition of a fixed geometry of the river bed in the near field of the spillway and of the power intakes. India has taken a sluiced zone of about 400 m upstream from the dam at el. 813 m asl, and Pakistan has admitted a bed slope of 2% upstream from the sill of the chute spillway, el. 825.7 m asl.

The numerical analysis is correct, but, evidently, depends directly on these hypotheses, and the point of view of the NE is that they are questionable, especially with respect to the Indian calculation.

c) Sediment concentration at the power intakes

Regarding the sediments trapped by the power intakes, both Parties assert that their design is appropriate to solve the sedimentation problem of the power intakes once the reservoir is full.

But, the position of the final bed level in front of the power intake after complete filling is mainly influenced by the extension of the scour cone created by the sluice spillway (for India: sill el. 808 m asl), and by the chute spillway (for Pakistan: sill el. 825.7 m asl). The results of the calculations depend directly on these hypotheses as it is the case for the analysis of the flow conditions in the near field.

The NE wishes to make two remarks on this matter:

- Observations made on the behaviour of reservoirs subject to potential large-scale sedimentation show that if sediment control, through technical measures in the design of the dam and its appurtenant works, as well as reservoir maintenance during the life of the dam, are not performed to avoid or to limit sedimentation, then at the last stage, when the deposits have already reached the dam, the river will have created a wide alluvial deposit (with a width of about 300 m near the dam in our case) and will flow along this plain developing its own morphology.[70,71] The approaches of 1D numerical modelling used today are not able to simulate this phenomenon.
- The existence of coarse aggregates and boulders are implicitly included in the calculations of bed load sediment transport; but this should be considered, as a major element, in the design of the work. The information given by India on the Salal dam[72] are conclusive on the difficulties which could result from an inadequate design.

Pakistan proposed, in a positive spirit as a contribution to the technical solution of the problem, the interesting solution of the SET (Sediment Exclusion Trough), which takes into account in its design some essential principles. Unfortunately, there is a great risk that the SET could be clogged by coarse sediments and floating debris.

[70] As an example, the Forni pre-storage basin Italy is at present almost full. The reservoir has never been flushed (this being prohibited by law). The river flows along the left bank of the reservoir, crosses the remaining very small pondage along the dam to flow into the water intake on the right bank. At each flood event, the river finds a new bed in its alluvial deposits.

de Cesare, G. *Sustainable management of Alpine reservoirs* - A transeuropean cooperation project. Proceedings of Hydro 2005 "Policy into Practice". October 2005, Villach, Austria .

[71] COIADO, E. M., and CAMPOS, R. (2000). Bottom-Sluice-Gate Influence on the Trap Efficiency of a Small Reservoir, Proceedings of 4th International Conference on Hydroscience and Engineering, on CD -ROM, ICHE-2000, Seoul, Korea.

[72] Note provided by India, *Salient features of Salal Dam and Comments on Prof. Rooseboom's Report,* 24 November 2006.

Moreover, as was said in the Reply of Pakistan[73], the live storage, *i.e* the pondage, will not be protected from sedimentation and also at the entrance to the reservoir, the level of the river bed level will rise, causing flooding of land upstream and of Pul Doda. The argument of Pakistan that the Indian design of sluice spillway used for sluicing without drawdown, has the same disadvantage, is not an argument for the acceptability of the Pakistan design.

5.6.7. STATEMENT S 6 relating to the level of the spillway [point (a) of the difference referred by Pakistan]

The simulations with numerical models, at the forefront of technology, presented by the Parties concerning reservoir sedimentation (infilling of the reservoir, flow conditions in the near field of the dam, suspended sediment concentration at the power intakes), are extremely interesting. These calculations are correct; their objective to justify the design of the works is achieved. However some hypotheses are questionable, such as the geometry of the models admitted in the near field of the dam.

But everybody recognizes the necessity to take into consideration lessons of the past, in particular the last decades, from the design, construction and operation of dams and hydropower plants on rivers with important sediment transport. We refer to, among other cases, Sanmenxia in China commissioned in 1960, Warsak in Pakistan, 1960, and Salal in India, 1987.

The design of Baglihar is not easy because of the large sediment load of the Chenab river, in addition to the requirement to respect the Treaty. The NE considers that it is essential, before doing any elaborate calculations, to determine a safe design[74] for the spillway, bottom outlet and power intakes, founded on clear and acknowledged principles and with a range of safety resulting from the uncertainties in this field of reservoir sedimentation, where the experience is not totally accomplished.

[73] Government of Pakistan. Reply to the Counter Memorial. Part II. 25 January 2006. Paragraph 1.4.2.1 Loss of Pondage, page 10, and Part I ANNEX I-A. Sedimentation of reservoir using HEC-6 KC model. Paragraph 1.8.4. Upstream flooding potential, pages 20, 21 and 22.

[74] In Annex 5.6.5 is given a short abstract from the novel of Mr Fernand Pouillon, architect, *"Les Pierres Sauvages"*, 1964, relating the design and construction of the Cistercian Abbaye of Thoronet, in Provence (France) in 1160 of our era. The NE considers this text as essential for the professions of civil engineers and architects.

5.7. MAXIMUM FLOOD DISCHARGE

5.7.1. Point of difference

1. The point of difference (a) concerning the maximum flood discharge presented by Pakistan[75] is underlined by the NE in the following statement:

   "Pakistan is of the considered view that the design of the Baglihar Plant on Chenab Main does not conform to criteria (e) and (a) specified in Paragraph 8 of Annexure D to The Indus Waters Treaty 1960 and that the Plant design is not based on correct, rational and realistic estimates of maximum flood discharge at the site."

   The Indian side does not agree with Pakistan's position.

2. According to the Indian Standard, the spillway capacity is based on an inflow design flood, which is, by definition, the Probable Maximum Flood (PMF). The experience in India shows that the PMF is not very different from the 10,000 year return period flood.[76] Therefore, the approach adopted by India for Baglihar was to calculate the design flood using two methods:[77]

   - The probabilistic method based on a series of annual peak discharges measured at the Dhamkund station (catchment area (CA): 18,750 km^2) on the Chenab river, several km downstream of Baglihar (CA: 17,325 km^2). The series of discharges included 28 years of measurements (1962 to 1987).
   - The deterministic method based on a determination of the probable maximum precipitation (PMP) which is then converted to calculate the PMF.

   The result of the Indian calculations is a value for the design flood of 16,500 m^3/s.

3. Pakistan used its own statistical approach with a longer annual peak series of 80 years that it obtained by correlation of the discharge measured at the Marala barrage.

   The result of Pakistan calculation is 14,900 m^3/s.

5.7.2. Accuracy of the calculations of maximum flood discharges

1. It can be observed that the values for the peak discharge presented by India have some variations. The value of 16,500 m^3/s was given in the information communicated to Pakistan prior to the construction, and in the Counter-Memorial[78]. In the Rejoinder, India

[75] Meeting No. 1 in Paris, 9-10 June 2005, and Government of Pakistan's Memorial, page 12.

[76] This is not surprising because as in other countries the PMF results from the Probable Maximum Precipitation, which is the combination of two events: the maximum wind with a probability of 1/100 and maximum rainfall also with a probability of 1/100.

[77] India's Counter-Memorial, Paragraph 1.21 page 57, and Planning and Model Test Documents. Volume 5(i). Hydrology.

[78] India's Counter-Memorial, Paragraph 1.3, page 34.

states: "[t]he PMF peak of 16,200 m^3/s estimated",[79] and in the responses to questions posed by the NE during Meeting No. 3, the value of 16,195 m^3/s was used in the calculations.[80] A hydrograph was also given and is used in Chapter 5.8.5. In this Chapter, the value of 16,500 m^3/s will be considered.

2. The difference between the values calculated by Pakistan and India is small, about 10%. It can therefore be said that the design floods calculated by both Parties have the same order of magnitude. But, it is clear that the absolute value of this difference (1,600 m^3/s) is not negligible; this represents approximately the discharge through a gate.

3. The accuracy of the statistical analysis should be appreciated, bearing in mind the following:
   - The accuracy of the value of the measured discharges,[81]
   - The transposition of the discharge from Dhamkund to the Baglihar site,
   - The accuracy of the result of a correlation between the discharges of two hydrometric stations to increase a series (for example the correlation between the discharges measured at Marala and Dhamkund),
   - The possible inadequacy of the probability model used, and
   - The extrapolation over 10,000 years based on a series of three decades.

4. The accuracy of the deterministic method PMP-PMF considers all the necessary steps to calculate the PMP first (analysis of storm rainfall data, storm transposition, storm rainfall maximization), then it considers the snowmelt contributions, and finally requires the conversion of the PMP to the PMF (estimation of runoff volumes; infiltration; evaporation; time distribution of runoff).

   This method was developed in USA at the beginning of the 20th Century. Important observations have been made from about the approximate 1000 storm events measured in 1950. The method is applied today in many countries of the world, sometimes without good knowledge of the origin of the practical experience.

   We can recall[82] also that in the literature before about 1950, the term 'maximum possible precipitation' (MPP) was used. This was changed to probable maximum precipitation (PMP) to reflect the uncertainties involved in estimating maximum precipitation potential.

5.7.3. Method of calculation of exceptional floods

To determine exceptional floods, no methods should be discounted without further analysis. As far as possible, all available data should be used including historical reports, empirical formulae, envelopes, probabilistic analysis based on discharges and rainfall data, and deterministic approaches.

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[79] India's Rejoinder, Paragraph 3.6, page 66.

[80] Answers to questions posed by the NE during Meeting No. 3, 19 June 2006, Paragraph 3.0, Page 34.

[81] For example, as an assessment element the staged discharge curve is established by the velocity method, which necessitates the choice of a reduction coefficient of 0.8 to convert the measured surface velocity to mean velocity. What is the accuracy of this coefficient?

[82] Safety of dams. Flood and Earthquake Criteria. National Academy Press. Washington DC, USA, 1985.

It is also essential to study the river and its basin (morphology, geology and vegetation cover). As direct observation is essential, the hydrologist should thus also be something of a naturalist.

5.7.4. **STATEMENT S 7** relating to the maximum design flood [point (a) of the difference referred by Pakistan]

India has correctly applied the statistical approach (unfortunately the series of peak annual discharges is short) as well as the deterministic approach.

Probably, for such a large catchment area, India has developed all possible methods of analysis; the NE thinks especially of both the climatological and the geomorphological analyses.

The value calculated by Pakistan is one value among the others, which is not unreasonable.

Finally, the choice of the design flood should be based on an analysis of all the results obtained, and supplemented by a strong engineering judgement.

5.8. ARTIFICIAL RAISING OF THE WATER LEVEL

5.8.1. Possibility of artificial raising

Paragraph 8 (a) of Annexure D of the Treaty reads as follows:

> *"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."*

Figure 5.8.1 shows the height above the full pondage level available for a possible artificial raising of the water level for both a gated and an ungated spillway.

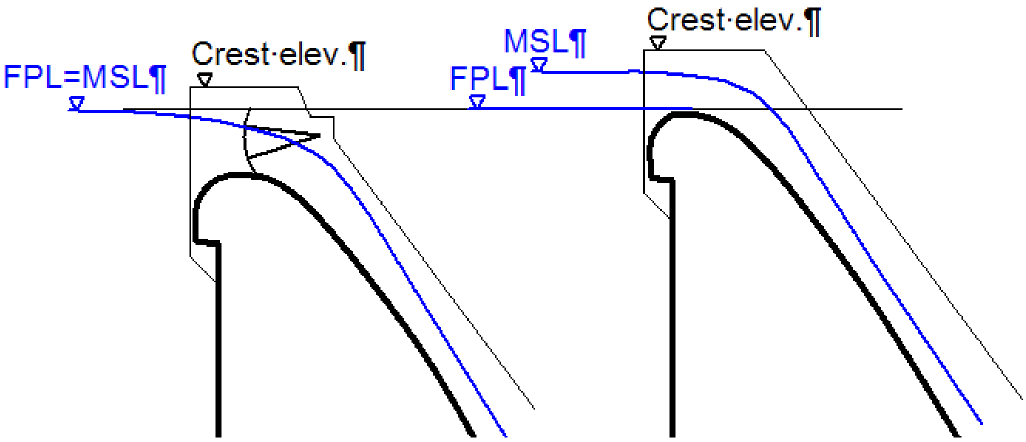

Figure 5.8.1: Gated and ungated spillways - definition of levels:
FPL: Full Pondage Level, MSL: Maximum Storage Level

For a surface gated spillway, the artificial raising of the level is possible by increasing the height of the gates; however, this is not technically easy unless measures for this purpose were allowed for in the initial design.

In the case of ungated surface spillways, the artificial raising of the full pondage level is easier. It is a generally accepted way of improving the performance of an existing dam. This is achieved by placing gates on the crest (possibly fusegates) so as not to affect the spilling capacity of the spillway.

A way to limit the technical possibility of raising the Full Pondage Level is to limit the freeboard to the minimum required.

In the case of Baglihar dam, utilizing a gated spillway, the Full Pondage Level is at el. 840, and the total freeboard above Full Pondage Level is 4.5 m.

Pakistan considers that this value is exaggerated and that the dam crest elevation could be lowered.

5.8.2. Definition of the freeboard

A definition of freeboard is given by ICOLD guidelines as follows[83]:

> "Freeboard is the vertical difference in elevation provided between maximum reservoir level during a routing of the design flood and the dam crest.
> In principle, its purpose is to provide protection against waves and seiches. It is usually calculated for a strong wind down the centreline of the reservoir, and may represent considerable surcharge reservoir capacity."[84]

Thus the elevation of the dam crest is determined by:

- The full pondage level;
- The raising of the reservoir level required to allow for the release of the extreme floods. The outflow discharge depends on the extreme flood hydrograph, the arrangement of spillway weirs and outlets, the operating rules of the spillways and the geometrical characteristics of the reservoir; and
- Safety criteria, which depend on the dam type (concrete, masonry or embankment), the spillway type (gated or ungated), and local conditions, such as wind conditions.

5.8.3. Criteria adopted by India

India has applied the Indian Standard IS 11223-1985.[85]

A summary of this Standard relating to the design conditions for verification of flood routing is given below:

a) Design Condition I:

- Inflow is the design flood for safety, which is the Probable Maximum Flood (PMF) for dams classified as large;
- The initial level in the reservoir corresponds to the top of the gates;
- One gated spillway, the one with the greater capacity, is inoperative; and,
- A reduced freeboard may be acceptable according to Paragraph 4.1.1 of IS 11223-1985.

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[83] ICOLD Bulletin No 82, Selection of Design Flood, 1992, page 169.

[84] A good definition is also given in the Federal Guidelines for Dam Safety, Selecting and A ccommodating Inflow Design Floods for Dams, US Department of Homeland Security, October 1998. Reprinted April 2004 stating:

> "Freeboard provides a margin of safety against overtopping failure of dams. It is generally not necessary to prevent splashing or occasional overtopping of a dam by waves under extreme conditions. However, the number and duration of such occurrences should not threaten the structural integrity of the dam, interfere with project operation, or create hazards to personnel."

[85] Indian standard IS 11223-1985 - Standard Guidelines for fixing Spillway Capacity – Bureau of Indian Standards, 2005, provided as an appendix to the Counter-Memorial of the Government of India.

b) Design Condition II:

- Inflow is the design flood for safety, which is the PMF for dams classified as large size;
- Initial level in the reservoir corresponds to the top of the gates;
- All gated spillways are operative; and,
- The minimum remaining freeboard, defined as the vertical distance between the top of the dam and still water level, is defined in Paragraph 5.8.3 of Indian Standard IS 6512-1984[86]: wind set-up plus 1½ times wave height.

The design flood is the PMF in both conditions; the difference lies in the coincidence of this either with a failure of a gate operation or with high wind conditions.

Indian Standard IS 11223-1985, Paragraph 4.1.1, specifies that a minimum of 1 m height above maximum water level to the top of the dam should be provided in the case of masonry dams.

Indian Standard IS 6512-1984, Paragraph 5.8.3, states that, notwithstanding the above requirement [for minimum freeboard], a 1.0 m high solid parapet shall be provided on the upstream side above the top of the dam in all cases.

The NE wishes to make two observations on these criteria:

- Baglihar is not a masonry dam, but a concrete one; and
- It is general practice in the case of concrete dams to consider that the dam crest parapet is a structural element which is able to support the water pressure without releasing a significant discharge. Some water may be released through the parapet joints or by dam crest drainage apertures.

India applies a national standard for designing its dam, and this does not necessarily mean that the project is compatible with the Treaty. No mention is made in the Treaty of any standard, be it national or international, apart from the fact that the design should be sound and economical. This leads the NE to consider that if a difference arises between the Parties on a point of design which is based, as often happens, on a standard, it is not necessarily the Indian Standard which should be applied, however valuable it may be, but commonly accepted world practice: the state of the art. The easiest solution is to make reference to the ICOLD guidelines, which is done in the following paragraph.

5.8.4. Criteria proposed by the NE

This proposal is largely based on ICOLD guidelines.[87]

The present trend is to make a distinction between dam safety and the discharge capacity of the structure. This approach leads to two design floods and their corresponding spillway discharge capacities.

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[86] Indian standard IS 6512-1984 – Criteria for the design of solid gravity dams (first revision) – provided as an appendix to the Counter-Memorial of the Government of India.

[87] ICOLD Bulletin 82, Selection of Design Flood, 1992, and ICOLD Bulletin 58, Spillways for Dams, 1987.

a) Criterion for the "design flood"

- Inflow design flood corresponds to a stochastically determined flood, 10,000 years (Indian hydrological analyses have found that the 10,000-year return period flood is equivalent to the PMF flood).
- Initial level in the reservoir corresponds to the Full Pondage Level.
- In the case of gated spillways, all gates are operative.
- Remaining freeboard, which is defined as the vertical distance between the overtopping level of the dam and the maximal water level reached during the flood event, should be higher than wind set-up plus wave run-up for an appropriate wind speed and direction. (It is generally observed on large concrete dams that this freeboard is in the range of 1 to 2 m).

b) Criterion for the "safety check flood"

- Inflow is the Probable Maximum Flood (PMF), calculated on the basis of a deterministic approach.
- Initial level in the reservoir corresponds to the Full Pondage Level.
- In the case of gated spillways, all gates are operative.
- Remaining freeboard should be higher than wind set-up plus wave run-up for a limited wind speed and direction, as the probability of having both a PMF and extreme wind conditions at the same time is not significant.

In addition, a third criterion is also applied for a gated spillway, and it is considered a safety check condition. It considers the case of malfunctioning of one or several gates during flood events. When the number of gates is limited, such as in the case of Baglihar with 8 high capacity gates plus the auxiliary spillway, the malfunction of only one gate can be considered as the third criterion.

c) Criterion for the case of malfunctioning of a gate

- Inflow design flood corresponds to a stochastically determined flood. A 10,000-year return period is considered.
- The initial level in the reservoir corresponds to the Full Pondage Level.
- All gates are operative except one, which is the one with the greatest capacity.
- Remaining freeboard can be calculated considering a limited wind condition, as the probability of having in concomitance a 10,000-year return period flood, malfunctioning of a gate and extreme wind conditions is not significant.

Finally, a fourth criterion is applied that considers the extreme and most unfavourable wind conditions. This case should not be combined with a low frequency flood event.

d) Criterion for extreme wind conditions

- It is considered that the inflow discharge can be managed through the turbines or through the gated spillway without the raising of the water level above the Full Pondage Level.
- Remaining freeboard should be higher than wind set-up plus wave run-up for extreme wind conditions, which is the most unfavourable combination of speed and direction.

For a concrete dam, in the case of safety check flood (criterion b), some limited overtopping of the dam crest may be accepted if it can be demonstrated that the overtopping wave discharge could not affect the safety of the dam by erosion of the downstream toe and flank of the dam.

5.8.5. Design flood

General considerations on the determination of the design flood are presented in Chapter 5.7.

In the case of Baglihar, the routing effect in the reservoir is limited due to the reduced volume of surcharge storage. Thus, the value of peak discharge is the most important parameter of the inflow hydrograph.

It can be observed that the value of the peak discharge value given by India varies. The value of 16,500 m^3/s is given in the information communicated to Pakistan prior to the construction and also in the Counter-Memorial[88]. In the Rejoinder, India states that "[t]he PMF peak of 16,200 m^3/s estimated (…)"[89], and in the Answers to questions posed by the NE during Meeting No. 3, the value of 16,195 m^3/s is used in the calculations.[90].

Figure 5.8.2 shows the 10,000-year return period hydrograph determined by India, and also admitted as the PMF hydrograph. This hydrograph has been discussed in Chapter 5.7 and admitted by the NE.

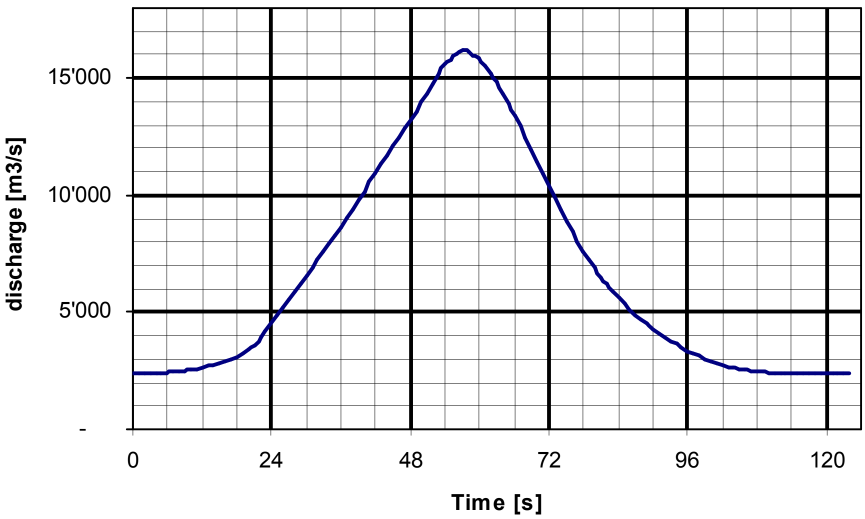

Figure 5.8.2: 10,000-year return period hydrograph, also admitted as PMF hydrograph.

[88] India's Counter-Memorial, Paragraph 1.3, page 34.

[89] India's Rejoinder, Paragraph 3.6, page 66.

[90] Answers to questions posed by the NE during Meeting No. 3, 19 June 2006, Paragraph 3.0, Page 34.

5.8.6. Spillway rating curves

Spillway rating curves depend on the hydraulic characteristics of the spillway devices. All the parameters used by India for determining the rating curve are provided in the documentation.[91]

Pakistan made its appraisal of the rating curves, and provided the corresponding calculation parameters during Meeting No. 3.[92]

The NE made his own appraisal of the spillway outlets rating curves. The results for two reservoir levels are given, along with those of the Parties, in Table 5.8.1.

		India's calculation	Pakistan's calculation	Estimate by the NE
Chute spillway (3 bays)	840	5,730	8,055	5,875
	843	6,975	11,540	7,310
Sluice spillway (5 outlets)	840	10,125	9,090	10,550
	843	10,680	9,585	11,125
Auxiliary spillway	840	60	---	55
	843	155	---	150

(The values are rounded to 5 m^3/s).

Table 5.8.1: Capacity of spillways.

To explain the differences between the values it is necessary to look in detail at the calculations.

a) Chute spillway

The discharge Q when gates are fully open is given by:

$$Q = C_d \sqrt{2g} \cdot B^* \cdot H^{3/2}$$

where: C_d: the discharge coefficient, which may vary with the ratio H/H_d

B^*: the effective total width of the spillway, considering the pier and abutment contraction effect:

$$B^* = B - 2 \cdot \left(K_a + (N-1) \cdot K_p\right) \cdot H$$

H: head above the weir sill

H_D: nominal design head of weir, considered for designing the weir profile

[91] India's document "Answers to questions posed by the Neutral expert during Meeting No. 3", 19 June 2006, Page 34, Chapter 3.0.

[92] Spreadsheet transmitted by Pakistan with the presentation files of Meeting No. 3, Parties' presentations and transcripts, London, 25-29 May 2006, CD-Rom 1 of 1.

K_a: abutment contraction coefficient
K_p: pier contraction coefficient

The reasons for the differences remain in the values considered for the design head H_D and for the contraction coefficients K_a and K_p.

- As for the head, India retained 19 m, and applied a discharge coefficient C_d independent from the water level.

  Pakistan used 14.25 m, considering a ratio of 1.33 between the water head at normal water level and the design head.

  Analysing the construction drawings[93], it appears to the NE that the shape of the downstream quadrant of the chute spillway ogee is given by equation $X^{1.84} = 23.012 \cdot Y$.

  The NE estimated the design head as 18 m and considered the increase of the discharge coefficient with the water head, applying the expression: $C_d = C_d^* \cdot (H/H_d)^{0.12}$.

  The NE also considers that this value of the design head could be reduced by optimising the project, as is normal practice in large spillway design. Limited negative pressure can be admitted on the chute surface during extreme events as the frequency of occurrence is very low. In instances of surface damage and the necessity for repair works, the capacity of the spillway would not be affected. Therefore, the NE will proceed to his calculations considering a design head H_d of 15 m.

- As for the contraction coefficients considered: K_a for abutments, K_p for intermediate piers, India admitted constant values of K_a = 0.10 and K_p = 0.01.

  Pakistan considered a constant value for K_a = 0.08, and variable negative values for K_p from -0.07 to -0.09. The analysis of the spreadsheet provided by Pakistan[94] shows that these values have been obtained by linear extrapolation of values for H/H_D between 0.2 and 0.4 to values between 1.33 and 1.50.

  The NE agrees with the value of K_a = 0.08 considered by Pakistan (which could be obtained by optimising the design) but he thinks that the values of K_p are inaccurate and he proposes to retain a constant value for K_p = 0.01.

Figure 5.8.3 gives the pier contraction coefficients according to USACE, based on an experimental observation and for different shape of pier.[95] Values considered by the Parties are indicated on the graph.

[93] Set of detailed construction drawings, provided by India as Document (i) on 2 8 October 2005, as requested by the Neutral Expert during Meeting No. 2.

[94] Spreadsheet transmitted by Pakistan with the presentation files of Meeting No. 3, Parties' presentations and transcripts, London, 25-29 May 2006, CD-Rom 1 of 1.

[95] Hydraulic Design Criteria, Sheet 111-7, rev. 11-87, US Army Engineer Waterways Experiment Station, Vicksburg, MI, USA.

b) Sluice spillway

The discharge Q when gates are fully open is given by:

$$Q = A \cdot \sqrt{2g} \cdot \left(\frac{H_c}{1 + \Sigma K_i} \right)^{0.5}$$

where: A: the effective surface of the control section
H_c: head above control section axis
K_i: head loss coefficients
where: K_e: entry loss coefficient
K_g: gate loss coefficient
K_f: friction loss coefficient

Values for these coefficients can be found in the literature.

India considered a maximum value of K_e = 0.2 for entry loss coefficient, corresponding to an inadequate bell mouth. The NE estimates that the entry shape could be emphasized and the coefficient of K_e = 0.1 could be reached.

The NE agrees with the other values of coefficients considered by India in its documentation, K_g = 0.2 and K_f = 0.011.[96]

Pakistan considered a global formulation for head losses, leading to an almost constant value for the discharge coefficient: C_D = 0.76. The NE could not find a reference for that coefficient which leads to low discharge values.

c) Auxiliary spillway

This outlet has limited capacity in comparison with chute or sluice spillways. Pakistan omitted the device in its calculations, which does not make a significant difference to the results.

India considered a discharge coefficient of C_D = 2.2.

According to the shape of the sill, the NE estimates that this discharge coefficient is too optimistic, and preferred to use for a wide sill formulation C_D = 0.42·(2g)½ = 1.86.

[96] India's document "Answers to questions posed by the Neutral expert during Meeting No.3", 19 June 2006, Annex 1.

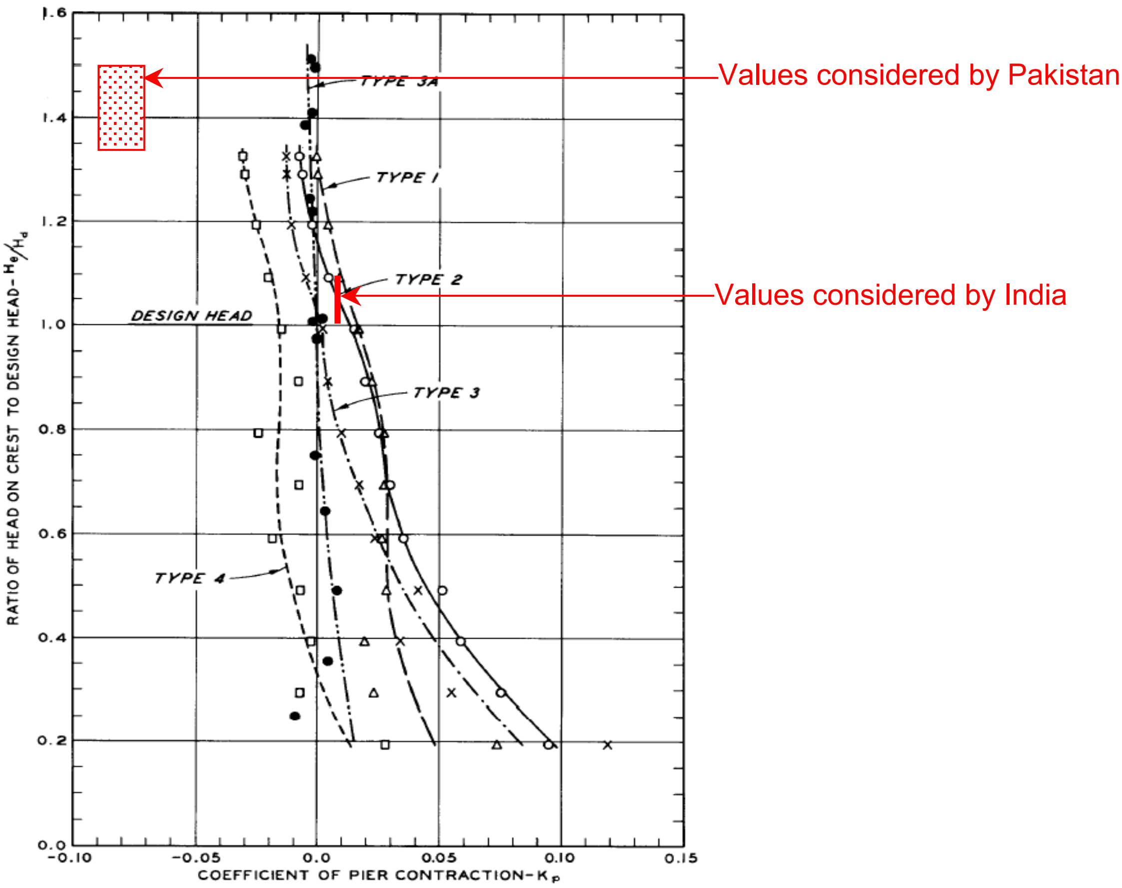

Figure 5.8.3: Pier contraction coefficients, USACE.

5.8.7. Flood routing and surcharge storage

Flood routing analysis makes it possible to determine the water level reached by the reservoir under specified flood conditions, and thus the surcharge storage can be determined.

Levels given by the Parties are presented in Table 5.8.2, which also shows the results of the calculations made by the NE. Details of the flood routing calculations made by the NE are given in Annexes 5.8.1 to 5.8.3. Annex 5.8.1 gives the results of the flood routing considering the rating curves provided by India.[97] Annex 5.8.2 gives the results of the flood routing considering the rating curves provided by Pakistan. Finally Annex 5.8.3 gives the results of the flood routing using the rating curves defined by the NE.

Three series of results are presented: those of each Party, those done by the NE using the coefficients of the Parties and finally those resulting from his own calculations based on coefficients which he considers to be realistic.

It appears that the calculations made by India give similar results to those of the NE. The maximum difference of 11 cm is in the range of accuracy of the software used for the flood routing.

[97] India's document "Answers to questions posed by the Neutral expert during Meeting No.3", June 2006, Annex 1.

<table>
<tr><th></th><th>PMF
3 chutes
5 sluices
1 auxiliary</th><th>(N-1) a
2 chutes
5 sluices
1 auxiliary</th><th>(N-1) b
3 chutes
4 sluices
1 auxiliary</th></tr>
<tr><td>Peak flood discharge [m³/s]</td><td>16,200</td><td>16,200</td><td>16,200</td></tr>
<tr><td>India’s calculation</td><td>840.24</td><td>843.98</td><td>843.22</td></tr>
<tr><td>NE calculation using India’s coefficients</td><td>840.22</td><td>843.92</td><td>843.11</td></tr>
<tr><td>Pakistan’s calculation[98]</td><td>840.00</td><td colspan="2">841.13</td></tr>
<tr><td>NE calculation using Pakistan’s coefficients (and auxiliary spillway)</td><td>840.00</td><td>841.83</td><td>840.54</td></tr>
<tr><td>NE independent analysis</td><td>840.00</td><td>842.53</td><td>842.04</td></tr>
</table>

Table 5.8.2: Result of flood routing calculations, comparison of the values given by the parties and the results of the calculations made by the NE.

Calculations done by Pakistan show differences compared with those of the NE. This is likely to be due to the improbable discharge rating curve adopted for the chute spillway. Moreover, it seems that the rating curves presented during Meeting No. 3 were different from those effectively applied in flood routing calculations.

The NE carried out his analysis retaining the coefficients as mentioned above.

5.8.8. Wave run-up

Wave run-up depends on the wind velocity in the direction considered and the reservoir geometry, mainly the fetch length. The depth is considerable for the reservoirs of high dams. For concrete dams, the dam’s upstream face can be considered as vertical.

Indian standard IS 6512:1984[99] prescribes values for the wind velocity to be adopted when no measurement is available: 120 km/h in the case of normal pool conditions (Full Pondage Level FPL), and 80 km/h in the case of maximum reservoir conditions (Maximum Flood Level MFL).

India considered a maximum wind velocity on land of 140 km/h for normal pool conditions. Pakistan agreed with that value, which is also retained by the NE.

For Maximum Flood Level, the wind velocity of 80 km/h proposed by Indian Standard is also accepted by the Parties and the NE.

[98] Pakistan’s Reply, Part I, Paragraph 4.3 b. (ix), page 89. It should be noted that during the presentation made during Meeting No. 3, levels 842.90 and 841.45 were mentioned as result of flood routing calculation with one gate out of service.

[99] Indian standard IS 6512-1984 – Criteria for the design of solid gravity dams (first revision) – provided as an Appendix to the Counter-Memorial of the Government of India, Paragraph 5.8.2.

For safety checks (PMF, gate malfunctioning), the NE considers that a reduced wind velocity can be used, as the probability of coincidence of these cases with extreme wind conditions is very low. He selected a limited wind speed velocity of 60 km/h for these cases.

Figure 5.8.4 shows the mechanism of wave reflection on a vertical wall, which gives the wave run-up on the upstream face of the concrete dam.[100] As reflection is complete, the reflected wave has the same amplitude as the incident wave, then ç = 1 and the height of the standing wave at the structure (clapotis) will be the significant wave height *2Hi*.

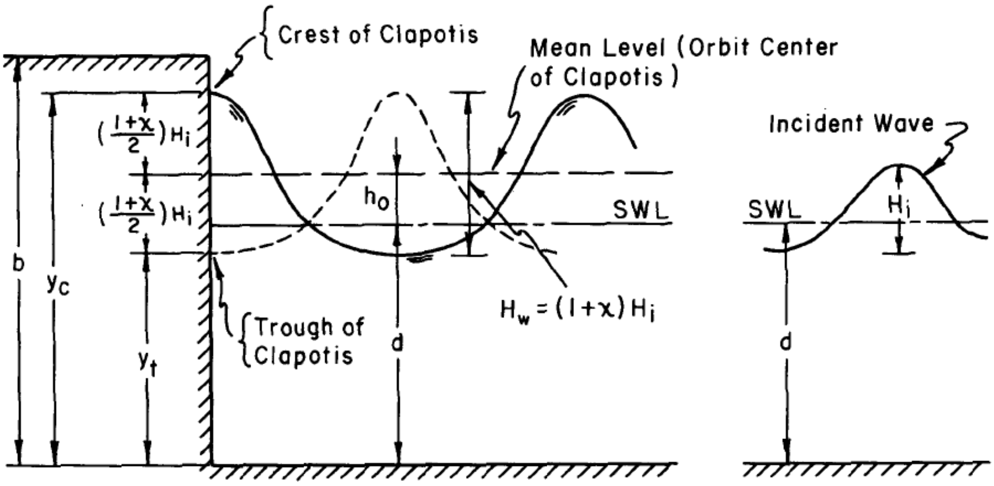

Figure 5.8.4: Wave run-up on a vertical face

Indian Standard IS 6512:1984 recommends the use of the T. Saville method for determining the wave height. It also gives a detailed procedure in its Appendix A. It specifies multiplying the wave height by a factor of 1.33 to obtain the wave run-up.

Based on the Indian Standard, the NE estimates that the limitation of the percentage of waves exceeding the considered value of 4% is too pessimistic for a concrete gravity dam. He considers the design height of the wave to be taken as being equal to the significant wave height, recognizing that a substantial splashing of waves above the dam crest during a limited period of time can be accepted on a concrete dam.

The Indian Standard does not justify the coefficient of 1.33 for the determination of run-up. Against a vertical wall, a wave will reflect against the wall, and the maximum level reached above the mean water level is equal to the incident wave height.

Considering these factors, the nomogram appended to Indian Standard IS 6512:1984 gives, for the design wave height 1.10 m for 140 km/h and 0.60 m for 80 km/h.

Other empirical approaches can be used to determine wave height, such as the Molitor formula, which gives 0.90 m for 140 km/h.

Using the Shore Protection Manual[101] approach, the NE obtains values for the design wave height of 0.80 m for 140 km/h and 0.40 m for 80 km/h.

[100] Shore Protection Manual, Volume II, Coastal Engineering Research Center, Vicksburg, MI, USA, Edition 1984, Chapter 7, page 7-162.

[101] Shore Protection Manual, Volume I, Coastal Engineering Research Center, Vicksburg, MI, USA, Edition 1984, Chapter 3, page 3-49.

In 2002, the US Corps of Engineers published the Coastal Engineering Manual[102], which superseded the Shore Protection Manual. The latter document presents a more scientific approach for determining wave height in open seas. The use of this approach in inland reservoirs of limited size such as Baglihar is actually not standard practice. It has not yet been demonstrated that the results obtained by these approaches are more correct than those derived from empirical formulae.

The uncertainty concerning the magnitude of wave height in inland reservoirs of limited size is quite small in comparison with other parameters determining the freeboard. Therefore, the NE recognises that empirical formulae give sufficiently accurate results for determining the wave height and run-up on a concrete vertical dam face. This opinion is limited to concrete dams, where splashing over the dam crest for a limited period is not critical.

The NE adopts the following values for wave run-up: 0.80 m for 140 km/h, 0.40 m for 80 km/h and 0.30 m for 60 km/h.

Wind set-up is the rising of the mean water level above the initial reservoir level. In a limited size reservoir, this set-up reaches maximum values of around 100 mm. According to Indian Standard IS 6512:1984, the wind set-up is less than 3 cm for 140 km/h and less than 1 cm for 80 km/h wind speed, depending of the average depth of water in the reservoir along the fetch.

The limited height of wind set-up is not a determining factor for establishing the freeboard. The NE will not consider this matter further, and will adopt the above mentioned values.

5.8.9. STATEMENT S 8 relating to artificial raising of the water level [point (a) of the difference referred by Pakistan]

The possibility of a further raising of the Full Pondage Level and the extent of the possible raising is directly related to the height of the available freeboard.

The freeboard, and thus the elevation of the crest of the dam, follows from the calculations of flood routing and from the effects of wind conditions.

India has fixed the dam crest at el. 844.50, 4.50 m above the Full Pondage Level. Considering the same arrangement for flood release devices, Pakistan is of the opinion that the crest level should not exceed el. 840.84.

The analysis carried out by the NE allowed him to define objective criteria, based on ICOLD guidelines and sound engineering. The freeboard is an essential safety element to protect the dam against overtopping. The criteria applied took into account the residual risk of malfunctioning of a gate.

The NE could also determine realistic parameters and coefficients for determining the spillway discharge rating curves. He admitted that the design could be optimised to achieve these coefficients.

[102] Coastal Engineering Manual, US Army Corps of Engineers, Washington DC, USA, No. 1110 -2-1100, 2002.

5.9. PONDAGE (LIVE STORAGE)

5.9.1. Reason for pondage

The consumption of electrical energy by industrial or domestic consumers in an interconnected grid varies throughout the year, and the available power also varies over a wide range during the day. On the other hand, river flows fluctuate moderately during the day, but with large seasonal variations. So an imbalance occurs between power demand and the power which can be produced by a river with its natural flow. A balance should be achieved, with production being adapted to meet consumer demand. One of the major means of doing this is to store water; this is the most efficient system for large quantities of energy. This can be done with a seasonal reservoir, or by run-of-river plants, with daily or weekly reservoirs. In this case they can, for example, store water during the night and release it through turbines during the day, principally during peak load hours, or they can store during the weekend and operate the plant during working days. This is known as "pondage". There are also pure run-of-river plants, without pondage, which exploit the water as it flows naturally.

5.9.2. Determination of pondage

The Treaty provides in *Annexure D, Part 1 – Definitions, 2(c)*:

> *"'Pondage' means Live Storage of only sufficient magnitude to meet the fluctuations in the discharge of the turbines arising from* <u>*variations in the daily and the weekly loads of the plant."*</u>[103]

and in *Annexure D, Part 3 - New Run-of-River Plants, 8(c)*:

> *"The maximum Pondage in the Operating Pool shall not exceed twice the* <u>*Pondage required for Firm Power*</u>*".*[104]

With these two provisions, the Treaty specifies that the pondage volume should be calculated to satisfy daily or weekly load variations of the plant and consequently the variations in the turbine discharge necessary to produce this variable demand of power.

An important matter to be stressed is that the Treaty does not say that "Pondage" means Live Storage of only sufficient magnitude to meet the fluctuations of the daily and weekly inflow of the Chenab river.

This is confirmed by the Treaty which fixes the limitation of India's use of water from the Western Rivers. According to *Annexure D, Part 3 - New Run-of-River Plants, Paragraph 15* provides:

> *"(…) the volume of water received in the river upstream of the Plant, during any period of seven consecutive days, shall be delivered into the river below the Plant during the same seven-day period (…)"*

[103] The underlining is by the NE.

[104] The underlining is by the NE.

and

(ii) *"where a Plant is located at a site on the Chenab Main river above Ramban, the volume of water delivered into the river below the Plant in any one period of 24 hours shall not be less than 50% and not more than 130% of the volume received above the Plant during the same 24-hour period; (…)"*[105]

This means that the plant could turbine, during one day, a discharge which is different from the river inflow, but not lower than 50% and not higher than 130%; consequently the power of the plant could vary.

No explicit mention is made in the Treaty of the use of pondage to regulate fluctuations in the river inflow to the reservoir. However, in the light of the object and purpose of the Treaty, the pondage could also be used for this purpose.

This leads the NE to consider that in the context of the Treaty the pondage volume should be calculated taking into account only the variations in load *i.e.* of the turbine discharge, and this, in accordance with the value of firm power fixed by the Treaty.

5.9.3. Determination of firm power

The definition of firm power is given in many manuals and guidelines. The NE has chosen to refer to a definition given by American Society of Civil Engineers, which appears to him to be the most understandable and which was mentioned by the Parties during Meeting No. 2, 19-21 October 2005, in Geneva,[106] providing:

> "Firm Power: Power intended to have assured availability to the customer to meet all or any agreed upon portion of his load requirements."

It is important to highlight[107] that firm power, according to the requirements of consumers, can be peak load or base load.

In the Treaty, the definition of firm power, which is in fact a method of calculation, is given in *Annexure D, Part 1 – Definitions, 2(i) stating*:

> *"Firm Power" means the hydro-electric power corresponding to the minimum mean discharge at the site of a plant, the minimum mean discharge being calculated as follows:*
> *The average discharge for each 10-day period (1st to 10th, 11th to 20th and 21st to end of the month) will be worked out for each year for which discharge data, whether observed or estimated, are proposed to be studied for purposes of design. The mean of the yearly values for each 10-day period will then be worked out. The lowest of the mean values thus obtained will be taken as the minimum mean discharge. The studies will be based on data for as long a period as available but may be limited to*

[105] The underlining is by the NE.

[106] American Society of Civil Engineers (ASCE). Civil Engineering Guidelines for Planning and Designing Hydroelectric Developments. 1989.

[107] This remark is made in reference to Pakistan's statement in its "Comments of Government of Pakistan on the Final Draft Determination by the NE". A12. (a): "Pondage is to be determined 'for Firm Power' (and not for peak power) in accordance with the specific provision of paragraph 8(c)." 24 October 2006.

the latest 5 years in the case of Small Plants (as defined in Paragraph 18) and to the latest 25 years in the case of other Plants (as defined in Paragraph 8).

The calculation of the lowest of the mean annual values for each 10-day period discharge, based on a series of 16 years (1975-76 to 1989-90, some of them being incomplete), gives a result of 125.68 m^3/s. The firm power which can be obtained from this discharge, based on a net head of 124 m and an efficiency factor for the equipment of 0.86, is 131 MW.

The two Parties agree with these values.

The NE has determined the probability of occurrence during the year of these discharge and power availability. For this purpose, a flow-duration curve of the Chenab river at Baglihar was established on the basis of 25 complete years in the period between 1976 and 2005 (Annex 5.9.1). We can observe on the curve that the discharge of 125.68 m^3/s is reached or exceeded on 341 of 365 days, *i.e.* 93% of the time. It is the same for the firm power of 131 MW; and consequently, this firm power is guaranteed not at 100%, but with a probability during the year of 93%.

The design discharge of the plant, in the first stage, is 430 m^3/s giving an installed capacity of 450 MW. The discharge of 430 m^3/s is reached or exceeded on 170 days of the year, *i.e.* 47% of the time. So during 170 days per year, the plant would be able to operate full time, 24 hours per day, with its full power capacity of 450 MW. During the rest of the year, 195 days, the number of hours per day at full capacity would be reduced.

A final remark: for a run-of-river plant, the basis of the calculation of its energy production is the flow duration curve, generally based on 30 years of historical stream flow; the firm power is the rating at which the plant should operate with certainty throughout the year, in fact, 95% of the time. This firm power is the result of the discharge reached or exceeded 95% of the time. For a given head, this is equivalent to power (energy per second: J/s which is a watt) or of discharge (volume of water per second: m^3/s), and finally, if we consider the existence of pondage the discharge of the turbines will fluctuate according to the demand of the consumers.

5.9.4. Pondage determined by the Parties

The difference in the value of the pondage which prevails between the Parties is significant; the values are as follows, taking into account the doubling of the pondage prescribed in *Annexure D, Part 3 - New Run-of-River Plants, Paragraph 8(c)*:

- Pakistan: Maximum pondage P = 6.22 $M.m^3$, (2 x 3.11)
- India P = 37.5 $M.m^3$, (2 x 18.75)

The reason for the difference results from the following facts.

In its Memorial, Pakistan calculates the pondage with the objective of regulating the daily inflow during the week (125.68 m^3/s +15%, -20%); the power remains constant with the values which result from the mean discharge of 125.68 m^3/s. In this case the required pondage (operating volume) is 3.11 $M.m^3$. Then Pakistan contends that, with the maximum pondage, which is a doubled value: 6.22 $M.m^3$, it is possible to produce peak energy during 6 to 9 hours per day, with a total 51 hours during the week. The plant will operate with a maximum discharge of 430 m^3/s (and the corresponding installed capacity of 450 MW), and with some discharge variations. More precisely, the time of operation is 47 hours at the design power and 4 hours at a reduced one, equivalent to 2.11 hours at design power; the total equivalent at design power is 49.11 hours.

For its part, India, in its Counter-Memorial, determined the pondage based on a constant daily inflow of 125.68 m^3/s and with variations in turbine discharge corresponding to electricity consumption and especially to the peak load hours. Respecting the mean value inflow during the week of 125.68 m^3/s, the plant would only operate for 49.11 hours per week at its design discharge of 430 m^3/s and its installed capacity of 450 MW.

Table 5.9.1 shows the hours of operation of the plant during peak loads hours put forward respectively by the Parties in the Memorial and Counter-Memorial.

	PAKISTAN					INDIA				
	No. hours	Morning	No. hours	Evening	Total hours	No. hours	Morning	No. hours	Evening	Total hours
Saturday	3 1	(8-11) (7-8)	4	(18-22)	8	-	-	3.51	(18-21:31)	3.51
Sunday	3 -	(8-11)	4	(20-24)	7	-	-	3.51	(18-21:31)	3.51
Monday	3 (1)	(8-11) (0-1)	4	(19-23) (23-24)[1]	8 0.9	1.5	(8-9:30)	5.65	(17-22:39)	7.15
Tuesday	3	(8-11)	4	(20-24)	7	-	-	6.12	(17-23:07)	6.12
Wednesday	3 (1)	(8-11)	3	(20-23) (23-24)[2]	6 0.39	3	(5-8)	6.12	(17-23:07)	9.12
Thursday	2 (1)	(8-10) (10-11)[3]	3	(20-23)	5 0.68	3	(5-8)	6.12	(17-23:07)	9.12
Friday	3	(8-11)	3 (1)	(20-23) (23-24)[4]	6 0.14	4.5	(5-9:30)	6.08	(16:55-23)	10.58
Total					49.11					49.11

[1] 385 m^3/s [3] 294.05 m^3/s
[2] 166.03 m^3/s [4] 60 m^3/s

Table 5.9.1: Operation of the plant during the minimum mean discharge week

The operation of the plant is represented graphically with mass curves of discharges entering the reservoir and discharges flowing through the turbines (Annexes 5.9.2 and 5.9.3). We can make the following remarks:

For Pakistan's graph, the pondage (operating volume), which is represented by the maximum distance between the mass curves of river inflow (variable) and discharge through the turbines (constant) is 3.11 $M.m^3$ and the maximum pondage is 6.22 $M.m^3$. If we assume the discharge through the turbines is variable, then the pondage would be 5.9 $M.m^3$ for a variable river inflow and 8.02 $M.m^3$ for a constant river inflow. It appears that the variable inflow, with an increase of the discharge during the working days is, as expected, favourable to the reduction in pondage. However, if we assume that the discharge decreases during the working days, then the pondage would be higher.

As regards India's graph, the time of peak load hours on Tuesday, Wednesday and Thursday does not exactly correspond to the power demand of the Northern Region in winter (Annex 6.5.3). It appears that this pattern of peak load hours is favourable to the increase of the operating pool, which reaches 18.75 $M.m^3$, and finally to the pondage which is double: 37.5 $M.m^3$.

5.9.5. **STATEMENT S 9** relating to the volume of Pondage [point (b) of the difference referred by Pakistan]

Applying provisions of the Treaty, and based on the state of the art, the NE considers that the role of the pondage is to regulate the river flow to meet consumer demand. When the pondage is calculated on this basis, it can also be used to regulate fluctuations in the river inflow.

The pondage is the operating volume necessary to produce firm power corresponding to the minimum mean discharge at the site of the plant. The method of calculating this minimum mean discharge is clearly explained in the Treaty, and no difference of opinion has arisen between the Parties concerning the value of this discharge.

The pondage calculation presented by Pakistan is done with the objective of operating the plant at constant power, while regulating the fluctuations in the river flow. The NE cannot agree to this objective.

The pondage calculation presented by India is done with the objective of operating the plant with a constant river inflow, while regulating the fluctuations in power. The NE agrees with the principle, but not with the hypothesis concerning the time peak load hours on which the calculations should be based; this is not clearly justified.

5.10. LEVEL OF THE POWER INTAKE

5.10.1. Points of differences

Paragraph 8 (f) of Annexure D of the Treaty reads as follows:

> *"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."*

Pakistan estimates that the design submitted by India does not conform to this criterion. "The Claimant State is of the view that the intake for the turbines is not located at the highest level consistent with the requirements mandated by Paragraph 8(f)".[108]

Pakistan also contends that the Treaty "further implies that all design choices related to the level of the power intake should be made so as to minimize the submergence of the power intake (…)."[109]

5.10.2. Design submitted by India

A longitudinal section of the intake is shown in Figure 5.10.1. The main parameters are as follows:

Design discharge (stage I)	430 m^3/s
Intake opening width	29.4 m
Gate opening size	2x 10.0 (W) x 7.5 (H)
Tunnel size	circular, 10.15 m diameter
Elevation of sill	818.0 m asl
Considered dead storage level	835.0 m asl
Minimum submergence depth	9.5 m from gate lintel
	12.75 from gate opening axis

The shape of the upper surface of the intake structure, as shown in Figure 5.10.1, has been modified compared with the Figures provided in pages 8 and 9 to Annex 4.1, (which are extracts from India's Counter-Memorial) to avoid a corner shape on the vertical profile.

It should also be pointed out that in Figure 5.10.1 the gate sill elevation – rectangular - is fixed at el. 808.0, while the tunnel bottom elevation – circular - is at a lower elevation.

The transition length behind the gate section is also very short: 7.50 m for passing from a 23 m wide rectangular section, divided by a 3 m wide pier, to a circular 10.15 m diameter section. India justifies this short length as being a cost/benefit optimum between local head losses and construction costs.

[108] Pakistan's Memorial, Chapter I, Paragraph 2, page 41.

[109] Pakistan's Memorial, Chapter I, Paragraph 7, page 42.

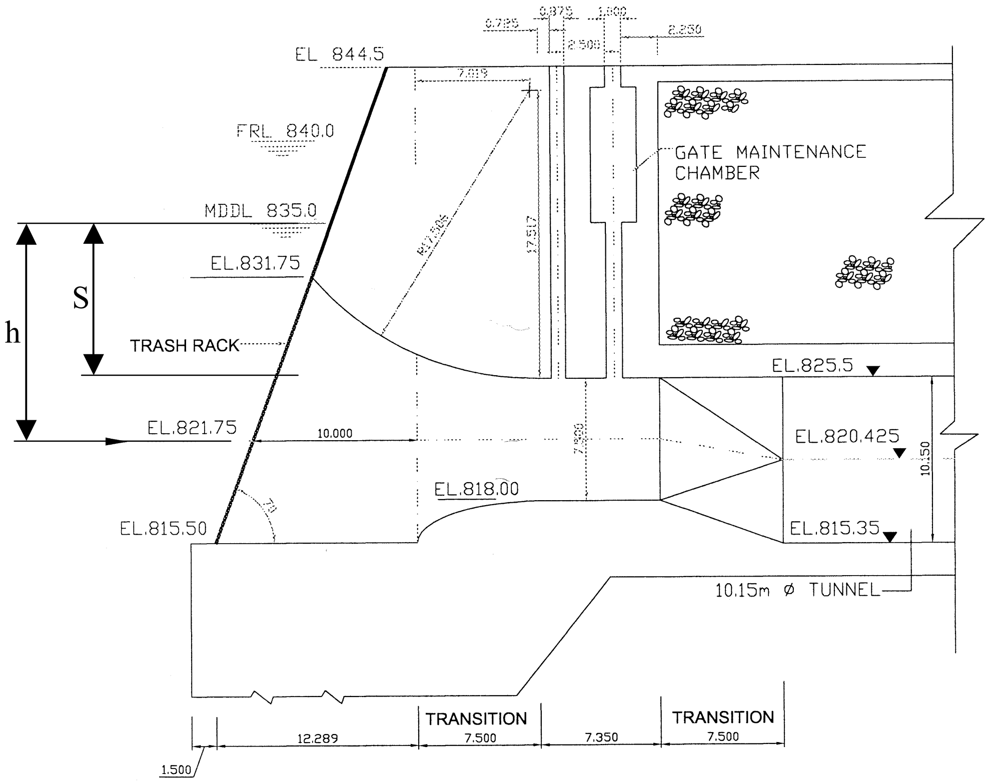

Figure 5.10.1: Power intake - longitudinal section.

The intake gate section is divided into two gate openings. Each bay thus has a nominal discharge of 215 m^3/s. It should be mentioned that the division of the flow into the two bays depends only on flow conditions. A 50-50 division of the flow is certainly not demonstrated; this division could have been verified during the hydraulic model tests.

In the design submitted, it is shown that a second intake, No. II, will be built for a future extension of the Plant (See Annex 4.1, pages 8 and 9). Intake No. II is located between intake No. I and the dam; the axes of both intakes are parallel in plan view. As the existence of the structure for intake No. II does not significantly affect the flow conditions in intake No. I, it does not need to be discussed.

5.10.3. Design proposed by Pakistan

Pakistan has developed and proposed a new design for the power intake structure. The purpose of this proposal was to demonstrate that alternatives leading to a higher intake structure level are possible. This is described in drawings reproduced in pages 6 to 9 to Annex 5.6.4.[110]

The main parameters are as follows:

Design discharge (stage I)	430 m^3/s
Intake opening width	40 m
Gate opening size	2x 10.0 (W) x 7.5 (H)

[110] Extract from Pakistan's Reply, Part II, Annex 2-D

Tunnel size	circular, 10.15 m diameter
Elevation of sill	822.0 m asl
Considered dead storage level	839.0 m asl
Minimum submergence depth	9.5 m from gate lintel
	12.75 from gate opening axis
Sill level of the sediment exclusion wall	826.5 m asl

The design proposed by Pakistan in its Reply includes a sediment exclusion wall, which is discussed in Chapter 5.6 above.

In its Memorial, Pakistan determined the minimum submergence depth as follows[111]:

Considered dead storage level	839.0 m asl
Minimum submergence depth, from gate lintel	
Assuming no anti-vortex devices will be used:	5.25-5.76 m
Assuming anti-vortex devices will be used:	2.50 m

5.10.4. Design principles for the intake

The design of a power intake structure must be based on the following objectives:

- to minimize hydraulic head losses,
- to prevent entry of floating material,
- to avoid sediment deposition in the intake structure,
- to minimize sediment suspended load in the diverted flow, and
- to prevent air entrainment to the turbines.

Hydraulic head losses can be minimized by using smooth transition shapes for the hydraulic structures, which could lead to structures of a large size and considerable length. An economical compromise has to be found between the construction costs and hydraulic head losses.

The entry of floating material can be prevented by having a submerged intake with a trash rack at the entrance, equipped with a trash rack cleaning machine.

Avoiding sediment deposition in the intake structure and minimizing the suspended sediment load in the diverted flow are more complex issues. These have been treated in detail in previous Chapters.

The last criterion mentioned is the prevention of air entrainment to the turbines. It is well known that eddies can appear in front of the intake, and that vortices can develop and entrain air into the intake and the turbines when concomitantly the reservoir is at a lower operating level and the diverted discharge is high.

The first remedy is to locate the intake structure at a sufficient depth. Several other technical measures can be taken to avoid the development of these vortices, such as appropriate design of the side walls, piers and other structural elements, a suitable profiling of the

[111] Pakistan's Memorial, Chapter I, Paragraph 14, pages 43 -44.

hydraulic surfaces and surface treatment. When the velocity in the headrace conduit is limited, it is also possible to prevent the air trapped in the conduit from reaching the turbine by placing a de-aeration chamber or shaft in the conduit. The surge shaft can also fulfil that function. In some cases, the diverted discharge allowed is limited when the reservoir level is low and the intake submergence is insufficient. This last solution is frequently used in deep reservoirs with a high live storage layer, which is certainly not the case for the Baglihar project.

Finally, resorting to a specifically designed anti-vortex device may be considered.

5.10.5. Use of anti-vortex devices

Anti-vortex devices are generally used in large volume reservoirs, where the discharge diverted through the intake structure is to be kept high, even when the reservoir level drops down to the dead storage level. They are also frequently used in pumped-storage schemes.

India's standard IS 9761:1995 gives some indications of the use of anti-vortex devices stating: "[w]ith well controlled approach flow conditions, with a suitable dimensioning and location of the intake relative to its surroundings and with the use of anti-vortex devices, submergence requirements may be reduced (…)".[112] It also gives some examples of the arrangement of anti-vortex devices. This gives the impression that the use of anti-vortex devices is a frequent practice in India.

In the IAHR Hydraulic Structures Design Manual, Volume 1, Rutschmann, et al. give some indications for the sound design of an intake structure stating: "[t]he design of a vortex-free intake has to consider the following points: submergence depth, intake geometry and approach flow conditions (…). If these points cannot be optimized in the design state for various reasons, additional, secondary measures e.g. special anti-vortex devices, can effect the elimination or suppression of surface vortices."[113]

It appears clearly that anti-vortex devices are second choice options, to be examined only if other means for eliminating vortices cannot be used.

Rutschmann also provides: "[a]s vortex phenomena are rather complex, it is not always possible to exclude prototype vortex appearance for a given design. In these cases, and for the investigation of the functionality of special anti-vortex devices, hydraulic model tests still enable the best prediction of prototype vortex occurrence to be made".[114]

The NE understands that only hydraulic model tests on an appropriate scale can demonstrate the efficiency of an anti-vortex device. Even in that case, the efficiency of the device cannot be guaranteed.

Rutschmann also gives several examples of intake structures where anti-vortex devices have been planned and designed during the construction phase.[115] In many of the cases presented, the intake is located at the bottom of a reservoir, mainly in pumped-storage

[112] Indian standard IS 9761-1995 – Hydropower intakes – Criteria for Hydraulic Design (first revision), Paragraph 5.2.2, pp. 11-12 – provided as an appendix to the Counter-Memorial of the Government of India.

[113] Rutschmann P., P, Volkart and D. Vischer, *Design recommendations,* in *Swirling Flow Problems at Intakes*, Hydraulic Design Manual, volume 1, IAHR - International Association for Hydraulic Research, pp. 92-93.

[114] Idem.

[115] Idem, pp. 95-100.

reservoirs, and the sedimentation of the reservoir is not an issue as there is no stream or river entering the reservoir. In such reservoirs, the dead storage level is only limited by the required submersion of the intake, which is to be minimized. In other examples, the intake cannot be lowered because of sedimentation difficulties.

As a conclusion, the NE considers that at the design stage vortices should be avoided by an appropriate intake location, orientation, depth and design as well as by using operational measures. The use of anti-vortex devices at the design stage should be limited to special cases, where other measures are not possible or will not provide sufficient protection.

5.10.6. Calculation of minimum submergence

"For low submergence, a withdrawal structure can be prone to vortices. A vortex is a coherent structure of rotational flow. It is mainly caused by the eccentricity of the approach flow to a hydraulic sink, but asymmetric approach conditions and obstruction effects, among other reasons, can also set up vortices."[116]

Several empirical relationships are generally accepted for determining the minimum required submergence to avoid the full development of vortices. They are mainly based on observations of the functioning of prototype scale intakes and model tests.

Gordon's formula is the most commonly used by engineers.[117] Later, Knauss proposed another formulation based on a wide review of research results.[118]

The application of these formulae to the Baglihar intake structure is not under discussion by the Parties, but their practical application is a matter of discussion.

The phenomenon of the development of vortices is well known and well documented, but there are various different conditions for their development. For that reason, more elaborate design criteria than semi-empirical formulations are not well established practice.

Gordon considered the simplified case of a circular section outflow conduit placed on a flat pond bed, as shown in Figure 5.10.2. These conditions are certainly not representative of a real project, but they give a good indication of the required submergence depth.

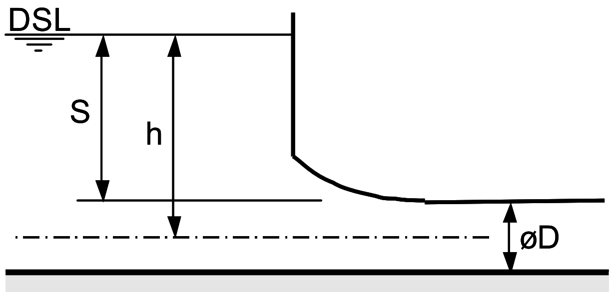

Figure 5.10.2: Simplified geometry of intake.

[116] Vischer D.L. and W.H. Hager, Dam Hydraulics, Wiley Publishers, 1998, page 221.

[117] Gordon J.L., *Vortices at intakes*, Journal of Water Power, April 1970, pp. 137-138.

[118] Knauss J., *Prediction of critical submergence,* in *Swirling Flow Problems at Intakes*, Hydraulic Design Manual, volume 1, IAHR - International Association for Hydraulic Research, pp. 57-76.

A difference appears between the Parties on the section to be considered for calculation of submergence depth in the particular case of Baglihar.

India states that it should be applied at more than one section, as specified by Gulliver (1986). In particular, the headrace tunnel section, behind the intake structure, should be taken into account.[119]

Pakistan considers that it should be applied to the gates section.

The NE examined the situation and found that the calculation of submergence depth with the section of the tunnel (circular, 10.15 m diameter) is not relevant. The formulae consider a simplified geometry for the vortex formation, as shown in Figure 5.10.2. In such geometry, the section available for a possible rotational movement increases from the conduit section to the pond surface. This is not the case when starting in a tunnel section, as upstream of the tunnel section, the channel is divided into two gate conduits. A swirl may be imagined in each conduit, creating each a specific rotational momentum. It is hardly possible for these two movements to join into a common rotational movement in the tunnel section. The friction between the two flows rotating in the same direction will annihilate the rotational movement. The central pier prevents the development of a vortex downwards to the tunnel section.

Therefore, the section to be considered for calculation of the submergence depth is the gate section.

Gordon's relationship for asymmetrical approach conditions is formulated as follow:

$S_{\min} = 1.7 \cdot D \cdot Fr$, for symmetrical approach conditions, and

$S_{\min} = 2.3 \cdot D \cdot Fr$, for lateral approach conditions

where *Fr:* Froude number $Fr = V / \sqrt{gD}$

V: Velocity in the outflow conduit, in [m/s]

D: Diameter of the outflow conduit, in [m],

$S_{min:}$ Required submergence from the opening lintel, in [m]

The Knauss formula is $h_{crit} / D = 2 \cdot Fr + 0.5$.

where h_{crit} is the critical depth, measured from the elevation of the axis of outflow conduit.

Knauss limits his relationship to a Froude number $Fr > 0.33$. For lower Froude numbers, a submergence depth of 1 up to 1.5 times the intake height (or diameter) is recommended. This recommendation is valid for proper approach flow conditions.

India's Standard IS 9761:1995 refers to the Knauss formula.[120]

In the conclusion of his text related to the prediction of critical submergence[121], Knauss states: "[t]he final conclusion is that in most of all cases, the critical intake conditions

[119] India's Counter-Memorial, Part I, Paragraph 3.9.3, page 145.

[120] Indian standard IS 9761-1995 – Hydropower intakes – Criteria for Hydraulic Design (first revision) – provided in the Appendix to the Counter-Memorial of the Government of India.

[regarding submergence depth] cannot be determined with sufficient accuracy. Fortunately, submergence is not the only remedy to improve intake conditions. Providing suitable approach flow properties in order to minimize circulation may sometimes be much more efficient".

Finally, the Gulliver criterion is also mentioned by both Parties as being frequently used to complement Gordon's formulation.[122] It specifies: $S > 0.7 \cdot D$ for $Fr < 0.5$. This criterion is included in Knauss's limitation of the Froude number, and is in accordance with the value recommended by Knauss.

The NE points out that the critical or minimum submergence depth is highly dependent on the inflow approach conditions and the measures taken to avoid circulation in the vicinity of the intake structure. It is not possible to quantify these parameters and to incorporate them in a simple calculation.

The parameters used for both Gordon's and Knauss's formulae are to be chosen taking into account the fact that the direction of the intake structure is almost perpendicular to the flow approach direction. Another arrangement of the intake, such as a frontal intake, could create more symmetrical approach conditions and may reduce the required minimum submersion compared with a lateral intake arrangement.

The power intake design for the Baglihar Plant has two openings with a central pier. The division of flow between the two bays may also vary with the approach flow conditions, the water level and eventually the sediment level.

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[121] Knauss J., *Prediction of critical submergence,* in *Swirling Flow Problems at Intakes*, Hydraulic Design Manual, volume 1, IAHR - International Association for Hydraulic Research, Chapter 4.7, page 76.

[122] Gulliver J. et al., *Designing Intakes to Avoid Free-Surface Vortices*. In Water Power & Dam Construction, September 1986.

5.10.7. STATEMENT S 10 relating to the level of the power intake [point (c) of the difference referred by Pakistan]

In the application of the provisions of the Treaty, and based on the state of the art, the NE considers that the elevation of the power intake should be determined to avoid the development of vortices at the Dead Storage Level and air entrainment to the turbines, without limitation of the operation discharge.

He observes that recourse to anti-vortex devices at the design stage is not common practice, and should be limited to particular cases where other measures cannot be undertaken to provide protection against the development of vortices.

He believes that the application of semi-empirical formulae for determination of the minimum required submersion depth is adequate. The application of such formulae should be restricted to sections where a permanent vortex connected to the pond surface could develop.

The required minimum submergence depth depends on the inflow approach conditions. The location of the intake structure proposed by India, which is not contested by Pakistan, leads to asymmetrical approach conditions. Another arrangement with more symmetrical approach conditions could reduce the required minimum submergence depth.

6. EXPERT DETERMINATION

6.1. MAXIMUM DESIGN FLOOD

1. The general criterion for the selection of the design flood is to reduce the risk to a value as low as is reasonably achievable. This is the reason for the choice of a probability of the design flood, generally accepted in the world to be 1/10,000.

   According to India's approach, the Probable Maximum Flood is used as the design flood, as it appears to be identical, in this region, to the 10,000 year return period flood.

   The analysis done by India results in a value of 16,500 m^3/s and that of Pakistan results in a value of 14,900 m^3/s.

2. **DETERMINATION D 1** relating to the maximum design flood [point (a) of the difference referred by Pakistan]

In view of all the uncertainties of flood analysis, the NE has decided to retain the value of 16,500 m^3/s. Climate change, with the possible associated increase in floods, also encourages a prudent approach.

6.2. SPILLWAY, UNGATED OR GATED

1. The dam of Baglihar is a large dam, with a height of 144.50 m above foundation, built on a site which has exceptional conditions as regards: hydrology, sedimentology, topography, geology, seismology. The following characteristics apply:

   (i) Very large design flood: 16,500 m^3/s, with a catchment area of 17,300 km^2.

   (ii) Very large sediment transport.

   (iii) Small reservoir volume (37 $M.m^3$ for the live storage; 400 $M.m^3$ for the total storage) compared with the volume of the design flood of 2,500 $M.m^3$.

   (iv) Narrow valley; width of the river bed is 60 m; length of the dam crest is 320 m; accordingly steep flanks of the valley (about 1/1).

   (v) Weak geology: quartzite with inter-bedded slate bands; shear zones and joints.

   (vi) High seismicity.

   The design of the spillway should also take into account the following points:

   - The flow of the design flood at the downstream toe of the dam will have a considerable energy which will have to be dissipated in the stilling basin, only 60 m wide, built in the river bed (a failure of this structure could lead to failure of the dam). The length of the spillway crest should be compatible with the following: the limited width of the river, and the flow from the crest being conveyed through a clear chute, ending in a ski jump to the chosen place where its energy will be dissipated.
   - The maximum water level of the reservoir cannot exceed el. 840 m asl to avoid flooding of Pul Doda town as well as some infrastructure upstream. The potential head of the site (ca. 130 m) should be totally utilized for energy production. The Full Pondage Level (FPL), according to the design submitted by India, is fixed at el. 840. If the design flood should occur, the spillway gates would be opened and the reservoir level would not rise above FPL. On the contrary, if the spillway were ungated, the level of water on the spillway crest would rise by about 12 m to allow for the discharge of the design flood. The reason is the short length of the dam crest which limits the length of the spillway weir. To avoid flooding of the upstream shores, the crest of an ungated overflow spillway should be fixed at el. 828 m asl. The 130 m head of the power plant will be reduced by 12 m, which would represent a loss of 9% in energy production throughout the life of the plant.
   - If protection of Pul Doda town is not considered, the maximum water level could be raised to a higher level than el. 840 m asl, for example by 12 m. No energy production would be lost, but the cost of the dam, even taking into account a saving relating to gates, would still be significantly higher. This is a purely economic consideration without human regard for the population of Pul Doda.

   As a result of the difficult conditions of the site mentioned under Points (i) to (v), a gated spillway is required.

   The disadvantage of a gated spillway in a highly seismic area is the risk of the gates jamming. Today this risk can largely be reduced by adopting various technical measures (structural and mechanical).

2. DETERMINATION D 2 relating to the issue of gated or ungated spillway [point (a) of the difference referred by Pakistan]

The Treaty provides in *Paragraph 8 (e) of Part 3 of Annexure D* the following:

"If the conditions at the site of a Plant make a gated spillway necessary,[123] *the bottom level of the gates in normal closed position shall be located at the highest level consistent with sound and economical design and satisfactory construction and operation of the works."*

The NE considers, in conformity with the state of the art, that the conditions at the site of Baglihar plant require a gated spillway. An analysis done by the NE on 13,000 existing spillways in the world shows that 89% of these structures, having a design discharge higher than 14,000 m^3/s, are gated.

This decision is consistent with the provisions of the Treaty requiring a sound and economical design, and satisfactory construction and operation of the works. It is also in accordance with the Preamble of the Treaty which provides that "[t]*he Government of India and the Government of Pakistan, being equally desirous of attaining the most complete and satisfactory utilization of the waters of the Indus system of rivers (…)".*

[123] The underlining is by the NE.

6.3. SPILLWAY, LEVEL OF THE GATES

1. Provisions of the Treaty dealing with the level of the spillway gates

Some data on the design of the spillway adopted by India are briefly summarized again below:

	Number of gates	Size WxH [m]	Sill el.
• Chute spillway	3	12 x 19	821 m asl
• Sluice spillway	5	10 x 10.50	808 m asl
• Auxiliary spillway	1	6 x 3	837 m asl
• Full pondage level	840.0 m asl		
• Dead storage level	835.0 m asl		

Referring to the Treaty, *Annexure D - Part 3 - New Run-of-River Plants, Paragraph 8 (e)* reads as follows:

> *"If the conditions at the site of a Plant make a gated spillway necessary, the bottom level of the gates in normal closed position shall be located at the highest level consistent with sound and economical design and satisfactory construction and operation of the works."*[124]

Pakistan declares in its Memorial[125] (14 August 2005) that even if it can be assumed (without conceding) that a gated spillway is necessary, the orifice spillway proposed by India is not located at the highest level consistent with the provisions of the Treaty.

The position of India in its Counter-Memorial[126] (23 September 2005) is that the three-bay design for the chute spillway, the five-bay design for the sluice spillway, and the auxiliary spillway are necessary to ensure safe passing of the design flood, and also a silt-free environment near the intakes for trouble-free operation, by transporting of sediments together with flood discharges through the sluice spillway. Consequently, the chosen spillway configuration is at the highest possible level consistent with a sound and economical design and satisfactory construction and operation of the works.

It appeared clearly to the NE during the inspection of the hydraulic model at the Irrigation Research Institute (IRI) in Roorkee on October 5 and 6, 2005, that the key stone of the design of the appurtenant works of Baglihar (and of the discussions between the Parties) was not the problem of flood discharge, but the flow of sediments which could create the following risks:

- Sedimentation of the operating pool (the pondage).
- Sedimentation of the power intake by bed load sediments.

[124] The underlining is by the NE.
[125] Memorial of Pakistan, page 28.
[126] Counter-Memorial of India, page 30.

- Suspended sediment with a high concentration and size entering the power intake and power tunnel, causing erosion of the turbines.
- Heightening of the river bed at the entrance of the reservoir and flooding of the town of Pul Doda.

This was the reason for the first list of questions on sedimentation, presented by the NE on October 11, 2005, to which answers were given by the Parties during Meeting No. 2 in Geneva, October 19-21, 2005. The NE also observes that during the subsequent months, important analyses, including numerical and physical models were developed by the Parties on this sediment problem, which were fully reported by Pakistan in its Reply[127] (January 25, 2006) and by India in its Report: Planning and Model Test Documents[128] (December 26, 2005), as well as in its Rejoinder (March 20, 2006). A second list of questions on the issue of sedimentation was proposed by the NE on April 13, 2006. The Parties responded during Meeting No. 3 in London, May 25-29, 2006, before their oral presentations, also dedicated, in part, to the design of the appurtenant structures in relation to sedimentation. And finally written and oral comments were done by the Parties on October 26, November 5-7 and 24, 2006.

The NE recalls here a paragraph of his general considerations in Chapter 5.3:

In fact the designer of a spillway is not only faced with the problem of flood control, but also with that of sediment control. Confusion and misunderstandings could arise because these two factors are not independent of each other. The element which links them is the role played by the bottom outlet. Referring to Bulletin 115 of the International Commission on Large Dams (ICOLD), "Dealing with reservoir sedimentation", the state of the art is today, that "[b]ottom outlets may be used for under-sluicing of floods, emptying of reservoirs, sluicing of sediments and preventing sediment from entering intakes, etc."[129]

For its part, the Treaty in *Annexure D - Part 3 - New Run-of-River Plants, Paragraph 8 (d)* reads as follows:

> *"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 NE considers that the two provisions 8 (e) and 8 (d) of the Treaty should be applied to the design of the spillway, and especially to the level of the gates, which also plays in part the role of a bottom outlet.[130]

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[127] Reply of Pakistan, Parts I and II, January 2006.

[128] Planning and Model Test documents, Volume 5(ii). *Sedimentation of the reservoir and Sediment Management."* Government of India, 26 December 2006.

[129] ICOLD Bulletin 115. *Dealing with reservoir sedimentation*. 1999.

[130] It is necessary to give some explanation about the terminology concerning gates. Up to the 1970s, bottom outlets were generally of relatively small size. For example, in the Alps dams were equipped with a bottom outlet for safety reasons: the control of the reservoir level during first impounding, the drawing down of the reservoir for maintenance or rehabilitation measures, or in case of an emergency. This was possible because of the re latively limited flood discharges. Concerning spillways, the two relevant types are surface spillway (free overflow or gated) and submerged or orifice spillway, which has its sills located well below the full supply level. By the 1980s, technical progress had made it possible to have very large bottom gates operating under very high heads for river flood discharge; in parallel, the term sluice gate was also adopted. These gates were required not only to evacuate floods, but also to control reservoir levels and to draw down the reservoir in the event of emergencies. The orifice spillway can be considered a bottom outlet; and finally we find in the literature just the word outlet.

2. Procedure for the design of the appurtenant structures

The opinion of the NE is that the procedure for the design of the appurtenant structures at Baglihar should be developed as follows:

a) The value of the design flood is known and, as stated in Chapter 6.2, a gated spillway is necessary. *Annexure D, Paragraph 8(e)* reads *"(…) the bottom level of the gates in the normal closed position shall be located at the highest level consistent with sound and economical design and satisfactory construction and operation of the works."* This means that the gated spillway should be, as much as possible, a surface spillway, also taking into consideration in its design the two next points below.

b) Bottom outlets under the Dead Storage Level are necessary for sediment control. *Annexure D, Paragraph 8(d)* reads *"(…) 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".*

c) ICOLD Bulletin 115 states "[b]ottom outlets may be used for under sluicing of floods, emptying of reservoirs, sluicing of sediments and preventing sediment from entering intakes, etc."[131] Sluicing or flushing operations of sediments are utilized during the occurrence of floods; therefore, part of the spillway will be not only a chute spillway, but also a sluice spillway.

The relevant question is what should be both the minimum size of the bottom outlets and their highest level, and consistent with both sound and economical design and satisfactory operation of the works?

3. Principles of design for bottom outlets

Bulletin 115 of ICOLD presents clear guidelines on this matter stating;

> "The most important consideration in planning bottom outlets is the elevation of the outlets. Other considerations include the plan layout and dimensions of the outlets in order to ensure efficient sluicing/flushing of sediment and operation of hydro power stations."[132]

Further, the guidelines note the following:

> "The ideal elevation of bottom outlets is at the original river-bed level, preferably not higher than the relative water depth 0.15 to 0.2 from the bed. Low level outlets can pass suspended load near the bed at relatively high concentrations, as well as coarse particles. For drawdown flushing or emptying, the outlets should be low enough to ensure retrogressive erosion of sediment deposits in the reservoir. At hydropower plants, the outlets should be below the intakes. For the venting of density currents, the elevation of bottom outlets should be lower than the interface between the sediment-laden stream and upper water mass."[133]

[131] ICOLD Bulletin 115. *Dealing with reservoir sedimentation*. Guidelines and Case Studies.1999.

[132] Idem, pp. 81-83.

[133] Idem.

A method to control reservoir sedimentation is to minimize deposition of sediment in the reservoir through sluicing, *i.e.* passing of sediment-laden floodwater "by operating the reservoir at a lower water level during the flood season in order to facilitate sufficient sediment transport capacity (turbulent and colloidal) through the reservoir. After the [flood] season the pool level is raised to store relatively clear water."[134] India proposed a similar approach for the Baglihar project.

With regard to the discharge necessary for this operation of sluicing, ICOLD Bulletin 115 states:

> "Ideally it would be preferable to pass even the biggest floods through a reservoir without reduction in velocity[135], but it is seldom practical or economical in most cases due to the excessively large outlet structures required and loss of reservoir benefit. As a compromise[136], Rooseboom (1985) proposed that inflows up to the 1-in-5-years flood discharge should be allowed to pass through without depositing significant quantities of sediment, while larger inflows would tend to deposit sediments, but these deposits should be flushed out during the flood period before consolidation takes place."[137]

The operation of "flushing is a technique in which the flow velocities in a reservoir are increased to such an extent that deposited sediments are remobilised and transported through bottom outlets. In many cases sluicing and flushing are used in combination or in alternation."[138]

The necessary condition for achievement of sluicing and flushing is to draw down the reservoir.

4. Possibility to draw down the reservoir below the Dead Storage Level (DSL)

In Chapters 5.4 and 5.5, considerations were developed with regard to the processes of operation and maintenance of the reservoir, and it is important to revisit this crucial question in relation to the design of the sluice spillway.

In *Annexure D*, *Part 1*, *Paragraph 2*, the Treaty provides the following relevant definitions:

> *"(a): 'Dead Storage' means that portion of the storage which is not used for operational purposes and 'Dead Storage Level' means the level corresponding to Dead Storage", and*
>
> *"(f): 'Operating Pool' means the storage capacity between Dead Storage Level and Full Pondage Level."*

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[134] Idem, page 29.
[135] The underlining is by the NE.
[136] The underlining is by the NE.
[137] ICOLD Bulletin 115. *Dealing with reservoir sedimentation*. Guidelines and Case Studies.1999. page 31.
[138] Idem, page 47.

a) It is certainly on the basis of this provision that Pakistan asserted in its Memorial of August 2005 the following statement:

"In the instant case, the Treaty specifically prohibits India from drawing the water level down in the reservoir below the Dead Storage Level (i.e. el 835 m). Due to this limited range of operation, flushing of deposited sediment will not be feasible."[139]

b) The Counter-Memorial[140] of India, of September 2005, confirms Pakistan's interpretation:

"The Treaty provisions limit the operation of the reservoir between Full Pond Level and Dead Storage Level. The Water level in the reservoir is to be maintained at Dead Storage Level (El. 835 metre) during the monsoon when lower streamlines of inflow have a high sediment load. Such inflows with sediments can be passed downstream through sluices located at an appropriate lower elevation. Such routing of sediment-laden flow through the sluices is expected to maintain a significantly silt-free environment in front of the intakes."

[…]

"Flushing will not be effective because of the operational constraints of the reservoir and is, therefore, not intended."

c) In its Reply[141] of January 2006, Pakistan emphasizes:

"There is no dispute over the fact that The Treaty specifically and unequivocally bars India from reducing the water level in the reservoir below Dead Storage Level. It is also not in dispute that this is not a stipulation which is subject to the principles of sound and economical design, but one which is mandatory and absolute.

Given this mandatory stipulation, effective sluicing is simply not possible. The Counter-Memorial and India's recent analysis of sediment management expend considerable time and effort explaining the concept of sluicing. The fundamental point with respect to sluicing, which point is being studiously ignored by India, is that sluicing does not work without a considerable reduction in the water level."

During Meeting No. 3, May 25-29, 2006, Pakistan presented this assertion orally,[142] which was refuted by India during the same meeting.[143]

The interpretation of *Paragraphs 2(a) and 2(f), Annexure D, Part I* of the Treaty, according to which the drawdown of the reservoir below the DSL would be prohibited, formed the basis of Pakistan's criticisms of India's sluice spillway design.

These criticisms demonstrated that the processes of sluicing and flushing would be efficient only if they would go "hand in hand with drawdown"[144]. They were so impressive and

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[139] Memorial of the Government of Pakistan. 14 August 2005. Page 28.

[140] Counter-Memorial of the Government of India. 23 September 2005. Page 40 and 56.

[141] Reply of Pakistan. Part I. 25 January 2006. Page 49.

[142] Meeting No. 3. Transcript. 28 May 2006. Page 3, lines 14 to 16. Page 21, lines 19 to 25.

[143] Meeting No. 3. Transcript. 28 May 2006. Page 138, lines 19 to 25. Page 139, lines 1 to 6.

[144] In particular: Comments of the Government of Pakistan on the final draft Determination by the NE. 24 October 2006. Letter of Prof. A. Rooseboom.

convincing, that it seems obvious that the best design, based on sound and proven principles to solve the sedimentation problems of the reservoir, was the sluice spillway system, with the imperative condition that it would be possible to draw down the reservoir.

Finally, the solution rests on the interpretation of *Paragraphs 2(a) and 2(f) of Annexure D, Part I* of the Treaty.

The NE reaches the following conclusions based on the statements expressed in Chapters 5.4 and 5.5.

The definition of the Dead Storage given in the *Paragraph 2(a) and 2(f) of the Treaty,* states that it cannot be used for "operational purposes", which for Baglihar means power generation. This is precisely the exclusive role of the Live Storage which has the purpose of generating power. But the capacity of the Live Storage should be protected against sedimentation. To meet this objective, "maintenance" of the Live Storage and of the Dead Storage should be carried out, having recourse to the various known processes of sedimentation control, and in particular, sluicing and flushing with reservoir drawdown. This process of "maintenance", which is necessary to ensure the "sustainability" of the scheme is not excluded by the Treaty.

5. Pakistan's proposal for a Sedimentation Exclusion Trough (SET)

During Meeting No. 2 in Geneva (October 19-21, 2006), Pakistan kindly developed, in response to the request of the NE, a solution for the problem of sediment control of the Baglihar project. This was done in a spirit of goodwill, and was helpful for the decision of the NE.

Pakistan's design[145] consists of a gated chute spillway and a Sediment Exclusion Trough (SET), which has the objective to avoid the sedimentation risk for the power intake. The characteristics of the SET are given in Chapter 5.6.4, and presented in Annexes 5.6.2 and 5.6.4.

The design principles of a water intake associated with a gravel sluice channel are well known[146] and are generally applied in the SET proposed by Pakistan. The sluice channel has its sill level at its outlet (808.0 m asl) placed below the sill level of the water intake (822.0 m asl); this one is protected by a sediment exclusion wall with a sill level which is higher (826.5 m asl).The calculations of the sediment concentration in front of the power intake are correct.

But, in the view of the NE, the fact that the sill level of the chute spillway (825.7 m asl) is practically the same as that of the exclusion wall (826.5 m asl) and higher than that of the water intake, the presence of the slots on the roof of the channel creates a great risk that the SET would become clogged by bed load sediments and floating or neutrally buoyant debris. In its comments, put forward in October 2006,[147] Pakistan suggested interesting adjustments

[145] Reply of Pakistan. Parts I and II. 25 January 2006.

[146] M.Bouvard. *Mobile barrages and intakes on sediment transporting rivers.* IARH Monograph. Balkema. 1992. Translated from the original book in French. Eyrolles. 1984.
This reference is quoted by Pakistan in its Reply, Part II, Footnote 17, page 20.

[147] Comments of the Government of Pakistan on the final draft Determination by the NE. 24 October 2006.

to its first SET design, but they appear to the NE as secondary elements. It is the general concept of the work which is questionable.

It is also essential to point out that the system – chute, spillway and SET - will not provide protection of the pondage from sedimentation, and will not avoid the raising of the river bed level at the entrance of the reservoir, which would cause flooding of land and of the town of Pul Doda located upstream. The position of Pakistan is very clear on that matter.[148]

The NE considers that the design proposed by Pakistan, which, it should be stressed, was graciously submitted, would not be sufficiently safe in the light of the sedimentation problems to be faced in this case.

6. India's design

The design of the bottom outlet with its five gates, which is also a sluice spillway contributing largely (2/3) to the evacuation of the design flood, has the objective of solving the sedimentation problems.

- The level of the gates is moderately low at el. 808 m asl *i.e.* 32 m below the maximum pondage level. Unfortunately, no bottom outlet is placed below the power intake.
- The total area of the gates, five times 105 m^2 seems to be relatively large, with a discharge capacity of 11,200 m^3/s for a Reservoir Level at el. 840.0 m asl.

The Sediment Management Plan prepared by India[149], with the objective of removing the risks described under paragraph 1 above, says that any river flow exceeding 430 m^3/s (the maximum discharge in the turbines), will be used for sluicing and under-pressure flushing of sediments, especially during the flood season (monsoon period), and at that time, the pond level will be drawn down to the Dead Storage Level (DSL) of 835 m asl.

However, it appears to the NE - and in accordance with the remarks of Pakistan - that with time (within two decades or perhaps less), the system will no longer be able to operate. The calculations done by India in the near field of the dam and the model tests (but with less evidence) do not represent reality,[150] which will involve sedimentation of the reservoir, including pondage, bed load sediments at the entrance of the power intake, suspended sediment in the power tunnel causing erosion of the turbines, and risk of flooding of Pul Doda town.

The reason is that a sound design of the bottom outlet necessitates carrying out sluicing and flushing operations with the reservoir drawn down to a level below that of the Dead Storage.

[148] The Reply of Government of Pakistan to the Counter-Memorial by Government of India. Part II. Page 10, states: "[t]he Baglihar reservoir will be completely filled with sediment within about 30 years […]. From that time the plant will still function as a run-of-river facility but with reduced Pondage.

Note that the far field sedimentation of the reservoir will occur both for the spillway arrangement proposed by India and with the spillway/intake arrangement proposed by Pakistan".

The NE considers that this position does not respect the Treaty, as for a sound and economical design.

[149] Government of India. Planning and Model Test Documents. Volume 5 (ii). Sedimentation of the Reservoir and Sediment Management. p 46. 26 December 2005.

[150] In particular to expect a cone just upstream of the sluice spillway, with a length of 300 or 400 m is illusory.

7. Analysis of the process of drawdown sluicing

During the months of November 2006, the NE discussed with Prof. Dr Anton Schleiss and his assistant Dr Giovanni De Cesare on the compatibility of the sluice spillway design done by India with the objectives described relating to sedimentation management. The result of this consultation is presented in the letter of December 22, 2006 of these Experts (attached as Annex 6.3). The NE quotes below some principal elements of the answer to the following question: what should be the drawdown level of the reservoir for an efficient sluicing operation, and at what frequency should the operation be performed?

"3.1 . . .

> This operation should be made each year during the monsoon season. The objective is that the floods discharged will create the highest tractive force on the river bed all along the river […]. Protection of the live storage necessitates not only designing low level sluice gates, but also, if possible, providing the possibility to evacuate the floods with a free surface flow through the orifice spillway. These conditions will determine the size of the gates, the flood discharge and its frequency.
>
> . . .

4.2 In the case of Baglihar, a free flow passage of flood events up to a 20-year return period discharge, representing 5800 m^3/s, is feasible, through the five sluice gates in their fully open position. The sluicing and flushing operations for maintenance should be carried out each year, and for that purpose, the reservoir level should be drawn down up to a maximum of about el. 818 m asl, that is to say 17 m below the DSL (...).

4.3 The sill level of the power intake being at el. 818 m asl, it is evident that the power plant could not operate during this phase of maintenance. Its duration can be limited to the duration of the maximum flood discharge, bed and suspended load transport. It should not be stopped at an early stage when solid material is still arriving at the dam. This operation should be monitored very carefully to ensure its success and moreover to prevent abrasion of the turbines.

4.4 Finally, we can state that with adoption of this operation of drawdown sluicing, the answers to the two first questions are clearly positive: a) the pondage volume will be sustainable, b) the power intake will be protected against the deposition of bed load sediments and against substantial suspended load sediments entering the power tunnel.

> As for the question c) concerning the protection of the town of Pul Doda, some calculations indicate that the protection against flooding would not be ensured. We consider that the situation could be safe with the sill level of the sluice gates lower, at about el. 800 m asl."

8. DETERMINATION D 3 relating to the level of the spillway gates [point (a) of the difference referred by Pakistan]

In reference to the Treaty, ***Annexure D Part 3 - New Run-of-River Plants, 8(e)*** provides: *"If the conditions at the site of a Plant make a gated spillway necessary, the bottom level of the gates in normal closed position shall be located at the highest level consistent with sound and economical design and satisfactory construction and operation of the works."*[151]

The NE considers that the gated chute spillway on the left wing, planned in India's design, which has its sill located at el. 821 m asl, is at the highest level consistent with sound and economical design and satisfactory construction and operation of the works.

Annexure D Part 3 - New Run-of-River Plants, 8(d) states: *"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."*[152]

The NE considers that the sluice spillway, planned in India's design and composed of five outlets, has two functions: sediment control of the reservoir and evacuation of a large part of the design flood. In conformity with international practice and the state of the art, he considers that the proposed outlets (five gates of 105 m^2) should be of the minimum size and located at the highest level (808 m asl), consistent with a sound and economical design and satisfactory construction and operation of the works. But to ensure protection against flood of Pul Doda, the outlets should preferably be located 8 m lower, at about el. 800.0 m asl.

Sound operation of the outlets will necessitate carrying out maintenance of the reservoir with drawdown sluicing each year during the monsoon season. The reservoir level should be drawn down to a level of about 818 m asl, that is to say 17 m below that of the Dead Storage Level. For this level, the free flow discharge is the annual flood of the order of 2,500 m^3/s. This is in conformity with *Annexure D, Part 1, 2(a)* of the Treaty, which provides that the *"'Dead Storage' means that portion of the storage which is not used for operational purpose"*. Operational purpose refers to power generation (and this is impossible for the Dead Storage because of the high level of the power intake). The reservoir drawdown below the Dead Storage Level will be done for maintenance purposes. It is commonly agreed in practice that maintenance is an absolute necessity, with its ultimate objective of ensuring the sustainability of the scheme.

[151] The underlining is from the NE.
[152] The underlining is from the NE.

6.4. ARTIFICIAL RAISING OF THE WATER LEVEL

1. Determination of dam crest elevation

   Based on the criteria mentioned in Paragraph 5.8.4 and the calculations mentioned in Paragraph 5.8.7, the minimum dam crest elevation can be determined.

   The NE considers it reasonable to admit a limited wind velocity for wave run-up calculations in case of safety check conditions (PMF and malfunctioning of a gate).

   Table 6.4.1 illustrates the calculation for the determination of the dam crest elevation, and the corresponding freeboard. The calculated required elevation of 842.84 can be rounded up to 843.0. The 16 cm difference is lower that the uncertainty we have on the characteristic values of the flood hydrographs and peak discharge.

Criteria	a) Design flood	b) Safety check flood	c.1) Malfunctioning of one chute spillway	c.2) Malfunctioning of one sluice spillway	d) Extreme wind conditions
Flood	Design	PMF	Design	Design	---
Flood peak inflow discharge [m^3/s]	16,200	16,200	16,200	16,200	---
Wind conditions	Normal	Normal	Normal	Normal	Extreme
Wind velocity [km/h]	80	60	60	60	140
Number of spillway devices in operation: Chutes	3	3	2	3	--
Number of spillway devices in operation: Sluices	5	5	5	4	--
Number of spillway devices in operation: Auxiliary	1	1	1	1	--
Initial level [m]	840	840	840	840	840
Maximum flood storage level [m]	840	840	842.53	842.04	--
Wind set-up [m]	0.01	0.01	0.01	0.01	0.03
Wave run-up [m]	0.40	0.30	0.30	0.30	0.80
Required level per criterion [m]	840.41	840.31	842.84	842.35	840.83
Required level [m]	842.84				
Minimum dam crest elevation [m]	rounded to 843.0				

Table 6.4.1: Calculation of required level for dam crest

The NE examined the possibility of placing a parapet wall on the dam crest. This parapet wall, located at the upstream face, would be a static structure, which should be able to support the water pressure. In that regard, possible climate change, the certain development of hydrological science and the better and more extensive knowledge of the Chenab river flow, the risk of getting higher flood discharge in a future reassessment should be considered.

He considers that, according to the drawings submitted by India, the dam crest is wide enough to give the possibility at any time in the future to add a parapet wall to provide additional safety in case of reassessment of flood discharge.

2. **DETERMINATION D 4** relating to artificial raising of the water level [point (a) of the difference referred by Pakistan]

In application of the provisions of the Treaty, the NE considers that the dam crest elevation should be set at the lowest elevation compatible with a sound and safe design based on the state of the art.

The dam crest elevation of the Baglihar dam, fixed in the design submitted by India at el. 844.5 m asl, resulting from a freeboard above the Full Pondage Level of 4.50 m is not at the lowest elevation.

The Determination of the NE is that the freeboard should be of 3 m above the Full Pondage Level leading to a dam crest elevation at 843.0 m asl. This is possible if the design of the chute spillway is optimised by minor shape adjustments in order to increase its capacity.

6.5. PONDAGE

1. The objective of the pondage is to *"meet the fluctuations in the discharge of the turbines arising from variations in the daily and the weekly loads of the plant"*. The maximum pondage *"shall not exceed twice the Pondage required for Firm Power"*; whereas, Firm Power means *"the hydro-electric power corresponding to the minimum mean discharge at the site of a plant"* (Treaty: *Annexure D, Part 1 - Definitions and Part 3 - New Run-of-River Plants*).

   The value of the minimum mean discharge at the site, which is agreed by the Parties, is: 125.68 m^3/s. The total inflow V_o resulting from this discharge during the week is 76.01 $M.m^3$.

2. The number of hours of operation, and the power of the plant during these hours, should be defined for each day of the week.

   We could first assume that the plant would operate continuously, with a discharge higher or lower than the mean value during the week: 125.68 m^3/s, and respecting the condition that *"the volume of water delivered into the river below the Plant in any one period of 24 hours shall not be less than 50% and not more than 130% of the volume received above the Plant during the same 24-hour period"* (Treaty: *Annexure D, Part 3 - New Run-of-River Plants, Paragraph 15(ii)*).

   We could also consider that the water will be stored in the operating pool during the weekend, when, as is generally the case, consumption is lower than during working days. The discharge through the turbines would be 62.8 m^3/s (0.5 x 125.68 m^3/s) for as long a time as possible, then during the working days 163.38 m^3/s (1.3 x 125.68). The mass curves of constant inflow discharges and flow through the turbine are represented on the graphic in Annex 6.5.1.

   The volume of the operating pool necessary to allow for this operation should be 14.3 $M.m^3$, and the maximum pondage double: 28.6 $M.m^3$.

   It is interesting to note that this value is independent of the variation of the inflow in the reservoir; it depends only on the total volume of inflow during the week and of the above mentioned coefficients (0.5 and 1.3) which limit the volume of water delivered each day into the river below (Annex 6.5.2).

3. But the objective of the pondage is to enable operation during peak load hours.

   Moreover, the NE cannot ignore the fact that one of the object(s) and purpose(s) of the Preamble is for the two parties to attain *"(…) the most complete and satisfactory utilisation of the waters of the Indus system of rivers (…)"*. In this context, the pondage should be as large as possible, with the condition, naturally, that the provisions of the Treaty are respected. In particular, the rule mentioned in Point 2 above is fundamental.

   If we introduce peak load hours in the mode of operation described in Point 2, the condition imposed by the Treaty, the volume of water delivered into the river below the Plant during a 24 hour day (no less than 50%, no more than 130%) determines exactly the total number of peak load hours during the week and the distribution each day.

The determination of the time of the peak load during each day should be based on a forecast of the power demand over 15 or 20 years in the Northern Region. We have made this only on the basis of the graph of power demand in December 2004 (Annex 6.5.3). We are aware of all the uncertainties of this approach, but it is the best available to us at this time.[153] The 49.1 hours of peak load are produced when the total demand in this region reaches approximately 22,500 MW.

Table 6.5.1 gives the peak load hours of operation of the plant determined for a total demand of 22,500 MW.

Day number	Week day	Total			Correction	Corrected total		
		time	hours	Daily hours	hours	time	hours	Daily hours
1	Saturday	17-21	4	4	---	17-21	4	4
	Sunday	---	---		---	---	---	
2	Sunday	17-19	2	2	(+1)	17-20	3	3
	Monday	---	---		---	---	---	
3	Monday	17-20:30	3.5	5.5	(+0.12)	17-20:37	3.62	5.62
	Tuesday	6-8	2		---	6-8	2	
4	Tuesday	8-8:30	0.5	7	(+1.5)	8-10	2	9.12
		17-21	4		(+0.62)	17-21:37	4.62	
	Wednesday	5:30-8	2.5		---	5:30-8	2.5	
5	Wednesday	8-9:30	1.5	8.5	(+0.5)	8-10	2	9.12
		17-21	4		(+0.12)	17:21:07	4.12	
	Thursday	5-8	3		---	5-8	3	
6	Thursday	8-11	3	11	(-1)	8-10	2	9.12
		16-21:30	5.5		(-0.88)	16:53-21:20	4.62	
	Friday	5:30-8	2.5		---	5:30-8	2.5	
7	Friday	8-10:30	2.5	9	---	8-10:30	2.5	9.12
		17-21	4		(+0.12)	17-21:07	4.12	
	Saturday	5:30-8	2.5		---	5:30-8	2.5	
			TOTAL	47			TOTAL	49.1

Table 6.5.1: Peak load hours of operation of the plant during the week of minimum mean inflow

[153] As an example of the possible evolution of the load curve, we give in Annexes 6.5.4 and 6.5.5 the load curves of Switzerland in 2000. This is a mountainous country, largely integrated in the Eur opean grid. Its population is 7.2 million, and its electrical energy consumption is about 7000 kWh/person/year. The peak load hours during a characteristic day (the third Wednesday of the month) in December, for a capacity of 6,000 MW, are between 6 h and 22 h, roughly similar, as for the limits, to those admitted for Baglihar.

The number of peak load hours is small on Saturday and Sunday, and also Monday; this is advantageous for the storage of water which can be carried forward to the working days.

The reason for the corrections is the necessity to increase the total number of hours from 47.0 to 49.1 and to respect the provision of the Treaty concerning the volume of water delivered into the river below the plant.

The calculations made on this basis are presented in Annex 6.5.6, accompanied by the graph of the mass curves of discharge (Annex 6.5.7). The volume of pondage necessary to operate is 16.28 $M.m^3$. The maximum pondage is double this amount: 32.56 $M.m^3$. This volume would allow, in addition to the operation of the plant during peak load hours, for regulation of the variations in river flow, if any.

4. **DETERMINATION D 5** relating to the pondage [point (b) of the difference referred by Pakistan]

Applying the provisions of the Treaty and based on the state of the art, the NE considers that the first objective of pondage is to regulate the flow of the river to meet consumer demand.

He considers also that the values for maximum pondage stipulated by India as well as by Pakistan are not in conformity with the criteria laid down in the Treaty.

The Determination of the NE is that the maximum pondage should be fixed at 32.56 $M.m^3$, and the corresponding Dead Storage Level is at el. 836 m asl which is one meter higher than the level of the Indian design.

6.6. LEVEL OF THE POWER INTAKE

1. The volume of Pondage and elevation of the dead storage level determined by the NE in Chapter 6.5 is considered.

   The criterion for fixing the elevation of the water intake is the dead storage level determined above, and the required submergence necessary to avoid the development of vortices. Other aspects, in particular in relation to sedimentation issues, are treated in Chapter 6.3.

   The flow approach conditions are highly asymmetric. These conditions influence the determination of the minimum submergence depth of the intake. The division of flow between the two gate openings in the intake structure should also be taken as a parameter in the calculation.

   As a general matter, the arrangement of the power intake is not discussed by the Parties. The NE points out that the asymmetrical approach conditions are unfavourable in terms of the intake elevation. A different arrangement with more symmetrical approach conditions, for example by embedding the intake structure in the dam body, could reduce the required minimum submergence depth. India has argued that another location was not possible due to geological conditions, but this was not clearly demonstrated.

   As the inflow approach conditions are evidently highly asymmetrical, the NE proposes to analyse the submergence with different distributions of the discharge between the two gate openings. The NE considered both 50:50 and 60:40 distribution ratios.

   Both Gordon's and Knauss's formulae have been applied to calculate required submersion in order to determine the minimum required submergence, and thus the highest location of the intake.

   As specified in Chapter 5.10.6, the submergence calculation is done based on the reduced gate section. The flow is divided in the two 7.5 m high and 10.0 m wide openings.

   Table 6.6.1 presents the results of the submergence calculations. Following the calculation method presented in Chapter 5.10.6, the level of the intake could be raised by 3.0 m and fixed at el. 821.0 m asl.

		Gordon (1)		Knauss (2)	
Discharge	430 [m^3/s]				
Flow distribution between the two intake openings		*50-50*	*60-40*	*50-50*	*60-40*
Discharge in the intake opening	[m^3/s]	215	258	215	258
Flow Velocity	[m/s]	2.87	3.44	2.87	3.44
Froude number ***Fr***	[-]	0.33	0.40	0.33	0.40
Minimum submergence above intake lintel	S_{min} [m]	5.76	6.92		
Minimum submergence above the opening axis elevation	h_{min} [m]			11.25	11.25
DSL – Dead storage Level	[m asl]	836.0	836.0	836.0	836.0
Required intake sill level	[m asl]	822.74	821.58	821.0	821.0

(1) Lateral or asymmetric inflow approach conditions.
(2) S = 1.0-1.5 · D. Coefficient 1.5 is selected.

Table 6.6.1: Calculation of intake sill elevation

2. **DETERMINATION D 6** relating to the level of the power intake [point (c) of the difference referred by Pakistan]

The NE considers that the elevation of the intake stipulated by India is not at the highest level, as required by the criteria laid down in the Treaty.

The determination of the NE is that the intake level should be raised by 3 m and fixed at el. 821.0 m asl.

The required minimum submergence depth depends on the discharge and the inflow approach conditions. The location of the intake structure proposed by India leads to asymmetrical approach conditions. A different arrangement, with more symmetrical approach conditions, could reduce the required minimum submergence depth.

The NE believes that at the design stage the normal practice is to avoid the development of vortices by an appropriate arrangement of the intake structure and sufficient submergence or operating restrictions at the minimum water level. In particular cases where these measures cannot be implemented for technical or economic reasons, then recourse to anti-vortex devices would be the best alternative.

He recommends that all possible structural measures should be taken to limit the circulation of flow within the intake structure and in its vicinity, especially avoiding sharp bends inside of the intake structure and in its vicinity.

7. APPORTIONMENT BETWEEN PARTIES OF COSTS OF REMUNERATION AND EXPENSES OF THE NEUTRAL EXPERT

1. *Annexure F* of the Treaty deals with the issue of the allocation of costs between the Parties. *Paragraph 10 of Annexure F, Part 2* reads as follows:

> *"Each party shall bear its own costs. The remuneration and expenses of the Neutral Expert and of any assistance that he may need shall be borne initially as provided in Part 3 of this Annexure and eventually by the Party against which his decision is rendered, except as, in special circumstances, and for reasons to be stated by him, he may otherwise direct. He shall include in his decision a direction concerning the extent to which the costs of such remuneration and expenses are to be borne by either Party."*

The provision of *Paragraph 14 of the Annexure F* stipulates that the Parties pay to the Bank (the World Bank - WB) amounts to be held in trust by the WB, and *Paragraph 15* provides that the remuneration and expenses of the NE and of any assistance that he may need, shall be paid or reimbursed by the WB from the amount held in trust by it.

2. During the time of elaboration of the determination of the NE, his remuneration, those of his legal adviser and of his assistant were carried out according to the rules mentioned above, each Party contributing equally to the trust fund.

3. The rules contained in *Paragraph 10* are rather similar to the rules and principles applicable to the allocation of costs in international commercial arbitration practice.[154]

4. The practice there is to confer discretion on an arbitral tribunal with respect to its award on costs. In principle, costs are to be borne by the unsuccessful party, i.e. the "Party against which his decision is rendered," to quote the terms of *Annexure F, Paragraph 10*. The logical basis for this policy appears to be that a "successful" claimant has, in effect, been forced to go through the process in order to achieve success, and should not be penalized by having to pay for the process itself. The same logic holds true for a successful respondent, faced with an unmerited claim.

5. Thus, emphasis is placed on the content and the findings of the decision as the significant element in an arbitral tribunal's consideration of the apportionment of the arbitration costs. In case an arbitral tribunal considers that the decision cannot be qualified as rendered against a single party, there could be some different apportionment.

6. In conclusion, having considered the content of his decision, *Paragraph 10 of Annexure F* which gives him discretion in "special circumstances" and the practices of international tribunals, the NE decides to share the costs equally among the Parties.

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[154] *See, e.g.*, Art. 40, UNCITRAL Rules ("1. Except as provided in paragraph 2, the costs of arbitration shall in principle be borne by the unsuccessful party. However, the arbitral tri bunal may apportion each of such costs between the parties if it determines that apportionment is reasonable, taking into account the circumstances of the case").

POSTSCRIPT

The points of difference referred by Pakistan were not trivial and their complexity required from the claimant as well as from the respondent a major work of analysis and of synthesis to present their theses. The exchanges between the Parties were documented with great care; the oral presentations during three meetings and the visit to the site of Baglihar were found to be of a high technical, scientific and legal interest. The process lasted one year. The work of the NE, of his assistant and of his legal adviser was also not easy. These are the reasons why the NE believes that the process was equally fruitful for all the participants.

The NE considers that his decision has not been rendered against one or the other Party. His opinion is that, in fact, specific Parties emerge successfully from the treatment of this difference: the Authors of the Treaty. The Treaty is the successful document.

Professor Raymond Lafitte
Neutral Expert

With the support of

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and of

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Lausanne, Switzerland
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