PAKISTAN ENGINEERING CONGRESS

75th ANNUAL SESSION
2018 – 2019

PROCEEDINGS

Volume 76 **LAHORE**

ON BEHALF OF PAKISTAN ENGINEERING CONGRESS

Pakistan Engineering Congress as a body does not hold itself responsible for the opinions expressed by different authors in this Volume

Compiled and Edited

By:

Engr. Syed Mansoob Ali Zaidi

Vice President / Convener Publication Committee

Published by:

Engr. Najam Waheed

Secretary

Price Rs. 1000/-
Members Free

Can be had at:

PAKISTAN ENGINEERING CONGRESS

(4th Floor) Pakistan Engineering Congress Building,
97-A/D-1, Liberty Market Gulberg-III, Lahore 54660
(Near Liberty Roundabout)
Phone: (042) 35784238, (042) 35784235 Fax: (042) 35784236
Web-site: www.pecongress.org.pk
E-mail: info@pecongress.org.pk
ISBN: 978-969-603-043-0

PAKISTAN ENGINEERING CONGRESS
THE EXECUTIVE COUNCIL FOR THE 75th SESSION

PRESIDENT
Engr. Tariq Rashid Wattoo

Immediate Past President
Engr. Ch. Ghulam Hussain (President 74th Session)

VICE-PRESIDENTS

1. Engr. Husnain Ahmad
2. Engr. R. K. Anver
3. Engr. Syed Mansoob Ali Zaidi
4. Engr. Ch. Muhammad Arif
5. Engr. Akhtar Abbas Khawaja
6. Engr. Syed Shehzad Raza
7. Engr. Khalid Javed
8. Engr. Ch. Muhammad Aamir Ali
9. Engr. Muhammad Usman

OFFICE BEARERS

1.	Engr. Najam Waheed	Secretary
2.	Engr. Capt (R) M. Qadir Khan	Joint Secretary
3.	Engr. Syed Nafasat Raza	Treasurer
4.	Engr. M. Anwar Qaseem Qureshi	Publicity Secretary
5.	Engr. Ijaz Ahmad Cheema	Business Manager

EXECUTIVE COUNCIL MEMBERS

1. Engr. Iftikhar Ahmad
2. Engr. Riaz Ahmad Khan
3. Engr. Ejaz Ahmad Cheema
4. Engr. Nayyar Saeed
5. Engr. Najam Waheed
6. Engr. Anwar Ahmad
7. Engr. Muhammad Ibrahim Malik
8. Engr. Jamil Ahmad Basra
9. Engr. Amjad Saeed
10. Engr. Ali Arshad Hakeem
11. Engr. Brig (R) Sohail Ahmad Qureshi
12. Engr. Parvez Iftikhar
13. Engr. Syed Anwar ul Hassan
14. Engr. M. Anwar Qaseem Qureshi
15. Engr. Capt. (R) M. Qadir Khan
16. Engr. Iftikhar ul Haq
17. Engr. Dr. Muhammad Saeed
18. Engr. Tahir Anjum Qureshi
19. Engr. Muhammad Aslam
20. Engr. Muhammad Tariq Butt
21. Engr. Usman-e-Ghani
22. Engr. Muhammad Sharif Shah
23. Engr. Syed Nafasat Raza
24. Engr. Sheikh Muhammad Saeed Tahir
25. Engr. Faisal Shahzad

NAME OF PRESIDENTS

1912–14	**……**	**The Hon'ble Sir H.P. Burt, K.C.I.E.**
1914–15	……	The Hon'ble Col. R.S. Maclagon, C.B., CIE
1915–16	……	The Hon'ble Col. R.S. Maclagon, C.B., CIE
1916–17	……	Col. S.L. Craster, C.I.E.
1917–18	……	The Hon'ble Mr. D.W. Aikman, C.I.E.
1918–19	……	Mr. F.W. Woods
1919–20	(April 1919–April 1920)....	Mr. A.S. Montgomery
1920–21	(April 1920–April 1921)...	Mr. H.W. MIVES/M.F.T. Butes
1921–22	(April 1921–April 1922)...	Mr. W.P. Sangster
1922–23	(April 1922–April 1923)...	Mr. F.A. Hadow
1923–24	(April 1923–April 1924)...	Mr. Sir Ganga Ram, C.I.E., M.O.V.
1924–25	(April 1924–April 1925)...	Mr. E.R. Foy
1925–26	(April 1925–April 1926)...	Mr. Lt. Col. H.E.C. Cowie, R.E./Mr. Lines
1926–27	(April 1926–April 1927)...	Mr. A.R. Astury
1927–28	(April 1927–April 1928)...	Mr. R.P. Hadow
1928–29	(Feb. 1928–Feb. 1929)…..	Mr. Col. C. Walton, D.S.O, R.E.
1930–31	(Feb. 1929–Feb. 1931)…..	Mr. W.S. Dorman
1931–32	……	Mr. J.B. Smith, C.I.E.
1932–33	……	R.B.W. Chopra
1933–34	……	Lt. Col. W. Macrae, R.E.
1934–35	……	R.B. M.S. Dhody
1935–36	……	Mr. D. Macfariane
1936–37	……	Mr. J.D. H. Bedford
1937–38	……	R.B.B. N. Singh
1938–39	……	Mr. D.A. Howell
1939–40	……	R.B.B.P. Varma
1940–41	……	Mr. R. Trevor Jones, M.C.
1941–42	……	Mr. A. St. G. Lyster
1942–43	(March 1942–Feb. 1943)...	Sir, William Roberts, C.I.E.
1943–44	(Feb. 1943–Feb. 1944)…..	Sir Arthur Griffin, Kt, O.B.E.
1944–45	(Feb. 1944–Feb. 1945)…..	Mr. F.F. Haigh, C.I.E.
1945–46	(Feb. 1945–Feb. 1946)…..	Mr. A.M.R. Montague, C.I.E.
1946–47	(Feb. 1946–Feb. 1947)…..	Mr. R.B.D. Khanna
1947–49	……	……
1949–51	(Feb. 1949–Feb. 1951)…..	Mr. K.B. M.A. Hamid, I.S.E.
1951–52	(April 1951–Dec. 1952)….	Mr. Khan Muhammad Azam
1952–54	(Dec. 1952–April 1954)….	Mr. K.B.A. Ghafoor
1954–55	(April 1954–March 1955)..	Kazi Zahir Hussain
1955–56	(March 1955–Feb. 1956)…	Mr. A.D. Ashraf
1956–57	(Feb. 1956–Feb. 1957)…..	Mr. Khan Muhammad Inamullah Khan
1957–58	(Feb. 1957–March 1958)…	Mr. M.M. Zubair
1958–59	(March 1958–Feb. 1959)…	Mr. Mir Bashar Khan
1959–60	(Feb. 1959–Feb. 1960)…..	Mr. S.I. Mahbub
1960–61	(Feb. 1960–Feb. 1961)…..	Mr. Ghulam Sadiq Khan
1961–62	(Feb. 1961–April 1962)…..	Mian Abdul Aziz
1962–63	(April 1962–Oct. 1963)…..	Mr. Abdul Rashid Kazi, S.Q.A.
1963–65	(Oct. 1963–March 1965)…	Mr. C.A. Hamid
1965–66	(March 1965–Oct. 1966)…	Mr. A.M. Akhoond, S.I. P.R.S.
1966–68	(Oct. 1966–Feb. 1968)…..	Mr. M.A. Waheed, P.S.E.I.
1968–69	(Feb. 1968–March 1969)…	Sh. Ahmad Hassan, S.Q.A.
1969–71	(March 1969–April 1971)..	Mian Alim–ud–Din S.Q.A.S.K.
1971–72	(April 1971–April 1972)….	Mr. I.A.S. Bokhari
1972–74	(Dec. 1972–Nov. 1974)…..	Sayyid Hamid
1974–75	(Nov. 1974–Dec. 1975)…..	Dr. Mubashir Hasan
1975–78	(Dec. 1975–May 1978)…..	Syed Muhammad Ayoob
1978–80	(May 1978–Dec. 1980)…..	Mr. Ashfaq Hasan
1980–82	(Dec. 1980–April 1982)….	Syed Muhammad Ayoob
1982–83	(April 1982–April 1983)…	Mr. Daud Beg
1983–85	(April 1983–Oct. 1985)….	Mr. Masih Ullah Khan
1985–86	(Oct. 1985–Oct. 1986)…..	Mian Masud Akhtar
1986–87	(Oct. 1986–Dec. 1987)…..	Ch. Abdus Salam
1987–89	(Dec. 1987–Jan. 1989)…..	Dr. Muhammad Ikramullah
1989–92	(Jan. 1989–Feb. 1992)…..	Mr. Shamsul Mulk
1992–94	(Feb. 1992–July 1994)…..	Rana Allah Dad Khan
1994–96	(July 1994–Oct. 1996)…..	Ch. Mazhar Ali
1996–98	(Oct. 1996–May 1998)….	Mr. Khalid Latif Khawaja
1998–2000	(May 1998–Dec. 2000)….	Syed Nazar Hussain Mashhadi
2000–2004	(Dec. 2000–Feb. 2004)…...	Ch. Muhammad Rashid Khan
2004–2006	(April 2004-Dec.2006)……	Rana Muhammad Saeed Ahmad Khan
2006–2011	(Dec.2006-July 2011)	Engr. Husnain Ahmad
2011–2013	(July 2011-Dec. 2013)	Engr. Riaz Ahmad Khan
2014–2015	(Jan. 2014-Dec. 2015)	Engr. Iftikhar Ahmad
2016–2017	(Jan. 2016-Dec. 2017)	Engr. Ch. Ghulam Hussain
2018–2019	(Jan. 2018-Dec. 2019)	Engr. Tariq Rasheed Wattoo

NAME OF SECRETARIES

1912–14	**……..**	**No Record**
1914–15	…….	No Record
1915–16	…….	No Record
1916–17	…….	No Record
1917–18	…….	Mr. W.S. Dorman M. Inst CE
1918–19	…….	No Record
1919–20	…….	Mr. W.S. Dorman M. Inst. CE
1920–21	…….	Mr. J.H.T. Middleton
1921–22	…….	Mr. A.R. Astbury M. Inst. CE
1922–23	…….	Mr. A.R. Astbury M. Inst. CE
1923–24	…….	Mr. D.J. Morris, Assoc, M. Inst. CE
1924–25	…….	Mr. D.A. Howell, Assoc, M. Inst. CE
1925–26	…….	Mr. C.A. Colyer Assoc, M. Inst. CE
1926–27	…….	Mr. C.A. Colyer Assoc, M. Inst. CE
1927–28	…….	No Record
1928–29	…….	Mr. John Peterson Gunn, M.A. B.Sc.
1929–30	…….	No Record
1930–31	…….	Mr. Ainsley Marshall Rendall, AMICE
1931–32	…….	Mr. John Hinton Fletcher, NC
1932–33	…….	Mr. John Peterson Gunn
1933–34	…….	Mr. Raj Behari Seth
1934–35	…….	Dr. E. Mckenzie Taylor, MBE
1935–36	…….	Dr. E. Mckenzie Taylor, MBE
1936–37	…….	Mr. Thomas William Roberton Easton
1937–38	…….	Mr. Wilfered John Benson, AMICE
1938–39	…….	Mr. Dev Chan Khanna
1939–40	…….	No Record
1940–41	…….	Mr. Dev Chan Khanna
1941–42	…….	Mr. Sita Ram Mehra A.M, Inst. CE
1942–43	…….	Mr. Sita Ram Mehra A.M, Inst. CE
1943–44	…….	Mr. Karnail Singh
1944–45	…….	Mr. Karnail Singh
1945–46	…….	No Record
1946–47	…….	No Record
1947–49	…….	No Record
1949–51	…….	Mr. A.M. Malik, MBPSEI
1951–52	…….	Mr. A.M. Malik, MBPSEI
1952–54	…….	Mr. R.F.T. Farrant, PSEI
1954–55	…….	No Record
1955–56	…….	Mr. Saeed Ahmad
1956–57	…….	Mr. Saeed Ahmad
1957–58	…….	Mr. H.J. Asrar, PSEI
1958–59	…….	Mr. H.J. Asrar, PSEI
1959–60	…….	Mr. H.J. Asrar, PSEI
1960–61	(Up to 30–11–1961)……	Mr. A.A. Jamal–ud–Din, PSEI
	(From 01–12–1960)……..	
1961–62	…….	Mian Shamim Ahmad, PSEI
1962–63	…….	Mian Shamim Ahmad, PSEI
1963–65	…….	Mr. I.A.S. Bokhari, PSEI
1965–66	…….	Mr. C.A. Vali PRS
1966–68	…….	Syed Fayyaz Ali Shah, PSEI
1968–69	…….	Mr. Sarfraz Khan Malik, PSEI
1969–71	…….	Mr. Abdul Latif Mirza, PSEI
1971–72	…….	Malik Muhammad Ahsraf, PSEI
1972–74	…….	Mian Iftikhar–ud–Din
1974–75	…….	Sh. Nisar–ul–Haq
1975–78	…….	Sh. Nisar–ul–Haq
1978–80	…….	Sardar Allah Bukhsh
1980–82	…….	Mr. M.R. Chaudhry
1982–83	…….	Ch. Muhammad Rashid Khan
1983–85	…….	Syed Nazar Hussain Mashhadi
1985–86	…….	Dr. Izhar–ul–Haq
1986–87	…….	Syed Nazar Hussain Mashhadi
1987–89	…….	Ch. Muhammad Khurshid
1989–92	…….	Dr. Izhar–ul–Haq
1992–94	…….	Mian Iftikhar–ul–Haq
1994–96	…….	Dr. Izhar–ul–Haq
1996–98	…….	Mr. M. Rafiq Shad
1998–2000	…….	Syed Mansoob Ali Zaidi
2000–2004	…….	Ch. Ghulam Hussain
2004–2006	…….	Syed Mansoob Ali Zaidi
2006–2011	…….	Ch. Ghulam Hussain
2011–2013	(July 2011-Dec. 2013)	Engr. Akhtar Abbas Khawaja
2014–2015	(Jan. 2014-Dec. 2015)	Engr. Syed Mansoob Ali Zaidi
2016–2017	(Jan. 2016-Dec. 2017)	Engr. Nayyar Saeed
2018–2019	(Jan. 2018-Dec. 2019)	Engr. Najam Waheed



Engr. Tariq Rashid Wattoo
President
Pakistan Engineering Congress
(75th Session)

PUBLICATION COMMITTEE

1.	Engr. S.M.A Zaidi	Convener
2.	Engr. Amjad Saeed	Co-convener
3.	Engr. Husnain Ahmad	Member
4.	Engr. Riaz Ahmad Khan	Member
5.	Engr. Iftikhar Ahmad	Member
6.	Engr. Najam Waheed	Member
7.	Engr. Nayyar Saeed	Member
8.	Engr. Iftikhar ul Haq	Member
9.	Engr. Usman-e-Ghani	Member
10.	Engr. M. Anwar Qaseem Qureshi	Member
11.	Engr. Tahir Anjum Qureshi	Member
12.	Engr. Muhammad Akram Khaloon	Member

TABLE OF CONTENTS

Sr. No.	Paper No.	Title of Paper	Author's Name	No. of Pages
01.	791	Technical Perspective of Diamir Basha Dam	Engr. Riaz Nazir Tarar	01
02.	792	Potential Climate Change Impact on Floods in Punjab, Pakistan	Dr. Muhammad Nawaz Bhutta	25
03.	793	Soil Property Correlations for Assessing Compressibility and undrained Shearing Strength of Lahore Clays	Sohail Kibria, Muhammad Ali	45
04.	794	Stabilization of a Terrace Slope at Bansara Gali, Murree	Sohail Kibria, Muhammad Ali	55
05.	795	Electrification of Karachi-Lahore Section of ML-1 under CPEC	Abdul Rehman Chaudhry	71
06.	796	Contours of the First Ever National Water Policy of Pakistan	Dr. Qazi Tallat M. Siddiqui	81
07.	798	Impact of Excess Groundwater Pumping and its Remedial Measures in Irrigated Area of Bari Doab, Punjab, Pakistan	Engr. Dr. Muhammad Saeed, Engr. Dr. Muhammad Basharat, Engr. Muhammad Jawad	97
08.	799	Water Quality Evaluation of Khanpur Dam through Physicochemical and Microbial Analysis	Sohaib Zia, Imran Hashmi	111
09.	802	Water Resource Management in Pakistan National and Provincial Perspectives on Institutions and Policies	Dr. Mahmood Ahmad, Tabeer Riaz	125
10.	804	Comparative Analysis of Physical and Numerical Hydraulic Model Study of Rehabilitation and up-gradation pf Panjnad Barrage	Engr. Muhammad Muneeb Khan, Engr. Muhammad Mohsin Munir, Engr. Raza-ur-Rehman Abbasi, Engr. Javed Munir, Engr. Mansoor Ali	137

Sr. No.	Paper No.	Title of Paper	Author's Name	No. of Pages
11.	805	Review on Aerobic Wastewater Treatment and Role of Biotechnology	N. Maqbool, Sher Jamal Khan	163
12.	807	Modeling of Future Discharge Projection and Estimation of Snow / Ice Melt Contributions from the Glacierized Hunza River Basin, Pakistan	Syed Hammad Ali, Muhammad Arshad Pervez, Mujahid Tanveer Ahmad, Rijan Bhakta Kayastha, Richard Armstrong	179
13.	808	Groundwater Prospectus, Challenges and Management Strategies in Indus Basin	Ghulam Nabi, Noor Muhammad Khan, Muhammad Waseem, Habib-ur-Rehman, Ijaz Ahmad	201
14.		List of Previous Papers Presented at Proceedings		211

Paper No. 791

TECHNICAL PERSPECTIVE OF DIAMIR BASHA DAM

Engr. Riaz Nazir Tarar

TECHNICAL PERSPECTIVE OF DIAMIR BASHA DAM

By:

Engr. Riaz Nazir Tarar

1. THE PROJECT

1.1 Engineering Status

Diamer Basha Dam Project (DBDP) is proposed on Indus River at a site which is: 315 km (195 miles) upstream of Tarbela Dam Project; some 180 km (113 miles) below the town of Gilgit, and 40 km (24 miles) downstream of Chilas, the headquarter of Diamer District in Gilgit-Baltistan (Location Map is Annex-01).

Reservoir will extend about 105 km upto Raikot Bridge (refer Annex-02). Engineering studies for project development were started in early 1980's by Montreal Engineering Company (MONENCO) under sponsorship of Canadian International Development Agency (CIDA). MONENCO completed the Conceptual Feasibility Report of the Project in 1984. This report proposed an earth core rockfill dam (ECRD) to create a live storage of 5.7 MAF and power installation of 3360 MW on the left bank.

MONENCO's Conceptual Feasibility of Report 1984 was reviewed by a World Bank appointed Panel of Experts (PoE). It recommended that dam types other than proposed ECRD should also be considered in view of peculiar site conditions.

During 2002, WAPDA engaged NEAC, a joint venture of national / international consultants, to conduct Feasibility Report of DBDP. This study was completed in 2004. Accordingly, a 277m high roller compacted concrete (RCC) dam was proposed to create a live storage capacity of 7.3 MAF and installed capacity of 4500 MW equally divided between two river banks.

During 2005, WAPDA engaged Diamer Basha Consultants (DBC), a joint venture of renowned international/national consultants, for conducting 'Review of Feasibility Report, Engineering Design Tender Drawings/Documents of Diamer Basha Dam Project'. This exercise was completed during 2008.

1.2 Comparative Technical Parameters

'Comparative Technical Project Features' based on the above mentioned three engineering studies are shown in Annex-03.

During conduction of these studies over a period of 27 years (1981 – 2008) extensive geotechnical investigations were conducted. According to details shown in Annex-04, these aggregated to: 17272 m of core drilling; and 2054 m aditing.

1.3 Salient Features as Per Engineering Design

Salient features based on engineering design completed by DBC in 2008 are as below: -

• **Main Dam**	
Maximum Height above Firm Bed Rock	272 meters
Type	Roller Compacted Concrete (RCC) Gravity (Slightly Curved)
• **Reservoir**	
Gross Storage	8.1 Million Acre Feet (MAF)

Live Storage	6.4 MAF
• **Power Houses**	
No.	2
Total Installed Capacity Total	4500 MW (2 X 2250 MW)
Type & Location	Underground, one each on right & left side
Mean Annual Generation at Site	18,100 Gwh

1.4 Project Implementation Status

Project PC-I Proforma as per engineering design of 2008, was approved by ECNEC of Government of Pakistan (GoP) in August 2009. This resulted from the consensus of all the four provinces for building the project achieved through the Council of Common Interests (CCI). While the preliminaries of land acquisition, construction of camps and access road, etc. started in 2009, construction of the core project remained stalled due to lack of foreign funding commitment. Lastly, during 2015, GoP took a policy decision to implement the core project in two phases, namely: dam and appurtenants; and power generation facilities.

Work on land acquisition was started through a separately approved PC-I during 2008 Revised PC-I of Rs. 101 billion was approved by GoP during 2016.

PC-I for Dam Part (Phase-I) costing Rs. 424 billion was approved by ECNEC in April 2018. PC-I for Power Generation Part (Phase-II) for Rs. 751 billion was reportedly also under scrutiny / processing before approval. According to 2018 estimates aggregate cost of DBDP was Rs. 1326 billion.

A major boost to start the inordinately delayed project came through a decision of the Supreme Court of Pakistan during late 2017, directing GoP to take up construction of the dam on priority basis. To financially support this effort through internal resources, Chief Justice of the Supreme Court established a special 'Dam Construction Fund'. Later on this was renamed Chief Justice/Prime Minister Fund. Prompt public response was quite encouraging and donations are still pouring. Therefore, the stage is now set for project construction take-off without further delay.

Implementing agency of WAPDA is now in the process of engaging consultants to start active core construction during 2020. Overall project construction period is envisaged between 9.5 to 10 years with progressive commissioning of power units starting in the 7th year.

1.5 Estimated Project Benefits

On a conservative basis, EIRR of the project is around 15% while FIRR is around 8%.

It is estimated that 6.4 MAF live storage of project will substantially improve diversions into Indus Basin Irrigation System, which are now stagnating even below Post-Tarbela development level due to lack of inadequate system storage caused by rapid sedimentation of three on-line storages.

Sediment trapped in Diamer Basha reservoir will enhance useful life of Tarbela by about 35 years. Besides, it will substantially enhance the lives of re-regulating storages at the upcoming downstream power generating facilities at Dasu, Pattan and Thakot.

It is estimated that due to cascading effect of Diamer Basha reservoir, generation at downstream facilities will be enhanced by: 2400 Gwh at existing Tarbela, Ghazi-Barotha and

Chashma; and 10500 Gwh at the upcoming Dasu Pattan and Thakot. This aggregate additionality of 13000 Gwh will constitute about 70% of at site generation.

2. EVALUATION OF ALTERNATIVE DESIGNS

As already mentioned, the final project design has evolved through three engineering studies of: MONENCO (1984); NEAC (2004); and DBC (2008). 'Comparative Technical Parameters of Proposed Dam' are shown in Annex-03. It will be noticed that original (MONENCO) design has got transformed from 200m ECRD to 272 m RCCD and power installation enhanced from 3360 to 4500MW.

In the above process, technical scrutiny particularly focused upon the following aspects of dam design: -

i. Type
ii. Siting
iii. Layout
iv. Power Optimization

It can be appreciated from 'Regional Geological Map' in Annex-05 that DBDP will be located in a highly seismic area. Therefore, after finalization of type of dam siting location, project layout and power optimization, an extensive 'Seismic Hazard Assessment was conducted, during the engineering design phase of 2005-08.

Upon completion, Diamer Basha Dam will be the highest 272 m RCC structure in the world. Therefore, during actual construction it could face serious challenges which were also duly considered during the engineering design phase.

3. Type of Dam

3.1 Alternatives Evaluated

The following alternative dam types are generally considered for such mega projects:-

i. Earth Core Rockfill Dam (ECRD).
ii. Concrete Faced Rockfill Dam (CFRD).
iii. Concrete Gravity Dam (CGD).
iv. Arch Gravity Concrete Dam (AGCD)
v. Roller Compacted Concrete Dam (RCCD)

As already mentioned, MONENCO's Conceptual Feasibility Report (1984), proposed an ECRD supported by limited geological investigations. At the proposed dam site, over 50m thick alluvium was deposited above the bedrock. Therefore, for construction of ECRD a positive cut-off upto bedrock would be required to effectively control seepage. Due to these limitations, ECRD proposal of MONENCO was not favoured by PoE (Panel of Experts) of the World Bank in 1988 and it recommended study of other suitable types of dams for the project.

Task-I of NEAC's Feasibility Study related to the selection of an appropriate dam type. NEAC evaluated in detail all of the above mentioned alternate dam types comprising: ECRD; CFRD; CGD; AGCD; and RCCD. After carrying out technical and optimization studies for various dam types, NEAC finally focused on the three types of: ECRD; CFRD; and RCCD. Comparative advantages / disadvantages of these types of dams emerged as briefly explained the following.

3.2 ECRD

MONENCO had proposed this dam type in their Conceptual Feasibility Report. This proposal inherited the following serious shortcomings:-

i. Lack of impervious natural core material in the vicinity and the problems of mixing silty material with the sandy gravels.

ii. Need to connect the core to bed rock which would double the excavation quantity.

iii. Differential settlement due to topography of the bedrock.

iv. Liquefaction risk of the river alluvium in case of earthquake.

v. Possibility of cracks in non-plastic erodible core due to earthquake.

vi. Doubtful integrity of the proposed concrete cut-off wall through 50 m river overburden containing very heavy boulders along with extreme difficulties of construction.

vii. Insufficient capacity of spillway cut in right abutment, which would necessitate provision of an auxiliary spillway.

viii. Catastrophic damage by likely overtopping in case of a glacial lake outburst flood (GLOF).

ix. Non-acceptability of a single powerhouse on left abutment by political stakeholders (GB and KP).

Above factors prompted 1988 PoE of World Bank to disfavor ECRD and, instead, proposed study of other types of dam.

3.3 CFRD

NEAC evaluated this type in detail in the Task-I Report of 2003. However, this type could not be selected also due to the following inherited disadvantages:-

i. Concrete face slab and plinth beam needed tie-up with over 50 m deep bed-rock.

ii. Rockfill to be placed on bed rock after 50 m excavation or on the compacted alluvium after removing 15 m from top of river bed.

iii. Could suffer deformation and cracks on face slab due to shaking in earthquakes.

iv. Rock cut for spillway in right abutment had insufficient capacity.

v. Conversion of diversion tunnels into low level outlet works (LLOWs) was not sustainable.

vi. Likelihood of catastrophic damage by overtopping through GLOF.

This type of dam could also not find favour with PoE appointed for review of NEACs Feasibility Study.

3.4 RCCD

This type of dam was also studied in depth by NEAC as part of Task-I and came out with the following significant advantages: -

i. Shorter diversion and power tunnels.

ii. Accommodation of spillway in the dam body.

iii. Provision of LLOWs in dam body for effective sluicing and supplemental irrigation releases.

iv. No risk from overtopping.

v. Foundation on bed rock

vi. Two equal capacity power houses on each side to meet political demand of Khyber Pakhtunkhwa and Gilgit Baltistan.

vii. Reduced cost, construction time and risk.

PoE appointed for NEAC's Feasibility Study endorsed RCCD for construction.

RCCD type proposed by NEAC was critically reviewed by DBC during the engineering design phase of 2005-08 and found preferable option. PoE appointed by WAPDA for Engineering Design of DBDP also endorsed RCCD. Consequently, DBC completed Detailed Engineering Design and Tender Documents for an RCCD. Type Dam.

4. SELECTION OF DAM SITE

4.1 MONENCO's Study

In 1984 Conceptual Feasibility Report of MONENCO, five dam / sites from A to E and seven dam axes were selected in 5km-long river section in consideration of topographic conditions. 'Alternative Axes Evaluated for Dam Location' are shown in Annex-06.

Arch gravity dam (AGD), concrete faced rockfill dam (CFRD), earth core rockfill dam (ECRD) and other dam types were compared and selected according to topographic conditions at various dam axes. MONENCO recommended dam axis C_2 and an ECRD built on overburden.

Though World Bank's PoE of 1988 did not accept ECRD, it endorsed proposed damsite location at axis C (including axes C_1 and C_2) on the river bend (refer Annex-06).

4.2 NEAC's Study

Based on preliminary research, under stage 1 of Task-I, NEAC compared and analyzed the layout plans for dam axes C_2, C_1 and D by evaluating a total of 12 layout schemes at all sites considering four dam types. Comprising of ECRD; CERD; CGD; and RCCD. Under stage 2 of Task-I, NEAC evaluated three (3) layout options based on study of only two dam types (CFRD and CGD to be constructed with RCC) at axis C and axis D.

NEAC, finally proposed the scheme of RCCD at axis D with: maximum height of 281 m; overflow dam section on river bed; spillway in the dam body; two equal capacity underground power houses on each side of the valley; and diversion tunnels on right abutment. This scheme was endorsed by PoE in 2003 and formed the basis of Feasibility Report completed by NEAC in 2004.

4.3 DBC's Engineering Design

Diamer Basha Consultants (DBC) undertook review of NEAC's Feasibility during engineering design completed between 2005 and 2008. While reviewing feasibility study of NEAC, it was detected from the subsequent results of Adit No. 1 on left bank of dam axis D, that it contained: a large number of shear zones; large unloading cracks; and potential sliding face filled with clay and other geological phenomenon such as lithological characters changing to ultrabasic rock

from norite. Thus, site D was assessed non-suitable for foundation of concrete dam with proposed maximum height of 281 m. Moreover, it would face serious problems during the construction of underground powerhouse and slope excavation.

In view of the above situation, DBC proposed shifting of dam downstream about one (1) km to axis $C_{d/s,}$ located between C_1 and C_2 (refer Annex-06). Reason for selecting dam axis $C_{d/s}$ was that there may be shear zone or fault on left abutment of C_2. Therefore, the right abutment of C_2 will be considered as the pivot point for clockwise rotation of the dam axis to the $C_{d/s}$. PoE supported this proposal of DBC. For relocating the dam from axes D to $C_{d/s.}$ DBC carried out further geological investigations and perfected the design of dam at location $C_{d/s}$.

4.4 Review By Chinese Expert Panel

During 2017, a Chinese Expert Panel (CEP) visited Pakistan for 'Assessment of Feasibility Study of Diamer Basha Dam Project'.

As part of reviewing the dams axis, in their report of May 2017 CEP recorded that: -

> *"Through about 30 years of investigation, design and research works, currently the dam axis Cd/s and roller compacted concrete gravity dam are recommended".*

CEP further commented that: -

> *"As all proposed damsites have no proper natural topographic conditions for arranging large-scale spillways for huge peak flow, the schemes of earth and rockfill dam (including earth core rockfill dam and concrete faced rockfill dam) have worse project layout condition and economy than those of concrete dams. For a concrete dam, it is able to provide overflow dam section on river bed to solve huge flood discharge, and the layout and economy are relatively favourable. In addition, DBDP plays a very important role in the Indus River as it could help control the risk of cascade reservoirs; moreover, considering the great unpredictable risk caused by glacier lake outburst flood, it is suitable to choose a concrete dam".*

5. KEY TECHNICAL PROBLEMS

Immense-sized DBDP is challenged by a number of technical problems including: complex regional geology including tectonics and seismic hazard; large scale and uncertainty of glacial lake outburst floods (GLOFs); construction of RCC gravity dam in a high seismic intensity area; great difficulty in construction organization and its intensity; high head-variation hydrogenator sets; and difficulty in the design and fabrication of ultrahigh-head hydromechanical equipment.

5.1 Complex Regional Geology Tectonics and Seismic Hazard

5.1.1 Complex Regional Geology

This is depicted in 'Regional Geological Map' in Annex-05.

5.1.2 Tectonic Setting

This is shown in Annex-07. It will be noticed from Annex-07 that project site sits nearby the west arc area of the Himalayan tectonic zone (western Himalayan Syntaxis) formed in India-Eurasia Collision. From north to south, the western Himalayan Syntaxis is composed of the Karakorum Block, Karakorum Suture Zone, Kohistan-Ladakh Island Arc, Indus-Yarlung Zangbo Suture Zone, and the Nanga Parbat-Haramosh Massif of the Indian Plate. On south of western Himalayan Synataxis exists Himalayan Main Boundary Thrust (MBT).

Project area is situated within south-eastern Kohistan Island Arc. Fortunately, this arc is sandwiched between three mountain ranges of Western Himalayas, Karakorum and Hidukush and thus has relatively calm seismicity.

5.1.3 Seismic Hazard Evaluation

Affected by ongoing plate collision the project area is seismically active. Recorded large seismic events mostly occurred along the MBT or MFT in the south. Therefore, seismic hazard of DBDP is mainly triggered by these major faults. According to long term historic record, no moderate to large earthquakes ($M \geq 6$) have been recorded in the range within 25 km from the dam site (basically Kohistan Island Arc).

Horizontal peak ground acceleration (PGA) for 10% probability of exceedance in 50 years on the seismic zoning map of Pakistan shows 0.24g~0.26g in the project area. To evaluate seismic hazard and determine seismic design parameters for the dam, studies have been carried out by MONENCO (1984), NEAC (2004) and DBC (2006 & 2007). Regarding PGA the studies covered: operation basis earthquake (OBE); maximum design earthquake (MDE); and maximum credible earthquake (MCE).

During engineering design stage (2006-2007), DBC carried out extensive seismic hazard assessment through South African Council of Geosciences (CGS) After a careful and detailed review by WAPDA / DBC, CGS report of May 2006 was referred back in February 2007 for including certain additional aspects to provide basis of final adoption of appropriate dynamic design parameters. This revised report of CGS was reviewed by DBC's expert, Prof. Dr. Wyss, and submitted to WAPDA in 30 November 2007. The results of this study were also presented by Prof. Dr. Wyss to PoE during the meeting of 3rd to 8th December 2007.

Peak ground acceleration (PGA) values were presented to PoE in December 2007 and endorsed for design. Finally adopted PGA values for design were as below:-

Earthquake	Peak Ground Acceleration (horizontal)	Peak Ground Acceleration (vertical)
OBE	0.22g (2.158 m/s^2)	0.146g (1.436 m/s^2)
MDE	0.37g (3.630 m/s^2)	0.247g (2.420 m/s^2)
MCE	0.46g (4.513 m/s^2)	0.307g (3.008 m/s^2)

While reviewing seismic studies of the project, CPE commented that:

> *"The CEP believes that the previous studies on the geology, tectonics, and seismic hazard are of extreme importance and very informative since the project lies in one of the most complex area in the world in terms of the regional geology and plate tectonics setting. The CPE holds that the seismic design parameters recommended by DBC for the DBDP are feasible and reliable. It can be concluded from the previous study that the dam will not suffer from the failure caused by fault-induced ground rupture".*

5.1.4 Glacial Lake Outburst Floods

In Indus Basin, where project site is located, river runoff mostly comes from glaciers and melted snow rather than from rainfall. Investigations indicate frequent catastrophic glacial lake or landslide outburst floods in history covering wide areas. Uncertainty of glacial lake outburst floods (GLOFs), featuring wide coverage, could pose challenges to the construction and operational safety of the project.

Record since 19th century shows frequent occurrence of GLOFs in July and August, with more details recorded on the flood events in June 1841, August 1858 and August 1929. Investigations also show even heavier flood in the late 18th century.

A brief history of three recorded critical GLOF events is as below: -

i. August 1929 GLOF in Shyok river was induced by the Chong Khumdan Glacier. Peak flood flow at downstream Partab Bridge station on Indus was 23,710 m^3/s, with 2-day flood volume of 2.3 Bm^3 (including 1.37 Bm^3 from GLOF and 0.93 Bm^3 from base flow).

ii. In August 1858, a landslide in Hunza Valley upstream of Baltit was the second largest flood event in history. This flood affected Hunza river for seven (7) months. According to record, flow near Attock Railway Bridge on Indus River was 17,000 m^3/s and flood volume during this event was 1.85 Bm^3.

iii. GLOF in June 1841 broke out at Lichar Gah at downstream of Bunji, near the upper fringe of Diamer Basha reservoir with a volume of 4.6 Bm^3.

Further investigations indicate that 44 places have been exposed to GLOF, nine (9) of which had a peak flow greater than 14,150 m^3/s. As it is highly difficult to monitor and forecast glacial lakes, plus the potential effects of global climate change, there exists high risk of GLOFs that could eventually lead to extensive flooding and mudsliding.

DBC proposed a safety check design based on GLOF. This assumed “A base flow of 5,530 m^3/s + Biafo GLOF” and considered as Probable Maximum Flood (PMF), resulting in peak flood flow at the dam site of 49,410 m^3/s and 2-day flood volume of 4.21 Bm^3. Design of various relevant dam structures will safely handle this PMF.

DBC’s proposed a safety check flood based on GLOF, is about 2.45 times of a 10,000-year recurrence flood. Therefore, it will be necessary to establish a system to monitor their occurrence and development and take timely actions for risk control. In this regard, Pakistan Meteorological Department has already established some satellite based monitoring facilities in Upper Indus Basin.

5.1.5 Design of Ultra-high RCC Dam in High Seismic Activity Area

With dam height of 272m and concrete volume of about 17 Mm^3, DBDP will be the highest and largest RCC dam in the world. Dam site is charactered by a complex regional tectonics and seismology with high basic seismic intensity. As adopted horizontal PGA for MCE is 0.46g, seismic safety of dam is one key issue of concern.

Existing ultra-high gravity dam projects include the global highest: concrete gravity dam - Grand Dixence (Switzerland, maximum dam height 285m); RCC gravity dam – Gibe III (Ethiopia, maximum dam height 246m); and a number of other existing or under construction 200m – scale RCC gravity dams such as Guangzhao (China, maximum dam height 200.5m), Huangdeng (China, maximum dam height 203m), and Longtan Phase I (China, maximum dam height 192m). All these projects have reinforced the confidence for safe design as well as efficient construction of DBDP.

For DBDP, foundation can be placed at the weak weathered to slightly fresh rock mass, dominated by hard norite. Rock mass at dam site is sound, in grade of general-excellent and has enough bearing capacity as dam foundation of high gravity dam. Extensive supportive including state-of-art analytical modelling, stability and stress evaluations were carried out by DBC during the engineering design phase.

5.1.6 Site Access and Construction Planning

Karakoram Highway (KKH) from Havelian to dam site is the only all-weather access for construction. Project of upgrading and relocation of KKH was initiated in 2006. So far, upgradation from Havelian to Besham has been completed including construction of a new bridge on Indus at Thakot. Upgradation of KKH from Besham to Dasu is virtually complete for

construction of Dasu Hydro Power Project. Relocation of KKH from Dasu to Shatial (downstream of DBDP) is now under construction. Work on construction of Shatial-Thor section is in hand of NHA to enable bye-pass of traffic to enable start of dam construction.

Relocation of KKH from Thor to Chilas and Chilas to Raikot Sections is being contemplated through NHA, for completion before start of impounding in the reservoir

In addition, upgradation of Kaghan Valley – Babusar Pass-Chilas Road has been completed by FWO. This link will provide a shorter access route to dam sited during 8 to 9 months of the year.

5.1.7 Design and Manufacturing of Large Head-Variation Hydrogenator Units

Operating head range of the hydrogenator units of DBDP will be between 204.2m~100.5m. Resultant head variation ratio of 2.03, is higher than that of existing large and medium hydrogenator units operating under similar conditions. Hydrogenator units at DBDP may be exposed to even greater vibration problem due to large head variation ratio and maximum head of about 200m.

Possible solutions to the operating instability of such a hydrogenator unit include: developing a new runner; adopting variable speed hydrogenator unit; adopting a certain number of hydrogenator units suitable for low-head operation; and adopting runners for high and low-head operation separately. An optimum solution may require further study of the proposed design during construction phase of DBDP.

5.1.8 Design and Manufacturing of Ultra High-Head Hydromechanical Equipment

There could be some difficulties in design and manufacturing for some hydromechanical equipment for DBDP, and risks involved with their operating. These may include: maintenance gates of headrace tunnels on both left and right banks (size/head: 5.2m x7.2m/148m); maintenance gates and service gates of the low level-outlets (LLOs) (size/head: 3.5mx4.8m/170.8m); maintenance gates and service gates of the reservoir flushing outlets (RFOs) (size/head: 3.5mx5.2m/170.8m); maintenance gates and service gates or diversion tunnel No. 1 to be used as power intake flushing tunnel (IFT) after construction (size/head: 3.0mx4.0m/198.0m), and maintenance of service gate of flushing tunnel on left bank (size/head: 3.0mx4.0m/190.0m).

All these are vertical-lift gates with high water-retaining and operating heads with anticipated hydraulic problems.

5.2 RCC Gravity Dam

As already mentioned, DBDP will be highest (272 m) RCC dam in the world. Therefore, DBC carried out extensive studies leading to its final design and configuration. These are highlighted in the following.

5.2.1 Dam Layout

Dam will be a Roller Compacted Concrete (RCC) gravity structure with a height of 272 m. Proposed crest level of the dam is at 1170m asl. Dam body is curved with arc radius of I,000m. At the topographic breach on left bank, wing dam made of RCC is built and connected to the abutment blocks. Project Layout is shown in Annex-08.

Dam will comprise 32 separate blocks (No. 5 to 36) as shown in ‘Longitudinal Section Along Dam Crest Axis’ (Annex-09). Block Nos. 5 to 17 on left bank and 25 to 35 on right bank do not contain any discharge devices. Central portion of the dam (blocks Nos. 18 to 24) includes spillway and low level outlets for supplemental irrigation releases and reservoir flushing. Joints between blocks will not be sealed with grout over the total dam length of 1006.5 m excluding wing dam.

5.2.2 Dam Profile

Preliminary calculations of six (6) dam profiles were made by DBC to select an appropriate one. Analyses considered combined static and dynamic loadings with different peak ground acceleration parameters.

For the highest dam cross section, a profile of variable slopes has been recommended. Upstream dam face is vertical below 1060m asl; upstream slopes are 1:0.1, 1:0.2, 1:0.31, 1:0.43, 1:0.57, and 1:0.69 between 1060m asl to 1080m asl, 1080m asl to 1100m asl, 1100m asl to 1120m asl, 1120m asl to 1140m asl, 1140m asl to 1160m asl, 1160m asl to 1170m asl, respectively. Downstream dam face is vertical below 915m als; the downstream slope ratios are 1:0.83, 1:0.64 and 1:0.45 between 915 m al to 990m asl, 990m asl to 1060 m asl and 1060m asl to 1170m asl, respectively.

5.2.3 Dam Structure

Central river section (Block Nos. 10 to 31) are each 35 m wide. There are no longitudinal joints, but shear keys have been provided in the block joints between 911.5m asl to 1139.5m asl. Eight layers of grout / drainage galleries are arranged in the dam and abutments.

For sealing the dam against reservoir, a 1.5m thick conventional concrete facing is placed with a 0 .5m thick grout enriched transition layer over RCC. At location of block joints facing of the dam, double V-type copper waterstops have been provided. There is a leakage control system by a vertical drainpipe between the two waterstops. I-type waterstops are at 3m distance and seal the RCC lift joints.

A reinforced concrete plinth, with width of 9m and thickness of 1.5m, is arranged at the heel of the dam for grouting. Connection between the reinforced concrete facing and the plinth is by a leakage-controlled system. Plinth is anchored to foundation and several rows of drillings for consolidation or curtain grouting will be performed from the plinth.

5.2.4 Safety Criteria

5.2.4.1 Safety Factor Against Sliding

Several codes were comprehensively compared by DBC including BoR, CoE, and FERC, etc. A lower safety factor was chosen, because DBC believed that a reasonably high degree of certainty exists for strength parameters used for DBDP.

Stability safety factors for dam/foundation interface against sliding are: 2.0 for usual static loads; 1.5 for unusual load of flood; and 1.1 for OBE earthquake. For MDE and MCE loads, seismically induced cracking is limited to 10cm. For post-MCE static conditions, safety factor is 1.5.

Stability safety factors of lift joints against sliding are as: 3.0 and 2.5 for static usual and unusual loads, respectively; 1.1 for OBE earthquake load, with limited local cracking; for MDE and MCE load, safety factors can reduce below 1.0 as long as no excessive displacement occurs on lift joints; and for post-MCE static conditions, the safety factor is 1.2.

5.2.4.2 Factors for Dam Body

Safety factors for dam body are 3.0, 2.0, 1.25, and 1.0 against compression failure for usual, unusual, OBE, and extreme seismic (MDE/MCE) loads, respectively. Generally, a safety factor of 1.0 is for all load cases against tensile failure, but tension violations should be permitted and tension zones further assessed for seismic conditions during construction design. For post-MCE static evaluation, the compressive safety factor is 1.25.

5.2.5 Stability Analysis

5.2.5.1 Dam / Foundation Interface Stability Analysis

Foundation stability analyses using 2D static method of two main block sections, i.e. a highest typical block section (No. 17) and a typical spillway section (No. 19), have been reported by DBC. Analyses are performed for both normal drainage and blocked drainage conditions.

For uplift load at dam-foundation interface, different assumptions have been made in the calculation. Seepage pore-water pressures from a 2D analysis of the block are based on, CoE and USBR assumptions. Pressures have been extracted from the respective 3D seepage modeling.

Two alternative rock strengths for dam/foundation interface have been assumed by DBC and are: c=2.02MPa, Φ49.3°; and c=2.41 MPa, Φ=54.5°.

In normal drainage condition, foundation stability of Block No. 17 meets the design criteria with a safety factor of 2.36. Corresponding safety factor is 1.81 if the drainage is blocked, which is also above the prescribed design criteria.

For Block No. 19, safety factors are 2.91 and 1.98 for the normal drainage and blocked drainage conditions respectively indicating that the dam/foundation interface is adequately safe against sliding.

Further investigations during pre-construction or even at the foundation excavation stage, mainly into the possible presence of unfavorable discontinuity systems have been recommended by DBC including adequate ground-water pressure control.

5.2.6 Foundation and Seepage Control Design

Foundation of the dam blocks is on norite and ultramafic rocks of variable but generally good quality. To enhance integrality of rock mass, consolidation grouting is concentrated in the 1/3 upstream foundation area for Block Nos. 5 to 27, and in the whole foundation area for Block Nos. 28 to 36.

To limit uplift force and seepage under for dam, grouting curtain will be provided through the plinth along the upstream periphery of the dam, with drainage curtain arranged in the dam body. Both grouting and drainage curtains will be extended into rock of the abutments from five layers of grouting/drainage adits extending from dam galleries. In downstream portion of Block Nos. 14 to 27, there will be another grouting and drainage curtain underneath the dam to reduce uplift effect from tail water.

The lowest level of the main grout curtain within central river section will be 750m asl and rise to l050m asl towards the abutments.

DBC has computed seepage flows using a 3D seepage model. Maximum seepage at upstream drainage curtain is about 521 l/s and at downstream drainage curtain is about 163 l/s.

5.2.7 Comments of CEP on DBC's Dam Design

As already mentioned, with a height of 272m, DBDP will be the highest RCC dam in the world. A profile of variable slopes has been recommended by DBC through a comprehensive analysis. For cross-sectional profiles, global ratio of dam height / bottom width is 1:0.77. Compared with common triangular profile of a gravity dam, slopes of dam faces seem less inclined and width is larger in upper part, which may avoid stress concentration and earthquake / thermal induced cracking. Therefore, the profile is beneficial to aseismic performance. Furthermore, the dam body is curved in plane to take advantage of arching action and thereby to better withstand earthquake loads.

CEP Report of May, 2017 recorded the following conclusion:

> *"CEP emphasize that: for DBDP, the highest RCC dam in the world will be built in a high seismic-intensity area; the seismic safety is one of the key issues concerned. DBC has carried out adequate studies on profile design and paid attention to the aseismic feature of dam body. Hence, the dam cross sectional profile design is appropriate".*

6. DAM CONSTRUCTION

6.1 Overall Construction Scheme

DBDP is of great national importance for enhancing food security, promoting industrial and agricultural development, optimizing energy structure and increasing the supply of clean energy and electricity. Factually, in the present water scarcity scenario, irrigation supplies are more critical than power generation.

Proposed construction scheme of DBC is technically feasible, in general, but the key technical issues involved in the project are significantly challenging. Though design challenges have been seriously addressed, some may still have to be faced and resolved during construction stage.

6.2 Main Quantities of Work and Materials

Construction of 272 m world highest RCC dam according to proposed layout and design will involve very large quantities of work and materials (refer to details in Annex-10). Besides excavation of 27.5 million cubic meters (Mm^3), it will require about 19 Mm^3 of connecting comprising: 16.7 Mm^3 RCC and 2.3 Mm^3 conventional concrete.

Similarly, very large material quantities will be required comprising: 30 Mm^3 of aggregate (coarse & fine); 2 million tonnes (Mt) of cement; 0.6 Mt of reinforcing steel; and 2 Mt of pozzolan (Gini material).

6.3 Construction Challenges

According to the present planning, DBDP is going to be constructed in two phases. Phase-I covering main dam and appurtenants is now proposed to be constructed on priority basis. Phase II covering hydropower component will soon follow and dovetailed into 'Overall Project Implementation Schedule'.

There will be significant construction procedural challenges for Phase-I as highlighted in Annex-11. In particular, the proposed procedure aims at a maximum RCC placement rate of 900 m^3/ hour sustained over a period of about three (3) years. This is intimately related with development of temperatures in the dam body as well as river handling from diversion to reservoir filling.

6.4 Construction Plan

Overall Construction Plan Phase-I (Dam Part)' is shown in Annex-12.

Accordingly:

i. Dam Construction will start with abutments excavation and foundation treatment at dam foot print. This will continue till about middle of 4th construction year.

ii. River diversion works including excavation and construction will also continue in parallel. Construction of cofferdams will start in 4th year and river diversion accomplished to coincide with conclusion of activity (i) above.

iii. River bed dewatering, excavation and foundation treatment will start after river diversion in 4th year and essentially completed within 5th year.

iv. RCC placing for dam will commence in 5th year and continue through 9th year.

v. Steel liner erection for reservoir low level outlets will also commence in 5th year and completed during 7th year.

vi. With availability of low level outlets, partial impounding of construction pit will start during 7th year and proceed in accordance with progressive raising of dam height.

vii. Spillway construction will commence towards the end of 7th year and full commissioning of reservoir including installation of gates accomplished by the middle of 9th year.

viii. After start on spillway construction, staged reservoir falling will also commence and full conservation level achieved by middle of 9th year.

Soon after start of Phase-I construction, Phase-II construction for hydropower development will also commence. This will be dovetailed into overall construction period of 9.5 to 10 years in such a way that power units are progressively commissioned during 7th and 8th years.

7. CONCLUSIONS

DBDP has been under extensive studies and investigations since early 1980s. Under this process, it has undergone three configural variations in an attempt to optimize the technical parameters of: dam site location; type of dam; safe design of world highest RCC dam in a seismically active zone; design challenges for ultra-high head hydrogenators and hydro-mechanical equipment; and ensured constructability within the proposed schedule.

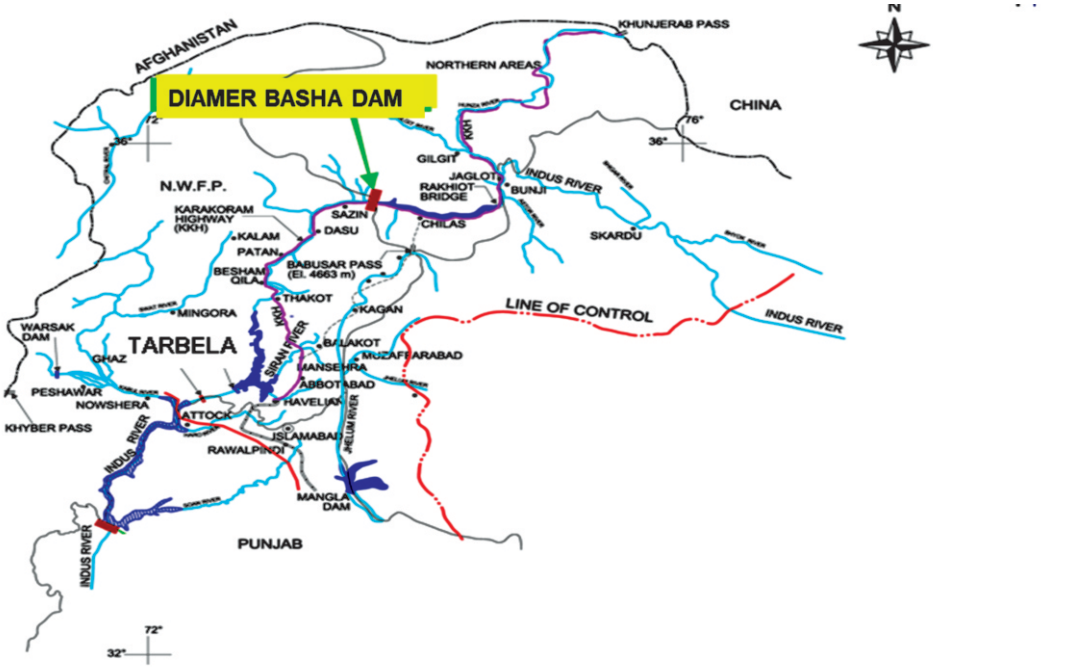
Notwithstanding the above factors, occasional voices are being raised against the project under the pretexts of: safety against seismic and GLOF hazards; and quality constructability of dam within the proposed schedule of 9 to 10 years.

In the overall national interest, protagonists of DBDP from different quarters should shun this attitude to launch smooth core project implementation, which has already slipped by over 10 years. No gainsaying that any further impediments in the proposed priority start on project construction will be suicidal for the national economy and even endanger sustainability of the country in face of glaring water scarcity.

ANNEXURES
01 THROUGH 12

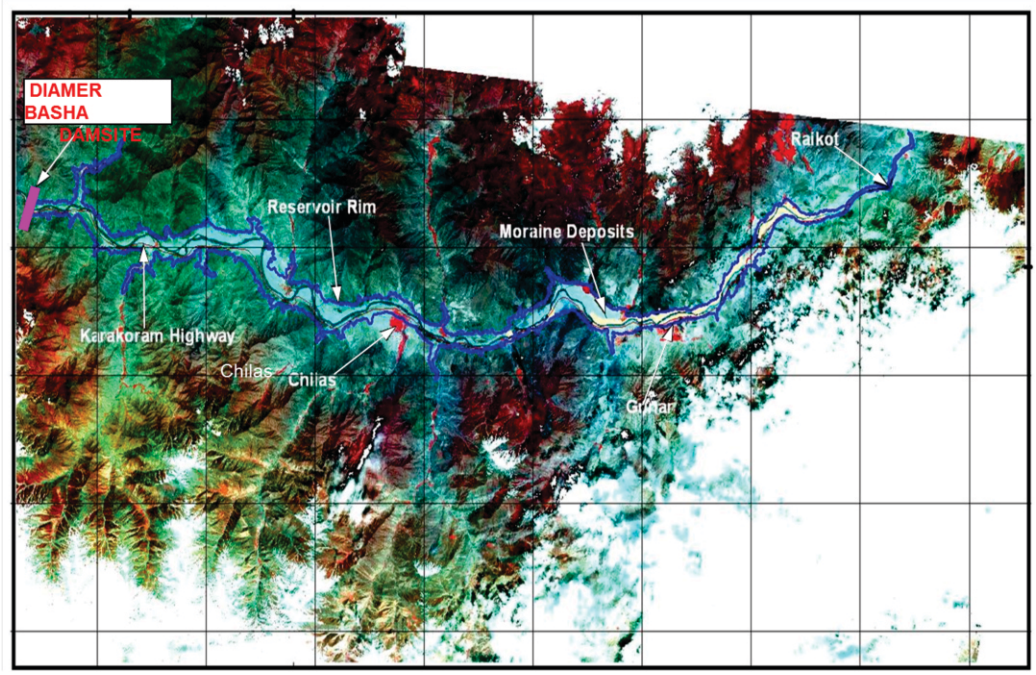
ANNEX-01

DIAMER BASHA DAM PROJECT (DBDP)
LOCATION MAP



ANNEX-02

RESERVOIR OF DIAMER BASHA DAM PROJECT
PROJECT LOCATION MAP



ANNEX-03

COMPARATIVE TECHNICAL PARAMETERS OF PROPOSED DAM

	MONENCO (1984)	NEAC (1984)	DBC (2008)
Dam			
Site	C2	D	Cd/s
Type	ECRD	RCC	RCC
Height	200 m	277 m	270 m
Length	920 m	1000 m	1006 m
Live Storage Capacity	5.7 MAF	7.3 MAF	6.4 MAF
Construction Time	9 years	8 years	9 year
River Diversion			
	4 Tunnels	4 Tunnels	2 Tunnels
	Right Bank	Right Bank	Right Bank
	Dia 17.5	18 m W x 21 m H	Dia 15.4 m (Q=2685 m^3/s)
			Open Channel (Q=14330 m^3/s)
	Length 980 m each	Length more than 1.5 km each	Tunnel Length about 950 m each
Spillway			
Design Flood	19300 m^3/s	20,000 m^3/s	20,000 m^3/s (40,000 m^3/s SCF)
	On Right Bank above	On top of Dam	On top of Dam
	Diversion Tunnels		
	16.6m W x 20m H with 6 Gates	16.5 m W x 15 m H with 10 Gates	11.5 m W x 16.24m H with 14 Gates
Power House			
Installed Capacity	3360 MW	4500 MW	4500 MW
	Underground on Left Bank	Underground on Left & Right Banks	Underground on Left & Right Banks
	3x2 Headracr Tunnels: -	2 x 2 Headracr Tunnels: -	2 x 2 Headracr Tunnels: -
	8.5 m dia	10.5 m dia	15.3 m dia
	Each 1000 m long	Each 1410 m long	Left / Right Length 450 / 1165 m
	3 Tailrace Tunnels 1500 m long		

ANNEX-04

DIAMER BASHA DAM PROJECT DETAILS OF GEOTECHNICAL INVESTIGATIONS CONDUCTED AT SITE

i. Drilling

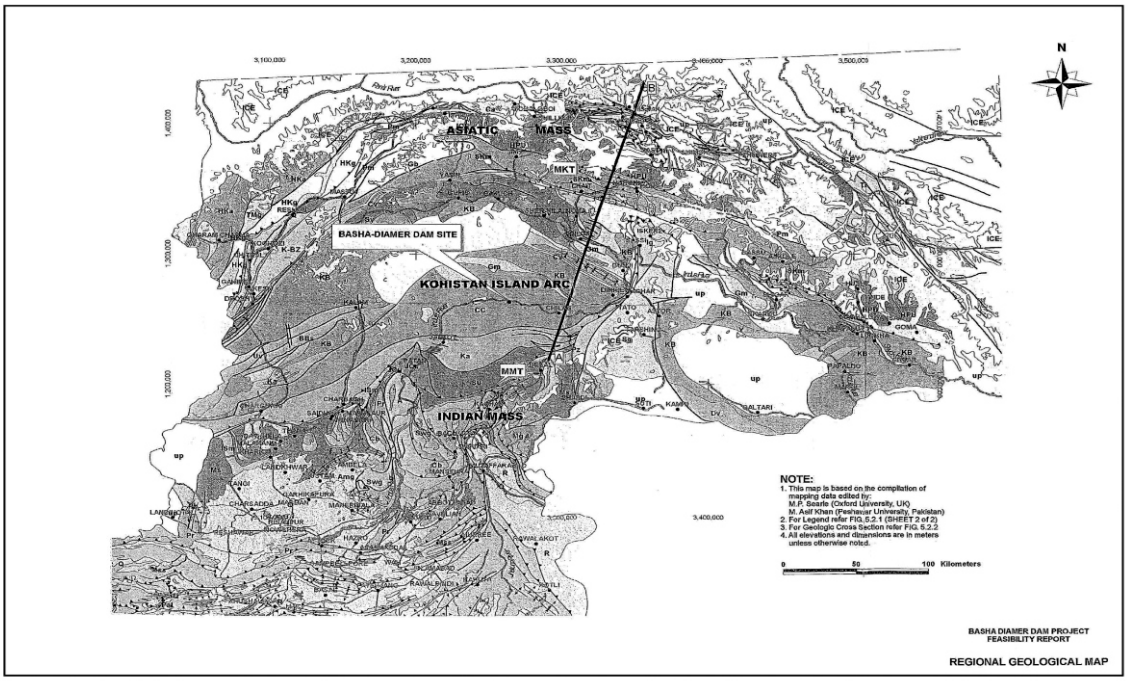
Sr. No.	Outfit	No. of Boreholes	Total Length (m)	Period
1	MONENCO	63	4,451	1981-84
2	WAPDA	15	1,073	2001-02
3	NEAC	23	1,830	2002-04
4	DBC	65	9,918	2006-08
	TOTAL	166	17,272	

ii. Editing

Adit No.	Preparing Outfit	Location	Length (m)	Remarks
1	NEAC	Left Bank	400	At the dam Axis D proposed in NEAC's Feasibility Report (2004)
2	NEAC	Right Bank	216	
3	DBC	Left Bank	256	Including Main (129.7 m) and side heading (126.1 m) at axis C2 (2006).
4	DBC	Left Bank	532	Including Main (422 m) and side heading / branch of 110 m at axis C2 d/s (2007).
5	DBC	Right Bank	650	Including Main (450 m) and two perpendicular branches of 100 m each at axis C2 d/s (2007).
		TOTAL	2054	

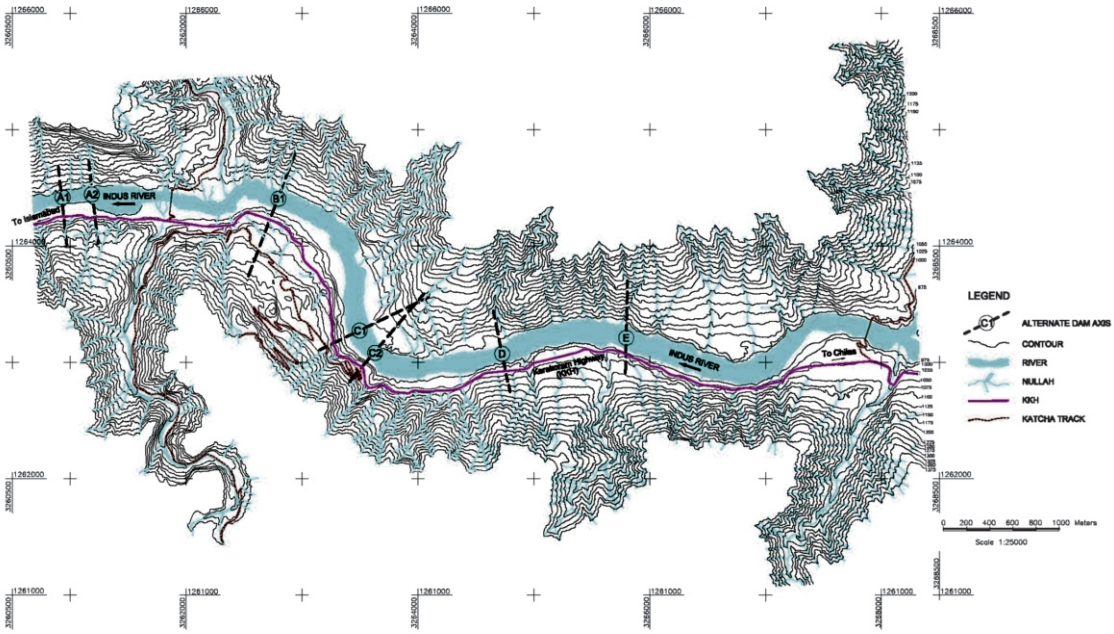
ANNEX-05

DIAMER BASHA DAM PROJECT FEASIBILITY REPORT – REGIONAL AGEOLOGICAL MAP



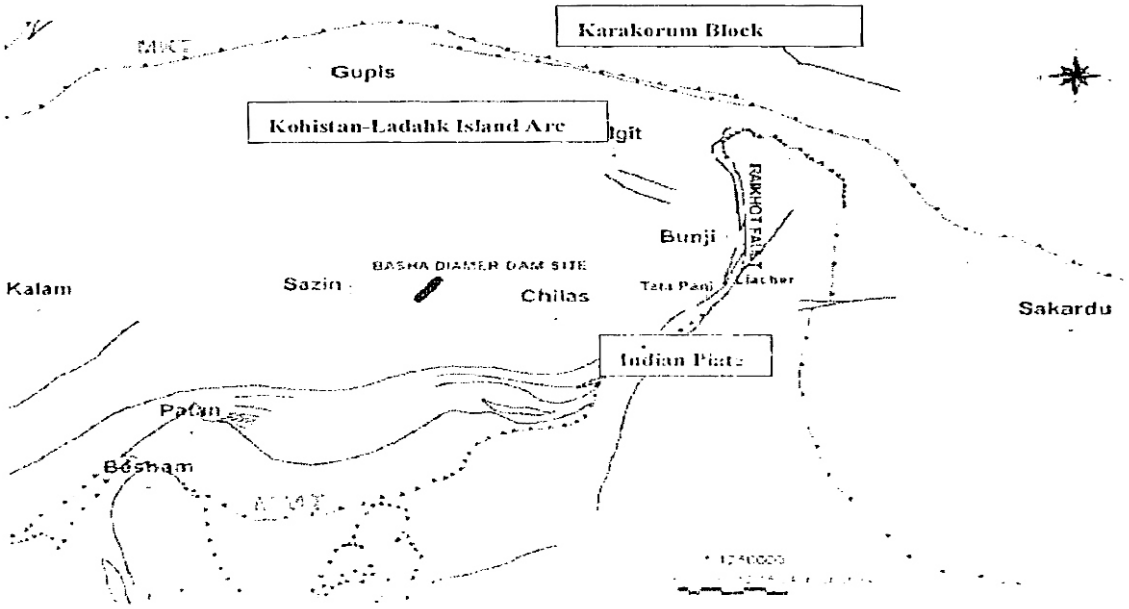
ANNEX-06

ALTERNATE AXES EVALUATED FOR DAM LOCATION



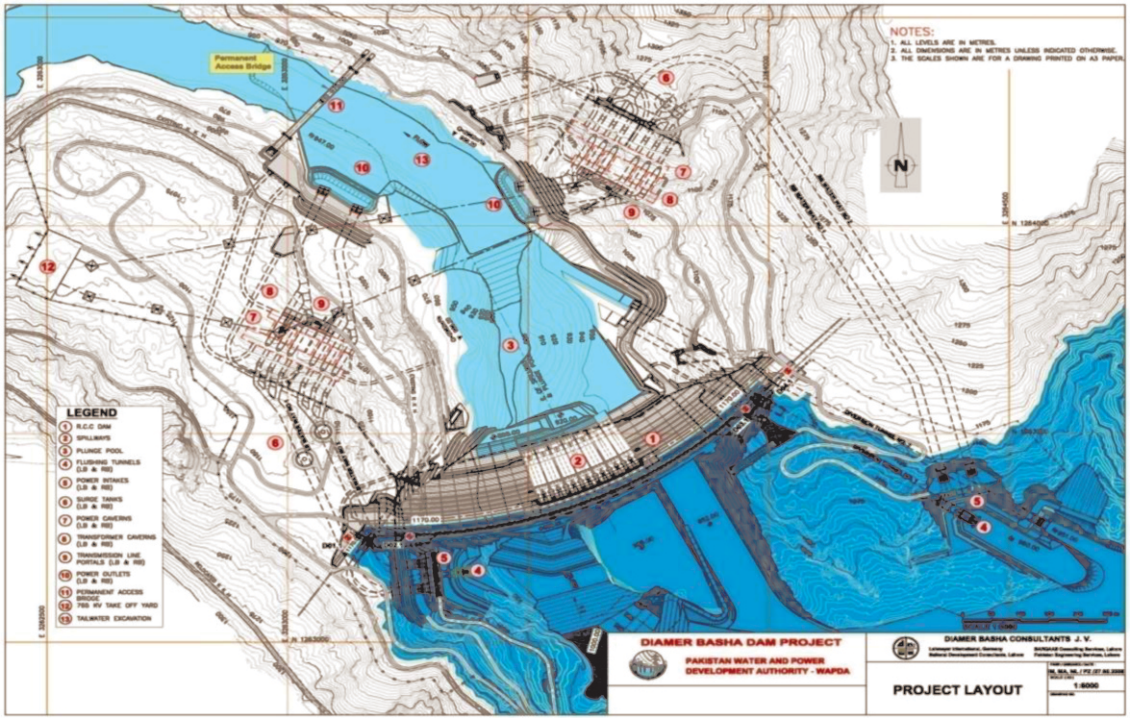
ANNEX-07

TECTONIC SKETCH OF DIAMER BASHA DAM PROJEC AREA



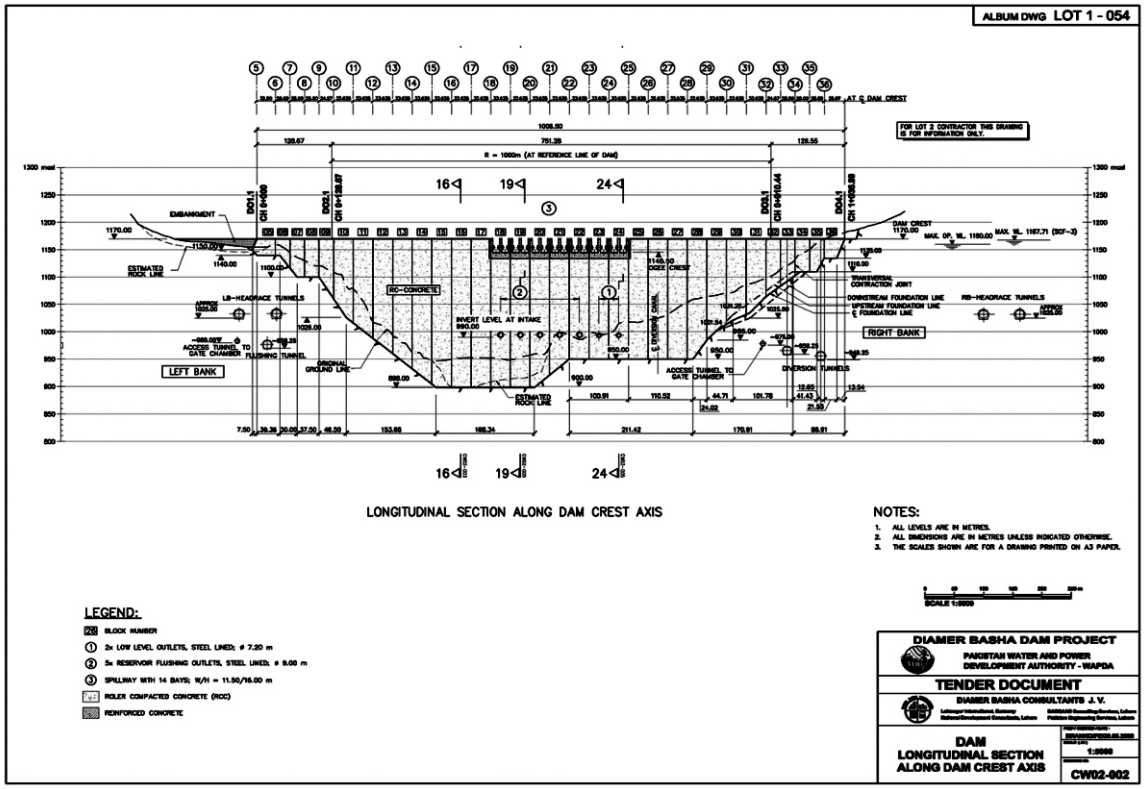
ANNEX-08

Diamer Basha Dam Project
PROJECT LAYOUT



ANNEX-09

LONGITUDINAL SECTION ALONG DAM CREST AXIS



ANNEX-10

Diamer Basha Dam Project
MAIN QUANTITIES OF WORK AND MATERIALS

WORK QUANTITIES:

- Excavation — 27.5 Mm^3
- Roller Compacted Concrete — 16.7 Mm^3
- Conventional Concrete — 2.3 Mm^3
- Grouting — 850,000 m

MATERIAL QUANTITIES:

- Reinforcing Steel — 0.6 M Tonnes
- Cement — 2 M Tonnes
- Pozzolan (Gini Material) — 2 M Tonnes

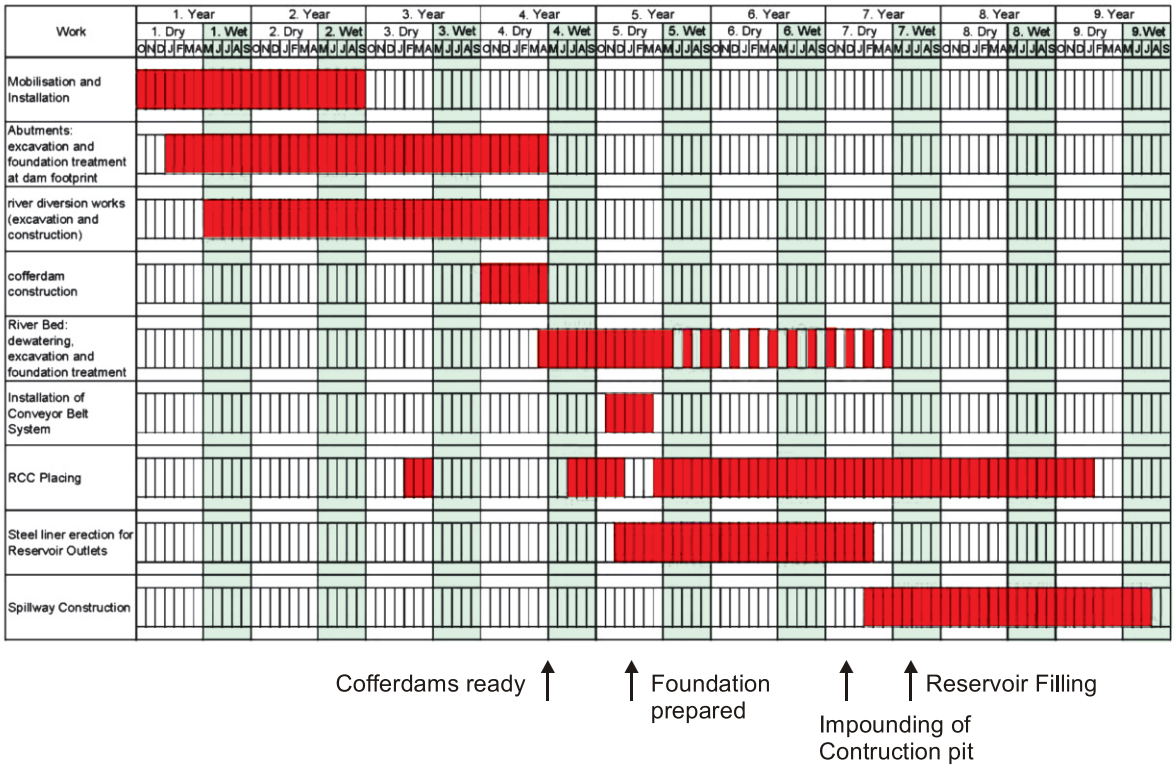
ANNEX-11

DAM PART CONSTRUCTION CHALLENGES

- The construction procedure aims for the shortest physically possible time with hourly placement rates of RCC of 900 m^3/hr.
- The construction procedure is intimately related with the development of temperatures in the dam. Any change requires re-calculation of temperatures and stresses.
- The construction procedure is directly related with river handling up to reservoir filling.
- The construction procedure and time to completion need the involvement of first class international contractors experienced with RCC Dam construction.
- The construction of the hydropower works can be performed during the construction period of the dam. Matching point for both is the reservoir filling.

ANNEX-12

OVERALL CONSTRUCTION PLAN PHASE-I (DAM PART)



Paper No. 792

POTENTIAL CLIMATE CHANGE IMPACT ON FLOODS IN PUNJAB, PAKISTAN

Dr. Muhammad Nawaz Bhutta

POTENTIAL CLIMATE CHANGE IMPACT ON FLOODS IN PUNJAB, PAKISTAN

By

Dr. Muhammad Nawaz Bhutta

Summary

The frequency and magnitude of disastrous floods have increased due to the impacts of climate change. The occurrence of extreme meteorological and hydrological events has increased over the last few decades and is one reason that potential climate change has been discussed in public at an increasing extent. The specific objectives of this paper are flood frequency analysis for climate change scenarios for selected gauging stations, determination of peak flow for return periods of 5, 10, 25, 50, 100 and 250 years and flood inundation coverage for climate change scenario. Ten districts of Punjab have been studied. Historic and climate change scenario annual peak discharge data were collected and analyzed. Jinnah Barrage flood at 100 year return period, considering climate change, is likely to occur at about 25 year return period, based on RCP 8.5 for JMPIRM2 GCM. Based on the same scenario and GCM future 100 year return period flood is equivalent to the historic 1000 year return period flood. Chashma Barrage flood at 100 year return period, considering climate change, is likely to occur at about 12 year return period, based on RCP 8.5 for JMPIRM2 GCM. Based on the same scenario and GCM future 100 year return period flood is equivalent to the historic 750 year return period flood. Taunsa Barrage flood at 100 year return period, considering climate change, is likely to occur at about 7 year return period, based on RCP 8.5 for JMPIRM2 GCM (General Circulation Model). Based on the same scenario and GCM future 100 year return period flood is equivalent to the historic 1000 year return period flood. HEC-RAS 2-D model was applied to estimate inundated areas for historic data and climate change scenarios for 10 selected districts of Punjab. Inundated are has increased for all the districts for climate change scenarios. Thus, future infrastructure design and protection requires adequate measures. An increase in areas inundated by the Indus River is greater than other rivers. More reservoirs, watershed management, small dams' construction, rainwater harvesting schemes and improvement of flood bunds will be needed to cope with climate change scenarios. Specific recommendations are also given in each district.

1. INTRODUCTION

Life loss and capital damages are major concerns in human societies. One of the major causes of such phenomena is floods. The frequency and magnitude of disastrous floods have increased due to the impacts of climate change. Flood risk is measured in terms of probability of occurrence of events and the related consequences. The occurrence of extreme meteorological and hydrological events has increased over the last few decades and is one reason that potential climate change has been discussed in public at an increasing extent. The study objectives, principles of phenomena, effect and geographic coverage are described below:

1.1 Objective and Purpose

The prime objective of the assignment is to carry out flood hazard inundation for climate change impact. The specific objectives are:

a) Flood (peak discharge) frequency analysis for climate change scenario for selected gauging stations.

b) Determination of peak flow for return periods of 5, 10, 25, 50, 100 and 250 years.

[1] Water Resource Engineer, Phone:00923004754050, email: nawazbhutta04@gmail.com

c) Flood inundation coverage for climate change scenario.

1.2 Study Area

Hydraulic reaches studies and corresponding districts are given in **Error! Reference source not found.**.

Table 1: Hydraulic Modelling Reaches and Districts

River	Modelling Reach	Districts
Indus	i) Jinnah-Chashma	Mianwali
	ii) Chashma-Taunsa	Mianwali, Bhakhar, Layyah, Muzaffargarh, DG Khan
	iii) Taunsa-Guddu	Muzaffargarh, DG Khan, Rajanpur
Jhelum	iv) Mangla-Rasul	Jhelum, Gujrat
	v) Rasul-Trimmu	Mandi Bahaud Din
Ravi	vi) Jacer- Balloki	Kasur
Sutlej	vii) Ferozepur-Sulemanki	Kasur

1.3 Principles of the Phenomena: Monsoon

Monsoon is a large scale circulation of air in the tropic and sub-tropic regions of the world. The position of the sun and thus the solar radiation varies depending on the inclination of the axis of the earth with the seasons. In the summer period, the Passat winds will be amplified due to the differential heating of landmass and oceans above the Indian Ocean. With the rising of warm air over land, a thermal low-pressure zone is created while the descending of colder air over the ocean generates a high-pressure zone. The resulting wind circulation is the monsoon wind (or monsoon circulation). The dry and warm air may absorb considerable amounts of water vapour. In the area of the low-pressure zone, it is subject to upwind and condensation takes place (**Figure 1**).

1.4 Effect of Climate Change on Runoff 2009

Runoff regimes in Himalayan basins are controlled mainly by melting of snow and ice cover. The air temperature is the principal variable to estimate the importance of the melting of the snow cover when using a snowmelt runoff model. Changes in temperature will ultimately affect stream-flow and snow/ice melt runoff in particular. Global atmospheric general circulation models (GCMs) have been developed to simulate the present climate and used to predict future climatic changes and its effect. These GCMs have certain disadvantages, therefore, another simple approach of hypothetical scenarios have been developed and successfully demonstrated in to investigate the effect of changes in temperature. Adopted plausible climate scenarios included three temperature scenarios (T+1, T+2, T+3°C).

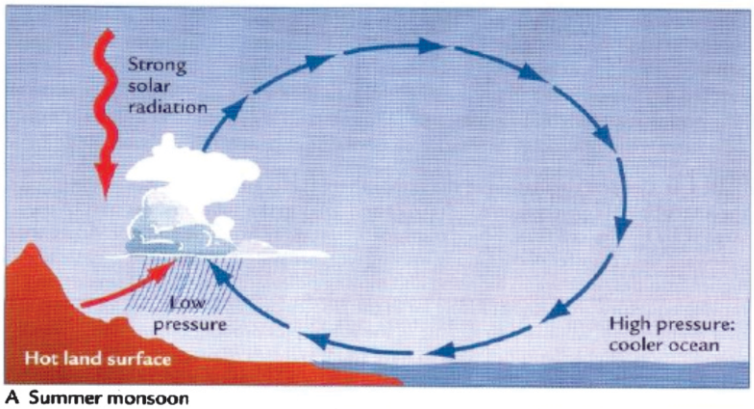


Figure 1: Principal Sketch for Monsoon Formation in Tropic / Sub-tropic Regions

2. Watershed Modelling

2.1 Climate Data

For future assessment, the requisite historical (1994-2004) and future (2007-2096) climatic data were obtained from the high resolution (0.44°) Coordinated Regional Downscaling Experiments (CORDEX) for South Asia for the RCP4.5 and RCP8.5 scenarios, which were simulated by five different GCM/RCM combination. These experiments include the whole set of representative concentration pathways (RCP) namely RCP4.5 and RCP8.5, each simulated by distinct global climate model (GCM) under the framework of coupled model inter-comparison project Phase 5 (CMIP5) and further downscaled by the regional climate model (RCM) under the CORDEX South Asia framework.

2.2 UBC Watershed Model

The watershed model developed by the University of British Columbia (UBC) was used for the Inuds River and Jhelum River. It is a conceptual semi-distributed model that divides the mountainous watersheds – for which the model was primarily developed – into several elevation zones and can be run with minimum hydro-meteorological input of maximum and minimum temperatures and precipitation[1] (Quick and Pipes, 1976). In view of scarce data availability within the mountainous watersheds, the UBC takes minimum set of point observations (T_{max}, T_{min}, and P) together with geophysical watershed characteristics to reproduce the hydrological response at hourly and daily time scales. Since the vertical gradients of hydro-climatic parameters are key factors in determining the hydrological behaviour of a watershed, model divides the watershed possibly into twelve elevation zones, within which all hydro-metro-climatic conditions are assumed to be homogeneous. The energy-balance based snowmelt routine of the UBC model can discriminate between the fresh, ephemeral and seasonal snow and glacier ice accumulation and ablation, as described in detail by Hassan (2016)[2]. The UBC model computes the runoff contributions discretely from rain, snow and glacier, which are then distributed into slow, medium and fast runoff based upon percentage of basin's impermeable area, soil moisture deficit and evaporative demands before routing it to the basin outlet. Considering soil moisture deficit under evaporative demands, the infiltrated water is further divided into groundwater and interflow (medium runoff) components. The groundwater is allocated to upper (slow runoff) and deep (very slow runoff) zones based on a predefined percolation coefficient. The model applies a water-conserved linear reservoir approach for routing the runoff from each component towards the watershed outlet.

The hydrological model has been calibrated and validated against real observations (1994-2096) and then forced with the future climatic data (2007-2096) from the CORDEX South Asia experiments, after adjusting for systematic biases. A decade long (1994-2004) meteorological observations of maximum and minimum temperatures and precipitation were taken from the Water and Power Development Authority (WAPDA), Pakistan. Discharge observations for the same period were obtained from the Surface Water Hydrology Project (SWHP), WAPDA of Pakistan for the Indus at Besham Qilla site, Jhelum at the Azad Pattan and Kabul at the Nowshera site.

2.3 Spatial Processes in Hydrology (SPHY) cryospheric-hydrological model

Jhelum, Chenab, Sutlej and Ravi Rivers are Transboundary Rivers with most of their upper catchment areas are located outside Pakistan and there was no access to rain and river flows

---

1 uick M.C. and A Pipe 1977 UBC Watershed Model

2 Hasson, S (2016). Future Water Availability from Hindukush-Karakoram-Himalaya upper Indus Basin under Conflicting Climate Change Scenarios. Climate. 26; 4(3):40

data for modeling. Flows of these rivers measured in Pakistan are not natural rather are regulated/controlled flows released by India after fulfilling its requirements. The river flows projections can be made both based on observed flows and from rainfall projections using hydrological modeling. Given the several uncertainties and data limitations, an output of regional study under the HI-AWARE project by Lutz et. al., 2016[1] has been used for future flows for Chenab, Ravi and Sutlej rivers extreme flows. The high resolution, raster-based, fully distributed Spatial Processes in Hydrology (SPHY) cryospheric-hydrological model (Terink et al., 2015)[2] which was applied in a river basin-scale study on climate change impacts for water availability in five major Asian river basins before (Lutz et al., 2014)[3]. The model runs at 1 km^2 spatial resolution with a daily time step. The actual runoff which is calculated for each grid cell consists of four possible contributing factors: rainfall-runoff, snowmelt, glacier melt, and base flow. For each grid cell the total runoff generated per time step is calculated from runoff contributed by glacier melt, snowmelt, rainfall-runoff, and base flow. To determine the contribution of each of the four components to the total runoff within a grid cell, a subgrid parameterization was used in which for each cell the fractional ice cover (GF), ranging from 0 (no ice cover) to 1 (complete ice cover), is determined. Glacier melt is simulated using a degree-day modeling approach (Hock, 2003)[4]. For the remaining, the model maintains a dynamic snow and soil water storage. The glacier fraction per grid cell is adapted dynamically in time. Variable groundwater storage is maintained for the entire grid cell fraction of the grid cell. Rainfall-runoff consists of the surface runoff from rainfall, and lateral flow released from the soil water storage. Soil water processes are simulated for a topsoil and subsoil layer and processes simulated include evapotranspiration, infiltration, percolation, capillary rise, surface runoff and lateral flow. Baseflow is released from the groundwater storage. Each of these four runoff types is routed downstream using a digital elevation model (DEM) and a routing recession function. A detailed description of the model has been published by Terink et al., 2015[5].

2.4 Climate Change Impact on Rivers Peak Discharges

Climate change impact on daily flows was assessed up to December 31, 2096. The impact was determined on the Indus River gauging stations (Jinnah, Chashma and Taunsa Barrages) and Jhelum River gauging stations (Mangla and Rasul), Chenab at Trimmu, Ravi at Balloki and Sutlej at Sulemanki.

3. Hydrological Analysis and Hydraulic Modeling

3.1 Hydrological Analysis

Estimation of flood peak discharges for historic data (HD), climate change Scenarios RCP4.5 JMPIRM2, RCP8.5 JMPIRM2, RCP4.5 Ensemble mean and RCP8.5 Ensemble mean of Indus at Jinnah, Chashma, Taunsa, Mangla, Rasul, Balloki and Sulemanki gauging stations using Gumbel Extreme Value (GEV1) Distribution for 5, 10, 25, 50, 100 and 250 years return periods

---

1 Lutz AF, Immerzeel WW, Kraaijenbrink PDA, Shrestha AB, Bierkens MFP (2016) Climate Change Impacts on the Upper Indus Hydrology: Sources, Shifts and Extremes. PLoS ONE 11(11): e0165630. doi:10.1371/journal.pone.0165630

2 Terink W., A. F. Lutz, G. W. H. Simons, W. W. Immerzeel, and P. Droogers (2015). SPHY v2.0: Spatial Processes in Hydrology. Geosci. Model Dev., 8, 2009–2034

3 Lutz AF, Immerzeel WW, Shrestha AB, Bierkens MFP (2014). Consistent increase in High Asia's runoff due to increasing glacier melt and precipitation. Nat Clim Chang. 4: 587-592. doi: 10.1038/NCLIMATE2237

4 Hock R. (2003). Temperature index melt modelling in mountain areas. J Hydrol. 282: 104-115. doi: 10.1016/S0022-1694(03)00257-9

5 Terink W., A. F. Lutz, G. W. H. Simons, W. W. Immerzeel, and P. Droogers (2015). SPHY v2.0: Spatial Processes in Hydrology. Geosci. Model Dev., 8, 2009–2034

was determined as given in **Error! Reference source not found.**. Remarks for each gauging station are given in **Error! Reference source not found.**.

3.2 Hydraulic Modeling

Climate change has shown a significant impact on all the gauging stations of Indus River and Rasul of Jhelum River. Therefore, hydraulic modeling of seven river reaches was done (**Table 2**). HEC-RAS 2-D model was used for hydraulic modelling and inundation mapping for the river reaches and districts given in **Table 1 Hydraulic Modeling Reaches and Districts Table 1.**

Table 2: Probable Flood compared with Climate Change Scenario (Cusecs)-GEV-1

Summary	Data Source	Return Period (years)								
		5	10	25	50	100	250	500	1000	10000
i. Indus **at Jinnah (Mianwali)**										
Flood at 100 year return period, considering climate change, is likely to occur at about 25 year return period, based on RCP 8.5 for JMPIRM2 GCM. Based on the same scenario and GCM future 100 year return period flood is equivalent to the historic 1000 year return period flood. Thus, future infrastructure design and protection requires adequate measures.	***HD***	618,610	707,126	818,966	901,936	984,293	1,092,729	1145193	1223866	1485075
	RCP4.5 JMPIRM 2	685375	724115	773063	809375	845403	928713			
	RCP8.5 JMPIRM 2	816,557	897,771	972,451	1,098,590	1223,798	1,388,655			
	RCP4.5 Ensemble mean	681467	716323	760395	793061	825516	868,211			
	RCP8.5 Ensemble mean	699019	738324	788011	824845	861431	909,565			
ii. Indus **at** Chashma / **Mianwali , Bhakhar, DG Khan**										
Flood at 100 year return period, considering climate change, is likely to occur at about 12 year return period, based on RCP 8.5 for JMPIRM2 GCM. Based on the same scenario and GCM future 100 year return period flood is equivalent to the historic 750 year return period flood. Thus, future infrastructure design and protection requires adequate measures.	HD	589,282	677,905	789,879	872,949	955,404	1,063,971	1116198	1195589	1459180
	RCP4.5 JMPIRM 2	692229	731357	780794	817470	853857	938000			
	RCP8.5 JMPIRM 2	859,254	936,098	1,017,059	1,152,922	1,287,782	1,465,347			
	RCP4.5 Ensemble mean	688,283	723,492	767,988	801,007	833,779	876,898			
	RCP8.5 Ensemble mean	706011	745704	795887	833108	870047	918,676			
iii. Indus **at Taunsa (DG Khan, Rajanpur)**										
Flood at 100 year return period, considering climate change, is likely to occur at about 7 year return period, based on RCP 8.5 for JMPIRM2 GCM. Based on the same scenario and GCM future 100 year return period flood is equivalent to the historic 1000 year return period flood. Thus, future infrastructure design and protection requires adequate measures.	HD	567,011	656,268	769,044	852,707	935,753	1,045,096	1063455	1138963	1389665
	RCP4.5 ***JMPIRM 2***	719918	760611	812026	850168	888012	975520			
	RCP8.5 JMPIRM 2	877,237	960,457	1,047795	1189062	1,302,485	1,415,493			
	RCP4.5 Ensemble mean	715,828	752,450	798,712	833,038	867,116	911,966			
	RCP8.5 Ensemble mean	734,263	775,545	827,705	866,410	904,832	955,403			
iv. **Jhelum at Rasul (Gujrat, Mandi Bahauddin)**										
Flood at 100 year return period, considering climate change, is likely to occur at about 60 year return period, based on RCP 8.5 for JMPIRM2 GCM. Based on the same scenario and GCM future 100 year return period flood is equivalent to the historic 250 year return period flood. Thus, future infrastructure design and protection requires adequate measures.	Historic Data	220,215	381,259	507,286	600,781	693,585	815,777	907389	1000252	1308572
	RCP4.5 JMPIRM 2	282,276	342,351	498,515	587,367	675,562	791,686			
	RCP8.5 JMPIRM 2	276,372	345,890	484,540	650,251	814,737	1,031,531			
	RCP4.5 Ensemble mean	249,781	287,249	334,606	369,709	404,600	450,474	485143	519776	634767
	RCP8.5 Ensemble mean	306,002	373,135	457,961	520,891	583,363	66,5611	727697	789751	995782

Summary	Data Source	Return Period (years)								
		5	10	25	50	100	250	500	1000	10000
		v. Chenab at Trimmu (Muzaffargarh)								
Flood at 100 year return period, considering climate change, is likely to occur at about 125 year return period, based on RCP 8.5 for JMPIRM2 GCM. Based on the same scenario and GCM future 100 year return period flood is equivalent to the historic 75 year return period flood. Thus, future infrastructure design and protection requires adequate measures.	Historic	397870	510916	653751	759714	864895	1003383	1107951	1212445	1559381
	RCP4.5 JMPIRM 2	401602	464243	543390	602106	660375	795071			
	RCP8.5 JMPIRM 2	442424	528777	637884	718826	799194	984834			
	RCP4.5 Ensembl e mean	402,481	464,600	543,069	601,303	659,078	735,181	792640	850055	1040683
	RCP8.5 Ensembl e mean	438,502	520,008	623,021	699,442	775,298	875,168	950587	1025946	1276151
		vi. Ravi at Balloki (Kasur)								
Flood at 100 year return period, considering climate change, is likely to occur at about 5000 year return period, based on RCP 8.5 for JMPIRM2 GCM. Based on the same scenario and GCM future 100 year return period flood is equivalent to the historic 5 year return period flood.	HD	138,504	179,734	231,829	270,475	308,837	359,346	397,484	435,595	562,129
	RCP8.5 JMPIRM 2	345,058	389,526	445,712	487,393	528,767	583,243			
		vii. Sutlej at Sulemanki (Kasur)								
Flood at 100 year return period, considering climate change, is likely to occur at about 1000 year return period, based on RCP 8.5 for JMPIRM2 GCM. Based on the same scenario and GCM future 100 year return period flood is equivalent to the historic 8 year return period flood.	HD	147,838	199,035	263,723	311,711	359,346	422,064	469,422	516,745	673,866
	RCP8.5 JMPIRM 2	335,007	378,180	432,730	473,197	513,366	566,255			

4. Hydraulic Modeling and Flood Inundation

HEC-RAS (version 5.0.5) 2-D model was used to simulate the flood extents and inundation depth of corresponding to 5, 10, 25, 50, 100 and 250 years return periods peak discharges from historic data and RCP*.5JMPIRM2 of selected districts.

4.1 Jinnah-Chashma

4.1.1 Mianwali Inundation

The flood inundation for Mianwali District cover an area of 6%, 10%, 12%, 13%, 14% and 16% for return periods 5, 10, 25, 50,100 and 250 years respectively against total district area of 5,840 km2. The extent of area inundated with different depths are shown in Error! Reference source not found.. Flooded area in Mianwali varied from 375 km^2 for 5 years return period to 929 km^2 for 250 years return period.

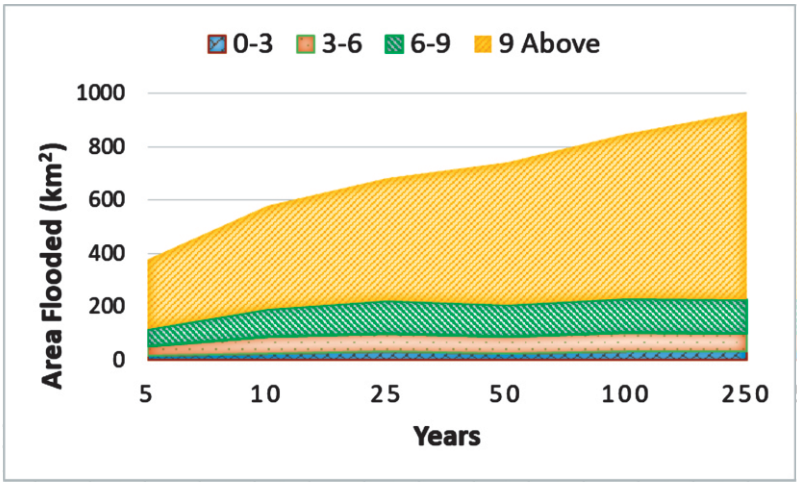


Figure 2: Area flooded in Mianwali District with CC

Comparison of inundated area with historic data peak discharges and climate change has made in **Figure 3**. Increase of inundated area due to climate change varied from 16 km^2 to 105 km^2 for 5 year RP and 250 years RP (Return Period) respectively.

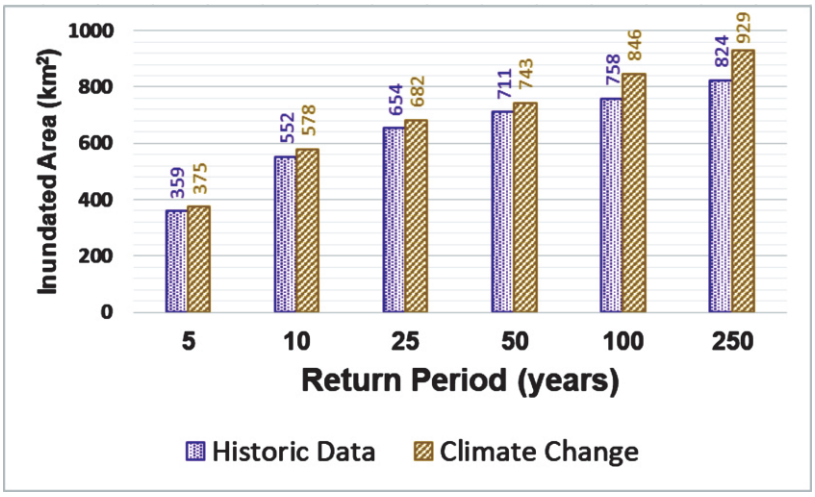


Figure 3: Comparison of Mianwali Inundated Area Historic Data vs Climate Change

Kalabagh Dam would greatly help in effectively controlling the floods in downstream reaches on the Indus River including Mianwali and Bhakkar Districts. Kalabagh Dam Project would be located on River Indus near Mianwali district. This multi-purpose project would have a live storage capacity of 6.1 million acre feet (MAF).

4.2 Chashma-Taunsa

4.2.1 Bhakhar Inundation

The flood inundation depth maps with CC for Bhakkar District cover an area of 1.8%, 3.3%, 3.7%, 4.7%, 5.8%, and 6.3% for return periods 5, 10, 25, 50,100 and 250 years respectively against the total district area of 8153 km^2. The extent of area inundated with different depths are shown in **Figure 4**. Flooded area in Bhakhar varied from 150 km^2 for 5 years return period to 513 km^2 for 250 return period.

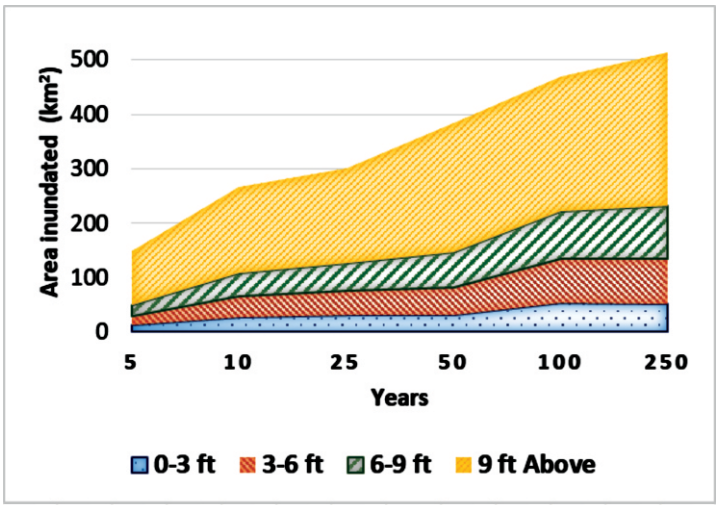


Figure 4: Area flooded with CC in Bhakhar District

Comparison of inundated area with historical data peak discharges and climate change has made in **Figure 5**. Increase of inundated area due to climate change varied from 7 km^2 to 94 km^2 for 5 years RP and 250 years RP respectively.

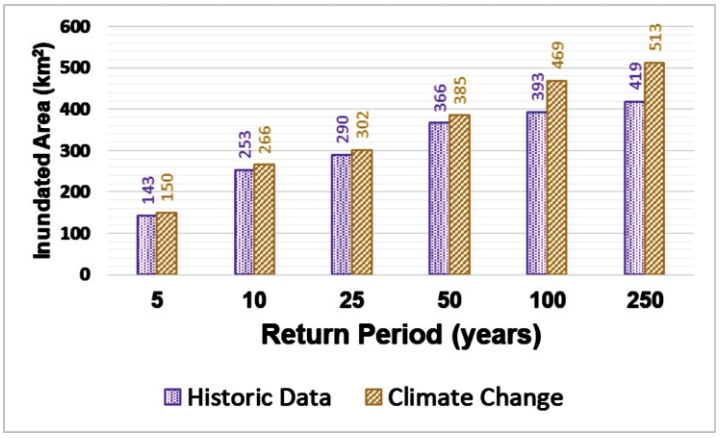


Figure 5: Comparison of Bhakhar Inundated Area
Historic Data vs Climate Change

Kalabagh dam would greatly help in effectively controlling the floods in downstream reaches on the Indus River including Bhakkar, DG Khan, Muzaffargarh and Rajanpur Districts.

4.2.2 Layyah Inundation

The flood inundation maps for Layyah District cover an area of 6.1%, 9.1%, 9.8%, 11.4%, 14.0% and 16.1% for return periods 5, 10, 25, 50,100 and 250 years respectively against the total district area of 6546 km^2. Flooded area in Layyah due to climate change scenario varied from 397 km^2 for 5 year return period to 1051 km^2 for 250 years return periods are shown in **Figure 6**. Major flooding of Layyah District is from the Indus River.

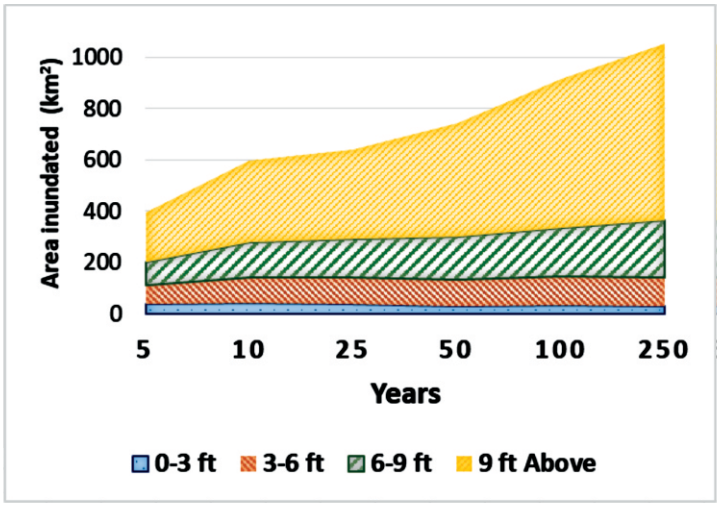


Figure 6: Indus River Flooded Area in Layyah District with CC

Inundated area based on historic data and climate change return periods are shown in **Figure 7**. The increase ranges from 10 Km^2 to 31 km^2 for 5 year and 250 years return respectively due to climate change scenario.

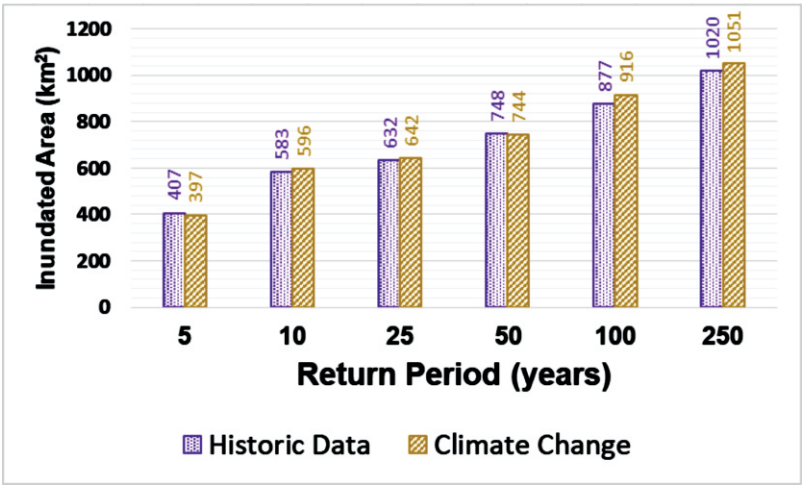


Figure 7: Comparison of Layyah Inundated Area
Historic Data vs Climate Change

Kalabagh dam would greatly help in effectively controlling the floods in downstream reaches on the Indus River including Bhakkar, Layyah, DG Khan, Muzaffargarh and Rajanpur Districts.

4.3 Taunsa-Guddu

4.3.1 Muzaffargarh Inundation

Indus River flood inundation maps for Muzaffargarh District cover an area of 8.3%, 11.0%. 11.5%, 13.8%, 16.1% and 16.8% for return periods 5, 10, 25, 50,100 and 250 years respectively against total district area of 8261 km^2. Area flooded by Indus River in Muzaffargarh District varied from 668 km^2 to 1387 km^2 for 5 years to 250 years return periods as shown in **Figure 8**.

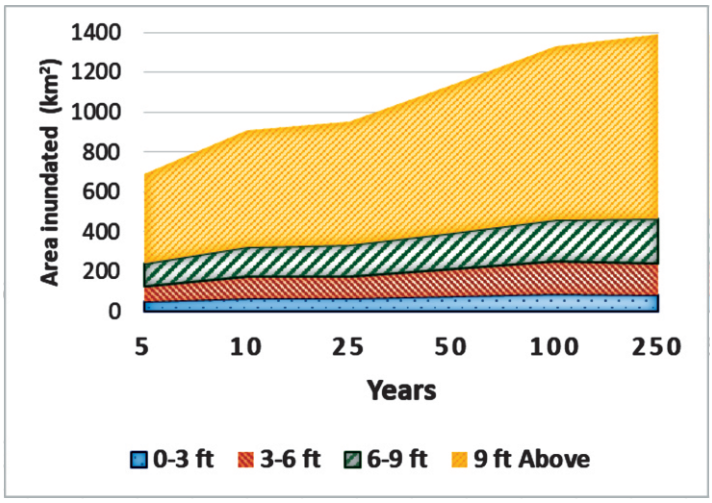


Figure 8: Area flooded by Indus River in Muzaffargarh District with CC

Indus River Inundated area based on historical data and climate change return periods are shown in **Figure 9**. The increase ranges from 48 Km^2 to 38 km^2 for 5 years and 250 years return respectively due to climate change scenarios.

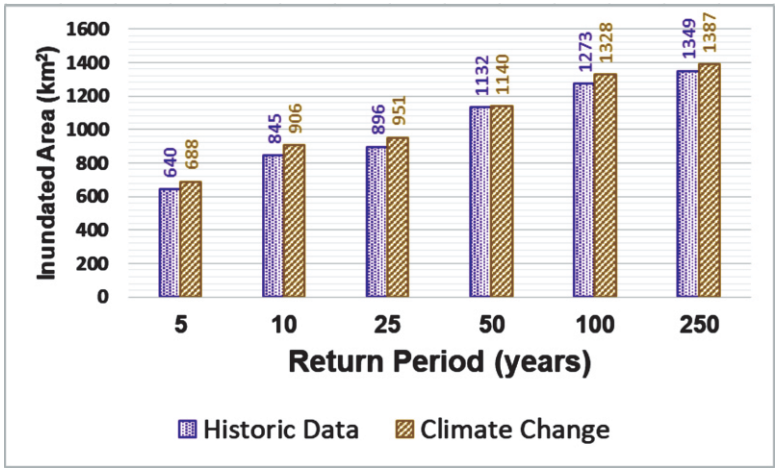


Figure 9: Muzaffargarh Indus Inundated Area Historic Data vs Climate Change

Kalabagh dam would greatly help in effectively controlling the floods in downstream reaches on the Indus River including Bhakkar, Layyah, DG Khan, Muzaffargarh and Rajanpur Districts.

4.3.2 D.G. Khan Inundation

The flood inundation depth maps for D.G. Khan District cover an area of 6%, 7%, 9%, and 10% for return periods 5, 10, 25, 50,100 and 250 years respectively against total district area of 11,922 km^2. The extent of area inundated with different depths are shown in **Figure 10**. Flooded area in D.G. Khan varied from 700 km^2 for 5 years return period to 1,181 km^2 for 250 years return period.

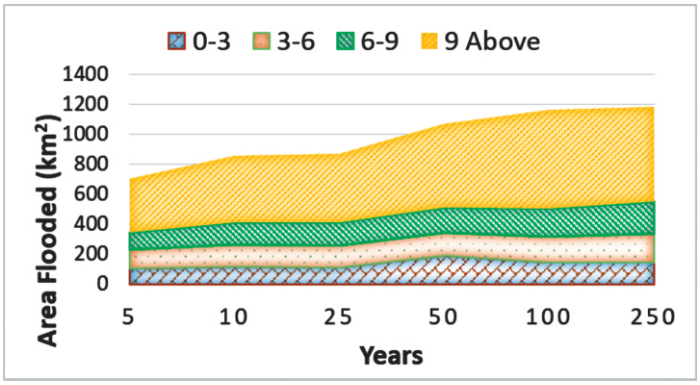


Figure 10: Area flooded in D. G. Khan District (Chashma + Taunsa) with Climate Change

Inundated area based on historic data and climate change return periods are shown in **Figure 11**. The increase ranges from 127 Km2 to 17 km2 for 5 year and 250 year return respectively due to climate change scenario.

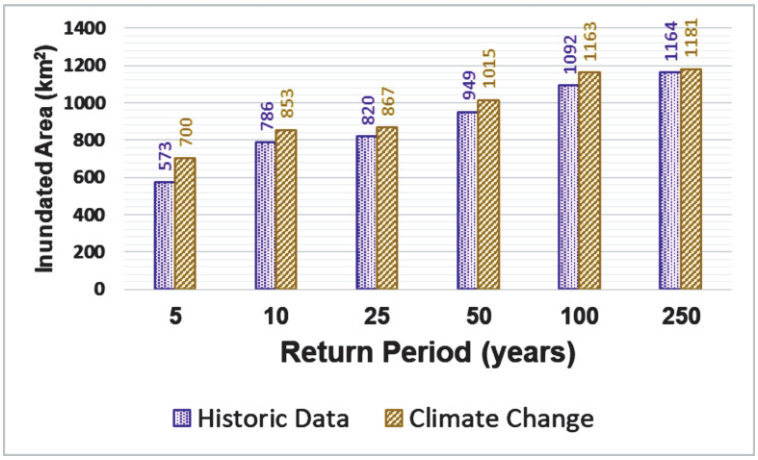


Figure 11: Comparison of D.G. Khan Inundated Area Historic Data vs CC

4.3.3 Rajan Pur Inundation

The flood inundation depth maps for Rajan Pur District cover an area of 6%, 9%, 12%, 13 %, 15 % and 16% for return periods 5, 10, 25, 50,100 and 250 years respectively against total district area of 12,316 km^2. The extent of area inundated with different depths are shown in **Figure 12**. Flooded area in Rajanpur varied from 698 km^2 for 5 years return period to 1885 km^2 for 250 years return period.

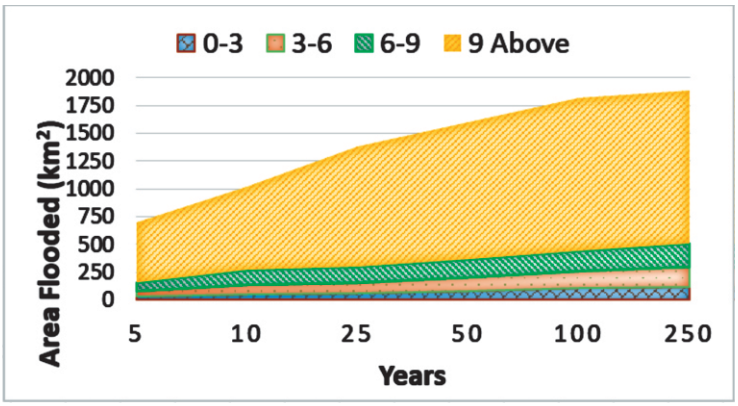


Figure 12: Area flooded in Rajan Pur District with CC

Inundated areas based on historical data and climate change return periods are shown in **Figure 13**. The increase ranges from 34 Km^2 to 15 km^2 for 5 years and 250 years return respectively due to a climate change scenarios.

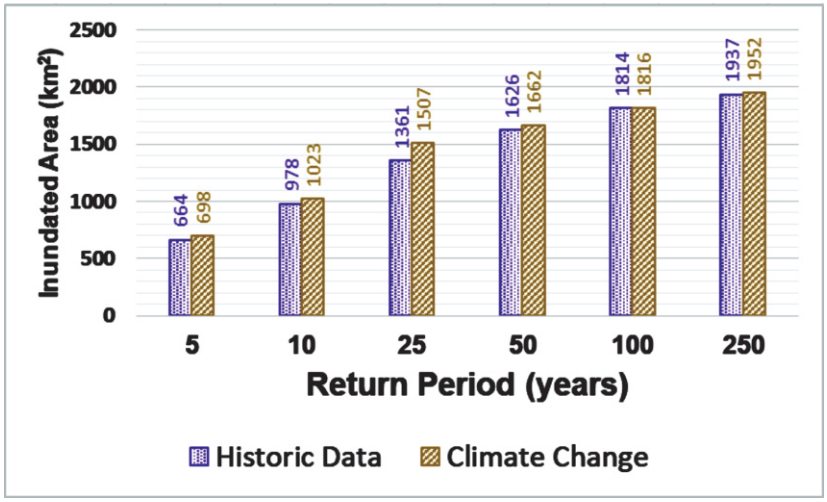


Figure 13: Comparison of Rajanpur Inundated Area Historic Data vs CC

4.4 Mangla-Rasul

4.4.1 Jhelum Inundation

The flood inundation maps for Jhelum District cover an area of 4.6%, 5.9%, 7.0%, 9.9%, 11.2% and 12.2% for return periods 5, 10, 25, 50,100 and 250 years respectively against total district area of 3,587 km^2. The extent of areas inundated with different depths with CC are shown in **Figure 14**. Flooded area in Jhelum varied from 167 km^2 for 5 years return period to 437 km^2 for 250 years return period.

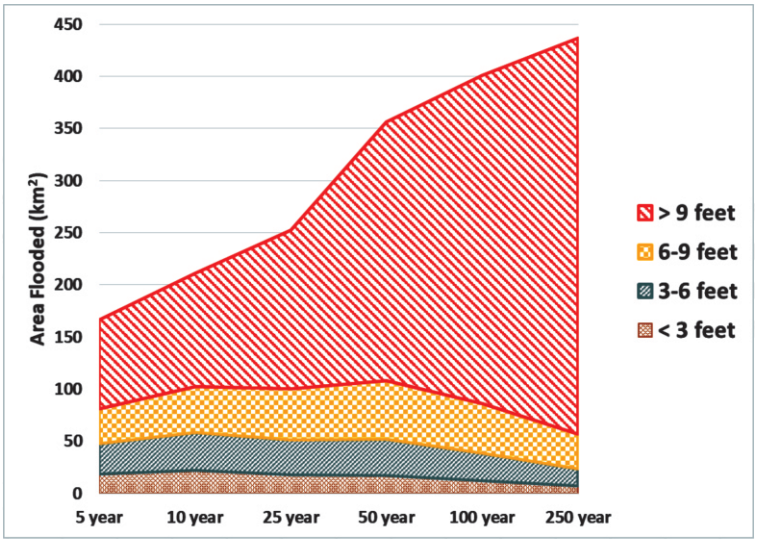


Figure 14: Area flooded in Jhelum District with CC

Inundated area based on historical data and climate change return periods are shown in **Figure 15**. The increase due to climate change scenario ranges from 10 Km2 to 19 km2 for 5 years and 250 years return respectively due to climate change scenarios.

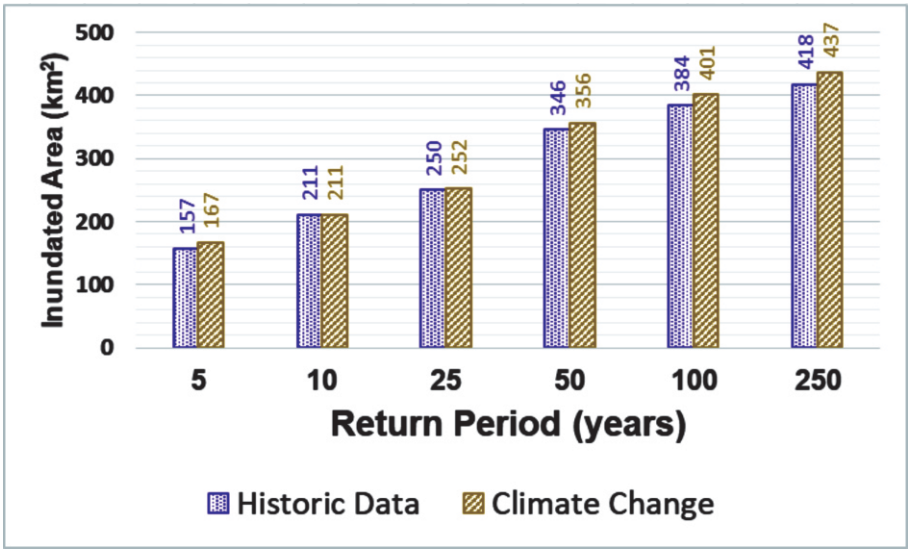


Figure 15: Comparison of Jhelum Inundated Area Historical Data vs Climate Change

Jhelum River d/s Mangla, raising of banks is proposed on right side to protect Jhelum City on left bank from Sarai Alamgir up to opposite of Pind Dadan Khan.

4.4.2 Gujrat Inundation

Gujrat District is inundated from both rivers Jhelum and Chenab. The flood inundation depth maps for Gujrat District cover an area of 7%, 9%, 10% and 11% for return periods 5, 10, 25, 50,100 and 250 years respectively against total district area of 3,192 km^2. The extent of area inundated with different depths are shown in **Figure 16**. Flooded area in Gujrat varied from 220 km^2 for 5 years return period to 364 km^2 for 250 years return period.

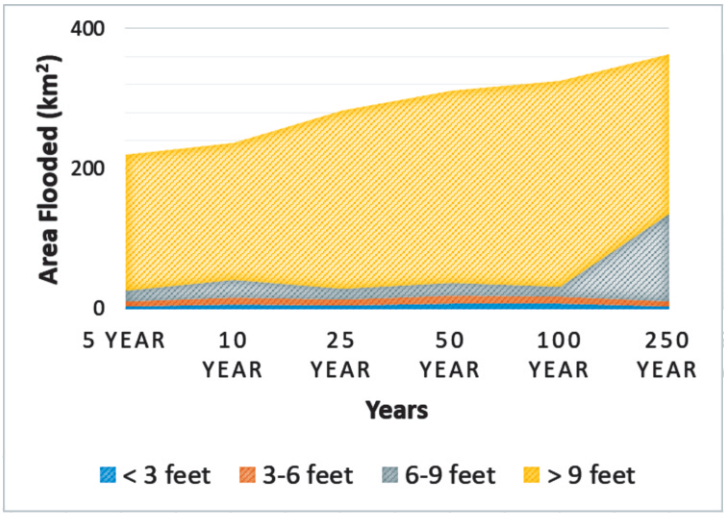


Figure 16: Area flooded in Gujrat District by Jhelum (CC) and Chenab

Inundated area based on historical data and climate change return periods due to Jhelum River are shown in **Figure 17**. The increase due to climate change scenario ranges from 1 Km^2 to 3 km^2 for 5 years and 250 years return respectively due to climate change scenarios.

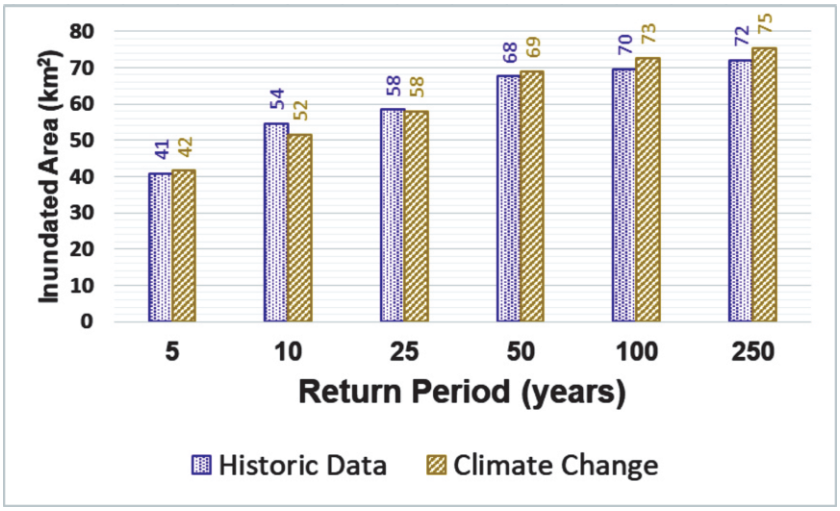


Figure 17: Gujrat (Jhelum River) Inundated Area Historic Data vs CC

Jhelum River d/s Mangla, raising of banks is proposed on right side to protect Jhelum City on left bank from Sarai Alamgir up to opposite of Pind Dadan Khan.

4.5 Rasul-Trimmu

4.5.1 Mandi Bahaudin Inundation

The flood inundation depth maps due to Jhelum River and Chenab River for Mandi Bahudin District cover an area of 6%, 7%, 8%, 11%, 12% and 13% for return periods 5, 10, 25, 50,100 and 250 years respectively against total district area of 2,678 km^2. The extent of area inundated with different depths are shown in **Figure 18**. Flooded area in Mandi Bahudin varied from 285 km^2 for 5 years return period to 513 km^2 for 250 years return period.

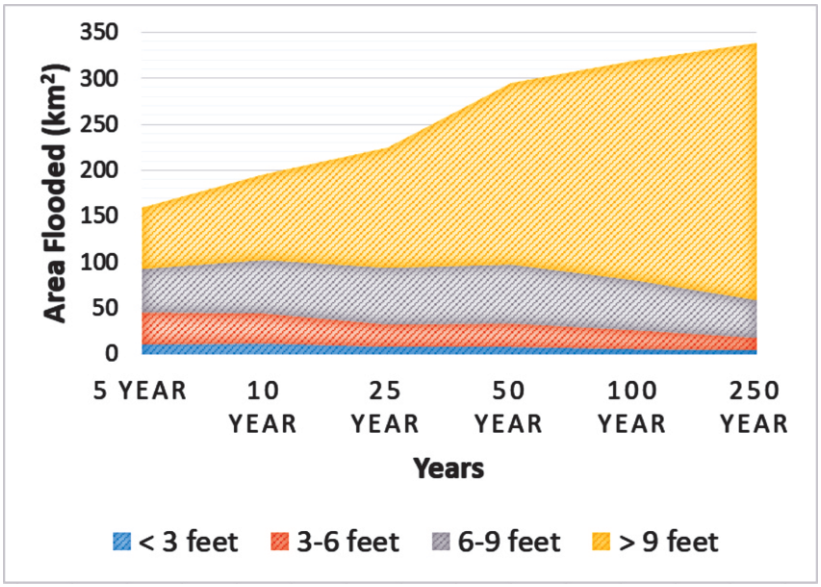


Figure 18: Area flooded in Mandi Bahudin District with CC

Jhelum River d/s Mangla, raising of banks is proposed on right side to protect Jhelum City on left bank from Sarai Alamgir up to opposite of Pind Dadan Khan.

4.6 Balloki-Sidhnai and Ferozepur-Sulemanki

4.6.1 Kasur Inundation

The flood inundation maps for Kasur District cover an area of 1.9%, 4.2. %. 6.3%, 7.2%, 8.0% and 8.4% for return periods 5, 10, 25, 50,100 and 250 years respectively against total district area of 4,796 km2. Area flooded in Kasur District varied from 90 km^2 to 402 km^2 for 5 years to 250 years return periods as shown in **Figure 19**.

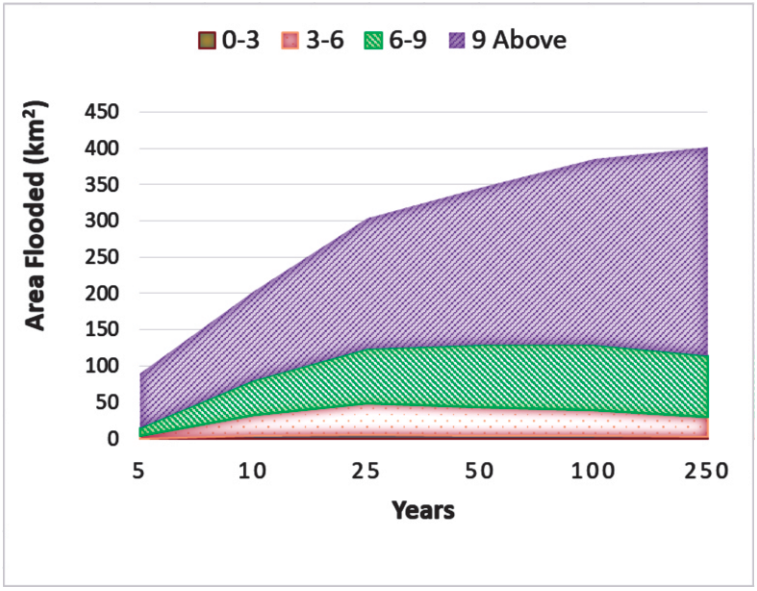


Figure 19: Area flooded in Kasur District-CC (Ravi + Sutlej)

Inundated areas based on historical data and climate change return periods due to the Sutlej River and Ravi River is shown in **Figure 20**. The increase due to climate change

scenario ranges from 1 Km^2 to 3 km^2 for 5 years and 250 years return respectively due to a climate change scenarios.

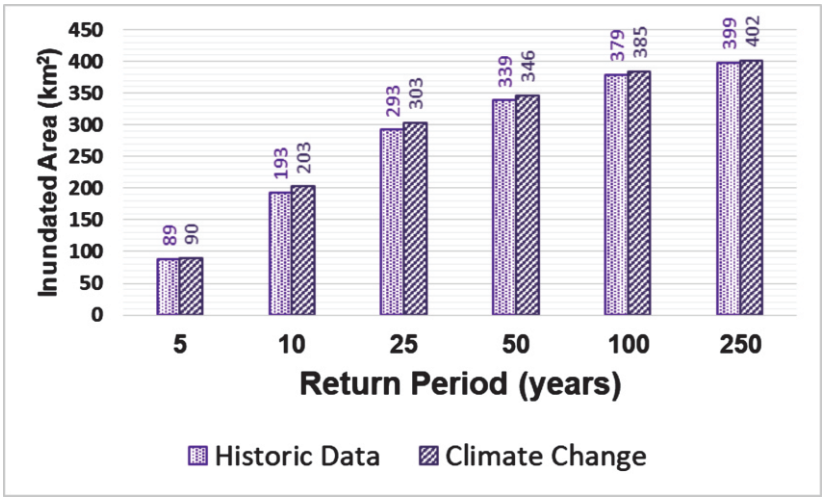


Figure 20: Kasur Inundated Area Historic Data vs CC

5. Data constraints and Limitations

Floods are among those hazards, complete control of which is an ambitious target. The hydro-meteorological events causing rainfall on various locations of the earth are all beyond the control of human beings. Every oncoming event proves to be a new challenge for the ingenuity future forecasts, thereby leading to improved techniques and models.

5.1 Limitations

The following constraints and limitations were faced during the study:

1. Climate Change Discharge at rim station have been generated with hydrological models without considering the dams under construction and planning.
2. Data and information sharing is not common.

5.2 Institutional gaps

The following is lacking in the institutions:

1. Coordination between federal and provincial departments during floods.
2. Technical data sharing mechanism among departments.
3. Lacking expertise and specialists in flood handling departments.

6. Conclusion and Recommendations

Based on hydrological analysis the following conclusion and recommendations made (**Table 3**).

Table 3: Hydrological Analysis Summary

Conclusions based on RCP 8.5 for JMPIRM2 GCM	**Recommendations**
i. Indus at Jinnah (Mianwali)	
Flood at 100 year return period, considering climate change, is likely to occur at about 25 years return period. Based on the same scenario and GCM future 100 year return period flood is equivalent to the historic 1000 year return period flood.	Future infrastructure design and protection requires adequate measures. For flood reduction: Dams and reservoirs, high flow diversions and channel improvement be studied and construction initiated (structural & non-structural).

Conclusions based on RCP 8.5 for JMPIRM2 GCM	Recommendations
ii. Indus at Chashma (Mianwali, Bhakhar, DG Khan)	
Flood at 100 year return period, considering climate change, is likely to occur at about 12 years return period. Based on the same scenario and GCM future 100 year return period flood is equivalent to the historic 750 year return period flood.	Future infrastructure design and protection requires adequate measures. Completion of watershed management plans in the uplands of rivers (non-structural). Feasibility and design of small storages in the areas away from the main rivers shall be completed and construction of small storages in those areas away be initiated. For flood reduction: Dams and reservoirs and channel improvement be studied and construction initiated (structural & non-structural). Coordination mechanism for stakeholders/departments shall be developed and adopted.
iii. Indus at Taunsa (Layyah, Muzaffargarh, Rajanpur, DG Khan)	
Flood at 100 year return period, considering climate change, is likely to occur at about 7 years return period. Based on the same scenario and GCM future 100 year return period flood is equivalent to the historic 1000 year return period flood.	Future infrastructure design and protection requires adequate measures. Completion of watershed management plans in the uplands of rivers (non-structural). Feasibility and design of small storages in the areas away from the main rivers shall be completed and construction of small storages in those areas away be initiated. For flood reduction: Dams and reservoirs and channel improvement be studied and construction initiated (structural & non-structural). Coordination mechanisms for stakeholders/departments shall be developed and adopted.
iv. Jhelum at Rasul (Jhelum, Gujrat, Mandi Bahauddin)	
Flood at 100 year return period, considering climate change, is likely to occur at about 60 years return period. Based on the same scenario and GCM future 100 year return period flood is equivalent to the historic 250 year return period flood.	Jhelum River d/s Mangla, raising of banks is proposed on right side to protect Jhelum City on left bank from Sarai Alamgir up to opposite of Pind Dadan Khan. Future infrastructure design and protection requires adequate measures. Feasibility study of Chiniot dam need to be prepared. Flood Management shall be integrated with water resource management and land drainage. The integration of development and flood management can yield multiple benefits from a single intervention.
v. Chenab at Trimmu	
Flood at 100 year return period, considering climate change, is likely to occur at about 125 years return period. Based on the same scenario and GCM future 100 year return period flood is equivalent to the historic 75 year return period flood.	Future infrastructure design and protection requires adequate measures. Feasibility study of Chiniot dam need to be prepared.

Based on the inundation due to climate change scenario shown in the previous section, the comparison of inundation areas based on RCP8.5 and historic data are given in **Table 4**. An increase in areas inundated by Indus River are greater than other rivers. Generally more reservoirs, watershed management, small dams, rainwater harvesting schemes and improvement of flood bunds will be needed to cope with climate change scenario.

Table 4 Inundated Areas Summary

No	District	Scenario	District Area (km^2)	Inundated Area for Different Return Periods in years (km^2)					
				5	10	25	50	100	250
1	Mianwali	RCP8.5	5,840	375	578	682	743	846	929
		Historic Data		359	552	654	711	758	824
2	Bhakhar	RCP8.5	8,153	150	266	302	385	469	513
		Historic Data		143	253	290	366	393	419
3	Layyah	RCP8.5	6546	397	596	642	744	916	1051
		Historic Data		407	583	632	748	877	1020
4	Muzaffargarh	RCP8.5	8261	688	906	951	1140	1328	1387
		Historic Data		640	845	896	1132	1273	1349
5	D.G. Khan	RCP8.5	11,922	700	853	867	1015	1163	1181
		Historic Data		573	786	820	949	1092	1164
6	Rajanpur	RCP8.5	12,390	698	1023	1507	1662	1816	1952
		Historic Data		664	978	1361	1626	1814	1937

No	District	Scenario	District Area (km^2)	Inundated Area for Different Return Periods in years (km^2)					
				5	10	25	50	100	250
7	Jhelum	RCP8.5	3,587	167	211	252	356	401	437
		Historic Data		157	211	250	346	384	418
8	Gujrat	RCP8.5	3,192	42	52	58	69	73	75
		Historic Data		41	54	58	68	70	72
9	M B Din	RCP8.5	2,623	53	68	81	106	114	116
		Historic Data		49	66	78	100	107	109
10	Kasur	RCP8.5	4,796	90	203	303	346	385	402
		Historic Data		84	141	207	262	372	596

Paper No. 793

SOIL PROPERTY CORRELATIONS FOR ASSESSING COMPRESSIBILITY AND UNDRAINED SHEARING STRENGTH OF LAHORE CLAYS

Sohail Kibria, Muhammad Ali

SOIL PROPERTY CORRELATIONS FOR ASSESSING COMPRESSIBILITY AND UNDRAINED SHEARING STRENGTH OF LAHORE CLAYS

By

Sohail Kibria[1] and Muhammad Ali[2]

Abstract

The importance of determining complex soil properties from simple characteristics with the help of correlations cannot be overemphasized in geotechnical engineering. Such correlations allow determination of important soil characteristics like compressibility & shearing strength in little time without any cost involvement and extra time requirement. A lot of work has been done by geotechnical experts around the world on developing soil property correlations for their local soils.

Compressibility of soil is used as an important property for determination of total settlement, differential settlement, rate of settlement, etc. for effective control on serviceability limit state. Similarly, cohesion is the shearing strength parameter of plastic soils, and is used for controlling ultimate limit state. Reasonable and quick determination of these important soil properties ensures appropriate settlement and bearing capacity analysis to prevent any significant foundation settlement or breakdown of ground in shear during life of the project.

A typical consolidation test may sometimes require several weeks before its results are available for use in the geotechnical design of foundations. Keeping in view these shortcomings and availability of vast quantum of reliable geotechnical data of a variety of projects located in Lahore, effort has been made to develop correlations for evaluation of compression index (c_c) and coefficient of volume compressibility (m_v) for the cohesive soils of Lahore, using simple soil properties like natural moisture content (NMC), dry density (γ_d), initial void ratio (e_o) etc. Similarly, plasticity index and maximum past pre-consolidation stress as well as effective overburden pressure have been used to evaluate the undrained cohesion of Lahore soils. It is expected that correlations presented in this paper will save a lot of time of consolidation and shear testing of cohesive soils for preliminary design as well as for ordinary projects located in and in the vicinity of Lahore.

Introduction:

Compressibility of soils is an important engineering consideration. The oedometer test is used to determine the compressibility characteristics of soils which are typically described using the compression index *(C_c),* coefficient of volume compressibility (mv) and the coefficient of consolidation *(C_v).* The compression index is used to predict how much settlement will take place and the coefficient of consolidation is a rate parameter used to predict how long it will take for a given amount of compression to take place. However, oedometer testing requires undisturbed samples and is quite time consuming and expensive. For this reason, researchers in the past have correlated compressibility characteristics with index properties. The first well-

[1] Expert Category – 1 / Ex. Vice President, Geotechnical & Geo Environmental Engg. Div., NESPAK, Lahore, Pakistan

[2] Senior Engineer, Geotechnical & Geo Environmental Engg. Div., NESPAK, Lahore, Pakistan

known correlation was presented by Skempton (1944), who gave the following correlation for the compressibility of remolded soils with liquid limit (w_L),

$$C_c = 0.007(w_L - 10)$$

Table 1. Compression index equations.

Equation	Applicability	Reference
$C_c = 0.007(w_L - 10)$	Remoulded clays	Skempton 1944
$C_c = 0.0046(w_L - 9)$	Brazilian clays	Cozzolino 1961
$C_c = 0.009(w_L - 10)$	Normally consolidated clays	Terzaghi and Peck 1967
$C_c = 0.006(w_L - 9)$	All clays with $w_L < 100\%$	Azzouz et al. 1976
$C_{c10} = 0.009(w_L - 8)$	Osaka Bay clay	Tsuchida 1991
$C_{c10} = 0.009 w_L$	Tokyo Bay clay	Tsuchida 1991
$C_c = 0.01(w_n - 5)$	All clays	Azzouz et al. 1976
$C_c = 0.01 w_n$	All clays	Koppula 1981
$C_c = 0.01(w_n - 7.549)$	All clays	Herrero 1983
$C_c = 0.0115 w_n$	Organic silt and clays	Bowles 1989
$C_c = 1.15(e - e_o)$	All clays	Nishida 1956
$C_c = 0.29(e_o - 0.27)$	Inorganic soils	Hough 1957
$C_c = 0.35(e_o - 0.5)$	Organic soils	Hough 1957
$C_c = 0.246 + 0.43(e_o - 0.25)$	Motley clays from Sao Paulo, Brazil	Cozzolino 1961
$C_c = 1.21 + 1.055(e_o - 1.87)$	Lowlands of Santos, Brazil	Cozzolino 1961
$C_c = 0.75(e_o - 0.50)$	Soils with low plasticity	Sowers 1970
$C_c = 0.208 e_o + 0.0083$	Chicago clays	Bowles 1989
$C_c = 0.156 e_o + 0.0107$	All clays	Bowles 1989
$C_c = 0.2 e^{1.6}$	Naturally sedimented young soils	Shorten 1995
$C_c = 0.5(\gamma_w/\gamma_d)^{2.4}$	All soil types	Herrero 1980
$C_c = 0.185[G_s(\gamma_w/\gamma_d)2 - 0.144]$	All soil types	Herrero 1983
$C_c = 0.5 I_p G_s$	All remoulded, normally consolidated clays	Wroth and Wood 1978
$C_c = 0.329[0.027(w - w_p) + 0.0133 I_p(1.192 + \mathrm{ACT}^{-1})]$	All remoulded, normally consolidated clays	Carrier 1985
$C_c = 0.2237 e_L$	All remoulded, normally consolidated clays	Nagaraj and Srinivasa Murthy 1983
$C_c = 0.2343 e_L$	All remoulded, normally consolidated clays	Nagaraj and Srinivasa Murthy 1986
$C_c = 0.274 e_L$	Clay – sand mixes	Nagaraj et al. 1995

Note: ACT, activity; C_c, compression index; C_{c10}, compression index when consolidation pressure $p = 10$ kg/cm^2; e, void ratio at a specific pressure; e_L, void ratio at liquid limit; e_o, initial or in situ void ratio; G_s, specific gravity; I_p, plasticity index; w_L, liquid limit; w_n, natural water content; w, water content of the remoulded soil considered; w_p, plastic limit; γ_d, dry unit weight of soil at which C_c is required; γ_w, unit weight of water.

Other subsequent correlations are presented in Table-1, which shows that different researchers have used various parameters, including liquid limit (w_L), natural moisture content (w_n), initial void ratio (e_o), dry unit weight (γ_d), plasticity index (I_p) and void ratio at liquid limit (e_L).

Similarly, literature provides good correlation between undrained cohesion "c_u" to maximum past pre-consolidation stress "σ_p" ratio as well as effective overburden stress "$p_{o'}$" ratio and plasticity index "PI".

The following notable relationships exist in the literature in this regard:

$c_u = 0.22\ p_{c'}$ ---------- Mesri 1989

$c_u / p_{o'} = 0.11 + 0.0037\ PI$ ---------- Skempton & Henkel 1953

$c_u / p_{o'} = 0.018\ (LI)^{0.5}$ for $LI > 0.5$ ---------- Bjerrum & Simons 1960

General Geology of Lahore:

The Lahore city lies on the alluvial plain called Bari Doab (Doab is a local word for area between rivers) which is a part of Indus plain. It is bounded by Ravi and Chenab rivers in the northwest and west and by Sutlej river in the southeast. The Northeastern boundaries of Doab lies near the foothills of the Himalayan Ranges. It is composed of a central slightly raised and relatively flat tableland bounded by the flood plains of Ravi, Sutlej and some parts of Chenab River (Kidwai & Siraj 1964; Kazmi 1966).

The Bari Doab is a part of the Indo-Gangetic alluvial plain formed by the Indus river and its tributaries. The Indus plain was formed by contemporaneous sedimentation and sinking of a geosyncline called Tethys sea. The geosyncline was created as a result of the Himalayan orogeny.

The Bari Doab is covered by Quarternary alluvium which presumably overlies semi-consolidated Tertiary rocks or Metamorphic and igneous rocks of Precambrian age. Except for a small area in the northeastern part of Doab where basement rock was encountered, no information is available at present regarding the distribution of Tertiary and precambrian rocks in the Doab.



Figure. 1: Geological Map of District Lahore (Geological Survey of Pakistan)

Legends:

Qfp_1 = Younger flood plain deposits Qmb_1 = Meander belt deposits

Qaoc = Older Alluvial Complex deposits Qfp_2 = Older Flood plain deposits

General Lithology of Lahore:

- Low plastic Silty Clays in firm to stiff state are present from top of ground to maximum depth of 7 to 10 m generally, below natural surface level (NSL).
- The above layer is underlain by medium-dense to dense Silty Sand / poorly graded Sand with Silt.
- The Silty Clay stratum is repeated at 21 to 29 m in the form of stiff to hard layer encountered around 8 m depth.

- Groundwater table within city limits varies from 60' to 110'. However, the groundwater table is as shallow as at 20' in city outskirts.

Procedure for Development of Correlations:

The test results of one hundred and fourteen (114) cohesive soil samples, collected from forty (40) scattered locations and tested by the credible testing laboratories within the city limits from 0 to 10 m depths, was used for this study. The location of all the points is shown in Figure-2:

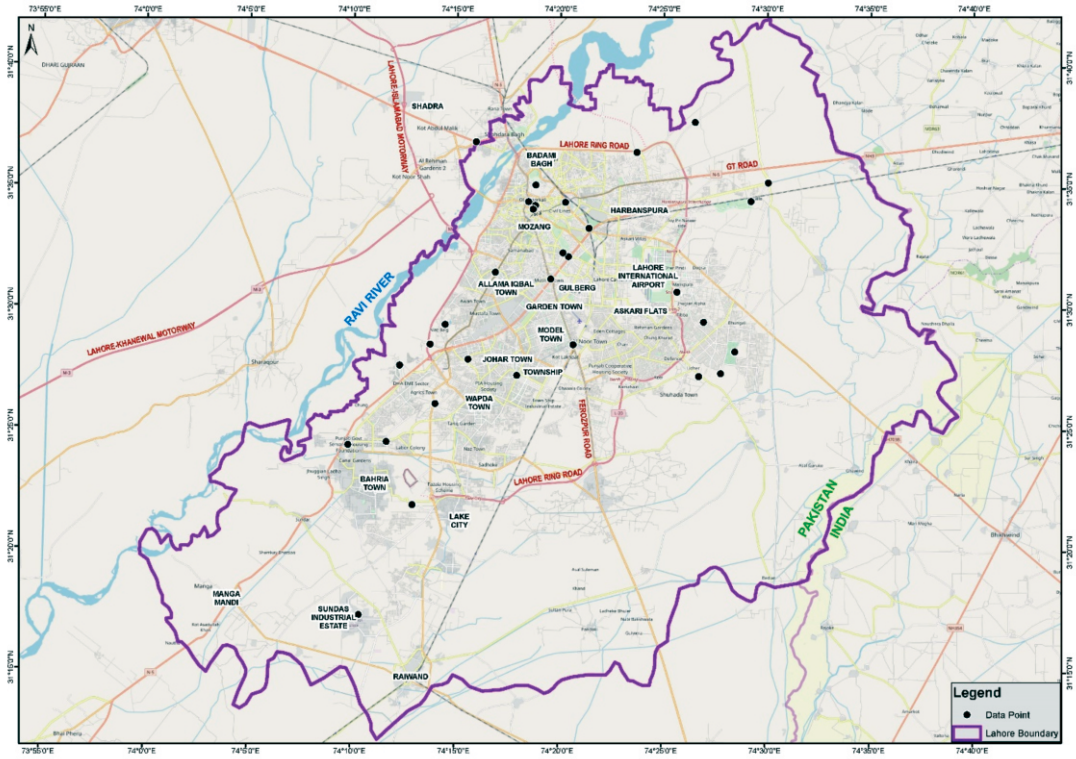


Figure. 2: Location Plan of Data Points

The data for cohesive soil samples indicated the following index properties:

- % Fines (passing # 200 sieve) = 54 % ~ 98 %
- Liquid Limit *(LL)* = 23 % ~ 44 %
- Plasticity Index *(PI)* = 5 % ~ 18 %
- Initial Void Ratio (e_o) = 0.56 ~ 0.85

During comparison of index soil properties with consolidation and shearing strength parameters derived from unconfined compression strength, the following graphical trends/correlations have been developed. The predominant cluster of test data has been enveloped for each correlation while selecting the trends to satisfy logic. Average trend between the envelope is also developed for each correlation, in the form of a straight line, whose linear equation has also been developed. Obviously, some data trend are poor on account of wide scatter of data.

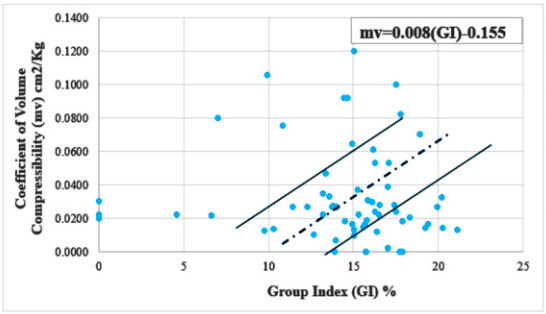


Fig. 3: Coefficient of Volume Compressibility v/s Group Index

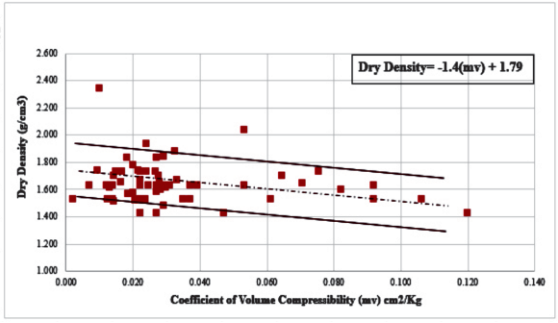


Fig. 4: Dry Density v/s Coefficient of Volume Compressibility

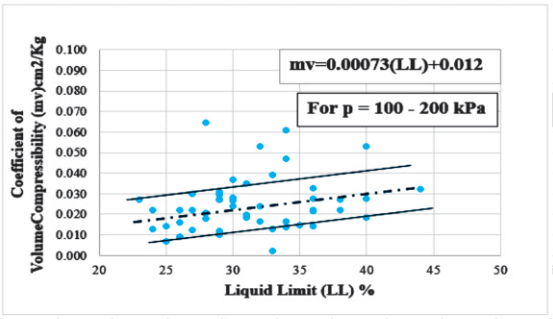


Fig. 5: Liquid Limit v/s Coefficient of Volume Compressibility

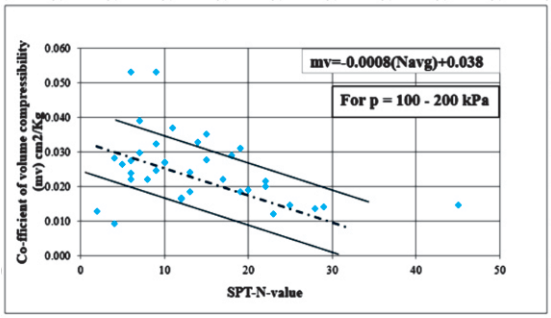


Fig. 6: Field SPT-N v/s Coefficient of Volume Compressibility

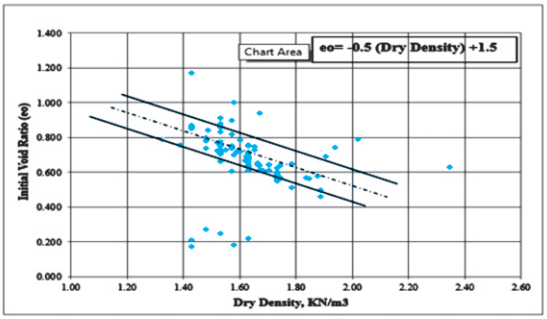


Fig. 7: Dry Density v/s Initial Void Ratio

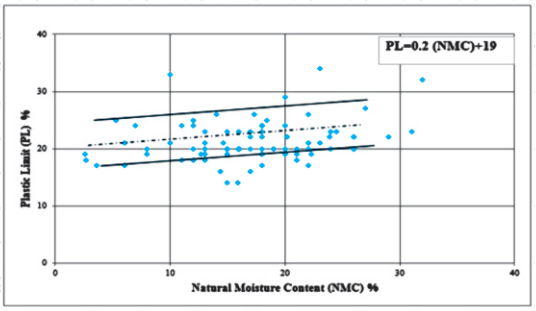


Fig. 8: Natural Moisture Content v/s Plastic Limit

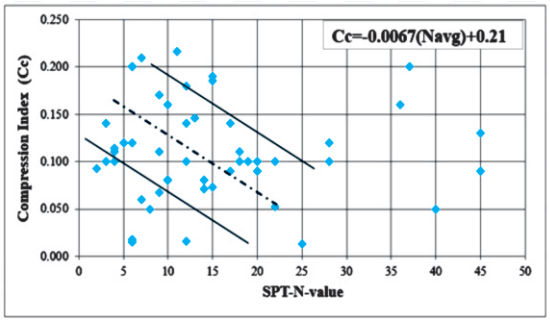


Fig. 9: Field SPT-N v/s Compression Index

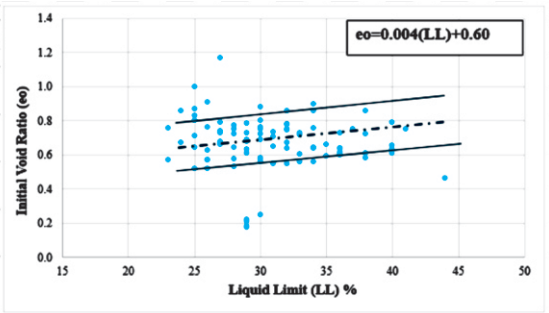


Fig. 10: Liquid Limit v/s Initial Void Ratio

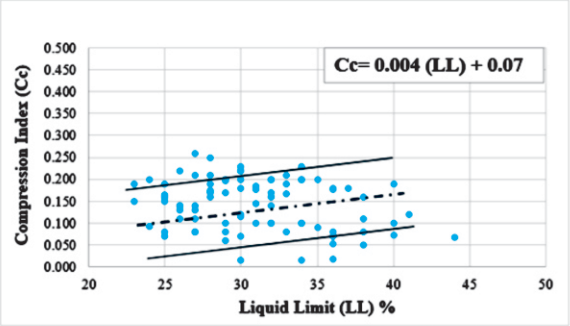


Fig. 11: Liquid Limit v/s Compression Index

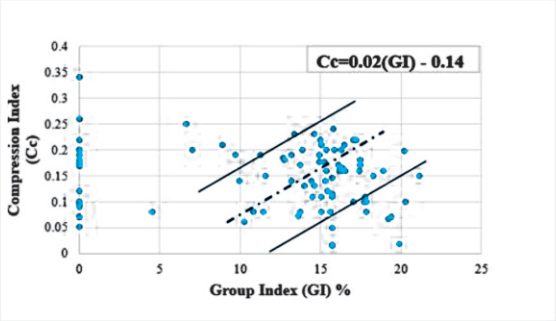


Fig. 12: Group Index v/s Compression Index

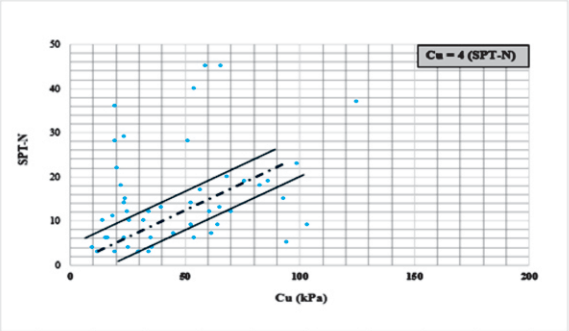


Fig. 13: Undrained Cohesion v/s SPT-N

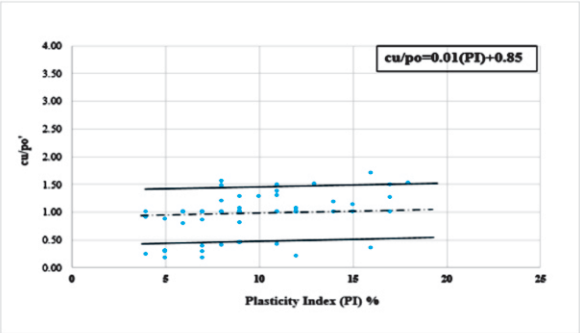


Fig. 14: Plasticity Index v/s Undrained Cohesion / Effective Overburden Pressure

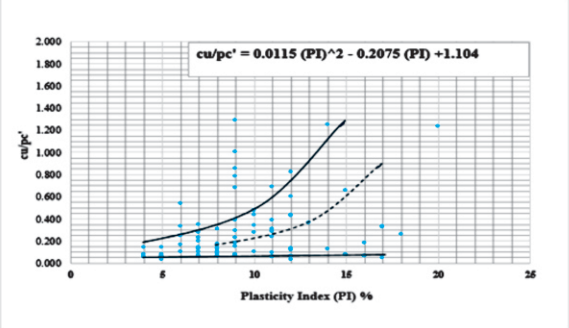


Fig. 15: Plasticity Index v/s Undrained Cohesion / Effective Pre-consolidation Pressure

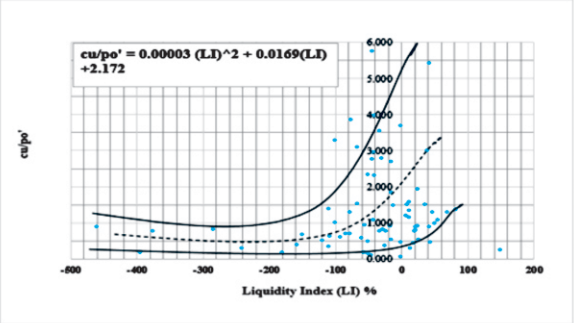


Fig. 16: Liquidity Index v/s Undrained Cohesion / Overburden Pressure

Discussions on the Developed Correlations:

- Fig. 3 to Fig. 12 show correlations for estimating the compressibility characteristics of Lahore clays from index properties whereas Fig. 13 to Fig. 16 comprise correlations for deducing undrained shearing strength.
- A soil with a high value of liquid limit (LL) will generally indicate high compressibility characteristics. The correlation between compression index (C_c) and liquid limit (LL) as shown in Fig. 11 slightly deviates from the Skempton's correlation. The deviation is primarily because that Skempton derived the correlation for remoulded clay samples. However, this correlation is solely based on the test data of undisturbed clay samples.

Another reason for deviation is that the cohesive soils in Lahore generally consist of silt and sand content as well.

- Over consolidated clayey deposits show high shearing strength and low compressibility characteristics. The cohesive soils do show over consolidation, primarily on account of desiccation.
- A soil with a high value of group index (GI) is likely to have a high value of compressibility.
- The undrained shear strength (c_u) normalized with the maximum past pre-consolidation pressure (p_c') shows an increasing trend with the plasticity index (PI).
- The undrained shear strength (c_u) normalized with effective vertical overburden stress (p_o') shows an almost horizontal trend with the plasticity index (PI).
- The undrained shear strength (c_u) shows an increase with an increase in Standard Penetration Test (SPT) blows, but on lower side as compared to Terzaghi's old correlation.

Conclusions and Recommendations:

In this paper, an attempt has been made to correlate the index properties of Lahore clays with the consolidation parameters especially with coefficient of volume compressibility (m_v) & compression index (c_c) as well as undrained shearing strength with the available soil data. These correlations allow saving time and money for arriving at reasonable estimates of deformation and strength parameters of cohesive soils vis-à-vis the laboratory test results. Therefore, these correlations can be used for controlling serviceability as well as ultimate limit states for preliminary design of foundations in Lahore clays.

References:

Wroth, C.P. and Wood D. M. (1978). The correlation of index properties with some basic engineering properties of soils. Canadian Geotechnical Journal, 15(2): 137-145.

O'Kelly, B. C. (2013). Atterberg limits and remolded shear-strength water content relationship. Geotechnical Testing Journal, 43(5): 502 – 507.

Azadi, M. R. E. and Monfared, S. R. (2012). Fall cone test parameters and their effects on the liquid and plastic limits of homogeneous and non-homogeneous soil samples. Electronic Journal of Geotechnical Engineering. 17K: 1615 – 1646.

Youseef, M. S., El Ramli, A.H. and El Demery, M. (1965). Relationship between shear strength, consolidation, liquid limit and plastic limit for remolded clays. Proc. Of the 6th Int. Conf. on Soil Mechanics and Foundation Engineering, Montreal, P. Q., Vol. 1, pp. 126 – 129.

Skempton, A. W. (1944). Notes on the compressibility of clays. Quarterly Journal of the Geological Society of London, 100C: Parts 1, 2, pp. 119 – 135.

Casagrande, A. (1947). Classification and identification of soils. Proc. of the American Society of Civil Engineers, 73(6): 783 – 810.

Feng, T. (2000). Fall cone penetration and water content relationships of clays. Geotechnique, 50(2): 181 – 187.

Geotechnical Investigations Report of various projects in Lahore prepared by M/s NESPAK.

Paper No. 794

STABILIZATION OF A TERRACE SLOPE AT BANSARA GALI, MURREE

Sohail Kibria, Muhammad Ali

STABILIZATION OF A TERRACE SLOPE AT BANSARA GALI, MURREE

Sohail Kibria[1] and Muhammad Ali[2]

Abstract:

Murree is a hill station located in northern part of Pakistan. The hill slopes in Murree area comprise so-called Murree formation which are characteristically soft rocks; mostly weak shale with some interbedding of weak to moderately hard sandstone. Murree receives heavy rainfall and is located at about 4-5 km from Murree Boundary Thrust (MBT). The landslide potential of slopes in Murree area is fairly high owing to weak rocks, steep slopes, and high precipitation, resulting in high pore-water pressure development. Besides, Murree has high potential seismicity as it falls in Zone-3 as per Building Code of Pakistan (2007).

Recently, the terrace of a slope had to be extended with reinforced earth, so as to accommodate surface parking of cars. The reinforced earth system comprised mechanical stabilization using polyethylene strips impregnated with polyester tendons and using granular soil as backfill. A few months after its construction, the reinforced earth part of the terrace and the downslope area showed signs of severe movement during the heavy rainfalls. About 70 settlement markers were installed immediately on the terrace and slope and were regularly monitored.

An immediate investigation revealed that the subsurface drainage system in the slope was inadequate. A series of horizontal and vertical drains were constructed within the slope. These drained heavily the trapped water immediately after their installation. The parallel monitoring of settlement markers indicated a gradual recession in the movement, starting from downslope to upslope area, thus stabilizing the slopes in a matter of about three months. This paper describes the movement of slope and the economical mitigative drainage measures taken to curb the movement effectively.

It is believed that such low-cost mitigation can be adopted elsewhere too, to stabilize a slope in a similar situation.

Keywords: Slope stabilization, Slope failure, Settlement markers

1. INTRODUCTION

The tourist influx in Murree has increased manifold over the past few years. The tourist season which was limited to summer season only has now spread over the whole year thereby creating extreme traffic congestion during peak periods both in summer and winter as well as during weekends. The resort lacks appropriate parking and allied facilities, therefore, the traffic congestion leads to blockage of road networks and causes air and noise pollution within Murree, as well. The Government of Punjab has a vision to establish parking facilities at various locations in and around Murree to control the traffic congestion issue. In order to achieve this objective, various sites were selected for development of car parking facilities in Murree area. Bansara Gali site is one of the identified sites, where a terraced surface parking facility was constructed by extending an existing terrace being already used as a limited capacity parking facility for the existing chairlift. This paper gives an account of the geological and geotechnical studies carried out for the design of surface parking facility at Bansara Gali site and design of the post-movement remedial measures, to control the slope movements initiated in part of reinforced earth and downslope area, after a few months of the construction of a part of the terrace.

[1] Expert Category – 1 / Ex. Vice President, Geotechnical & Geo Environmental Engg. Div., NESPAK, Lahore, Pakistan

[2] Senior Engineer, Geotechnical & Geo Environmental Engg. Div., NESPAK, Lahore, Pakistan

2. GEOLOGICAL CONDITIONS OF MURREE

The hill slopes in Murree area comprise Murree formation which are characteristically soft rocks; mostly weak shale with some interbedding of siltstone and weak to moderately hard sandstone. The landslide potential of slopes is fairly high in this area owing to weak rocks, steep slopes, high precipitation resulting in high pore-water pressure development and high potential seismicity, as Murree falls in Zone-3 as per Building Code of Pakistan.

The Main Boundary Thrust (MBT) runs at a distance of about 4 – 5km from Murree.

3. SITE GEOTECHNICS

The proposed site is located at Rawalpindi Murree Kohala (RMK) road at an approximate distance of 8 km from Murree GPO through Kashmir-Kuldana road. The site comprises two terraces, i.e. Terrace-1 and Terrace-2 and shown in **Figure 1.** Before development of the recent eco-friendly parking facility, Terrace-1 was being used as a surface parking facility for chair lift system which connects proposed site to Pindi Point, whereas, the second terrace (Terrace-2) existed as barren land.

The geological and geotechnical investigations run on both the terraces comprised geological mapping of the site area, drilling of bare holes, in-situ testing and laboratory testing on selected soil/rock samples as well as geophysical surveys. A comprehensive geological and geotechnical investigation plan was implemented to capture the subsurface features. **Figure 2** shows the geological and geotechnical investigation plan of the site.

During these investigations, the subsurface was explored to a maximum depth of twenty-three (23) m below the existing ground surface. Groundwater table (GWT) was not encountered in any of the boreholes. The subsurface strata on the terrace/slope comprise the following lithological units:

a) **Overburden:** This layer comprises silty clay/ lean clay with variable percentages of sand and gravel. The thickness of overburden ranges from 4.5 m to 18.0 m.

b) **Bedrock:** The bedrock comprises shale/ shale interbedded with subordinate beds of siltstone and sandstone. These deposits belong to Murree formation.



Figure 1: Location Plan of Site

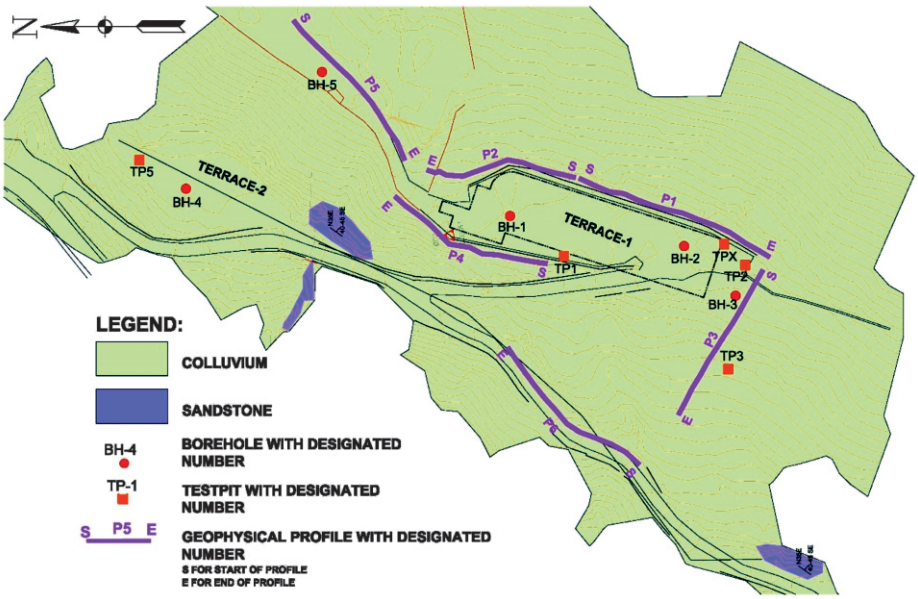


Figure 2: Geological and Geotechnical Investigation Plan of the Site

Based on the information gathered from the drilling of boreholes, surface geological mapping and seismic refraction surveys, geological profiles were developed which were subsequently utilized to create models for slope stability analyses.

The geotechnical design parameters for slope stability analyses were selected keeping in view in-situ test data, laboratory test results, recent literature and engineering judgment based on the previous working experience in Murree area, as shown in **Table 1**.

Table -1:Geotechnical Design Parameters

Sr. No.	Description	Bulk Unit Weight	Drained Shear Strength Parameters	
		γ_b, kN/m^3(pcf)	c',kPa (psf)	ϕ'(deg)
1	Overburden (Silty Clay/ Silty Gravelly Clay)	18.5 (118)	10 (209)	24
2	Shale/ Shale interbedded with Siltstone & Sandstone	20 (131)	0	27
3	Sandstone	25 (158)	150 (3133)	31

4. STABILITY OF TERRACES AND SLOPES

In order to evaluate safety of the existing terraces and slopes, slope stability analyses were carried out for different possible scenarios: a) Natural Slope under static condition, b) Natural Slope under seismic condition, c) Slope with surcharge/ building loads under static condition, and d) Slope with surcharge under seismic condition. The stability analyses were carried out using the software "Slope/W" developed by Geo-studio.

The groundwater was not encountered at this site during geotechnical investigations. However, keeping in view the geological and extreme weather conditions of Murree area, sensitivity

analyses were carried out for varying groundwater conditions i.e. fully dry slope, wet slope and partially saturated slope.

As per Revised Seismic Provision (2007) of Building Code of Pakistan, project site falls in Zone-3 with peak horizontal ground acceleration of 0.24 to 0.32 g with an average value of 0.28g (ground motion with return period of about 500 years for 10% probability of exceedance in 50 years) for soft rock foundation condition. For seismic design, horizontal seismic coefficient k_h of 0.19 (2/3 of 0.28 g) was used for pseudo-static slope analysis.

Figure 3, Figure 4 and Figure 5 show the slope stability model with the results of analyses of natural slope in dry, partially saturated and wet conditions under static loading. The analyses results depicting critical Factor of Safety (FOS) for various scenarios are provided in **Table 2**. The results of slope stability analyses indicated that the proposed site could be utilized for the development of a parking facility, with some improvement of surface and subsurface drainage.

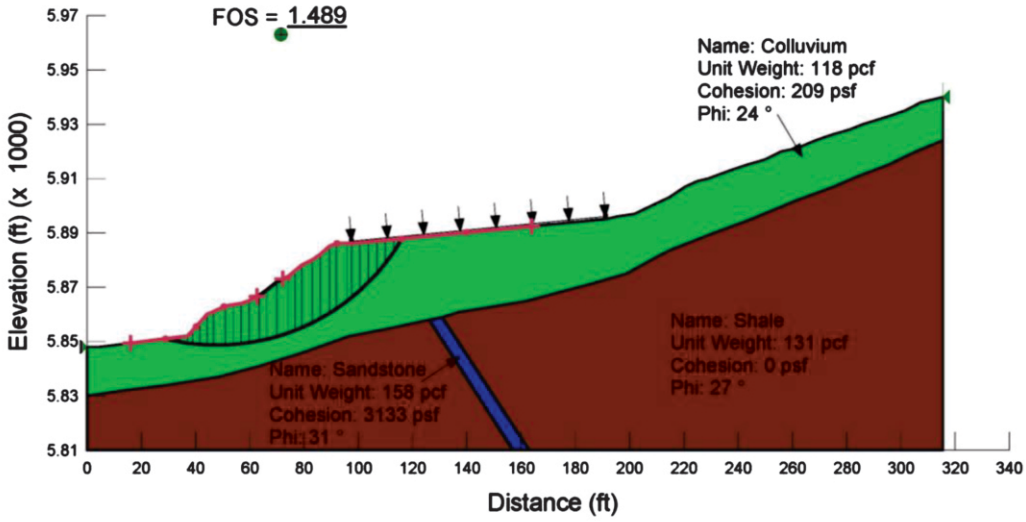


Figure 3: Slope Stability Analyses – Natural Slope in Dry Condition under Static Loading

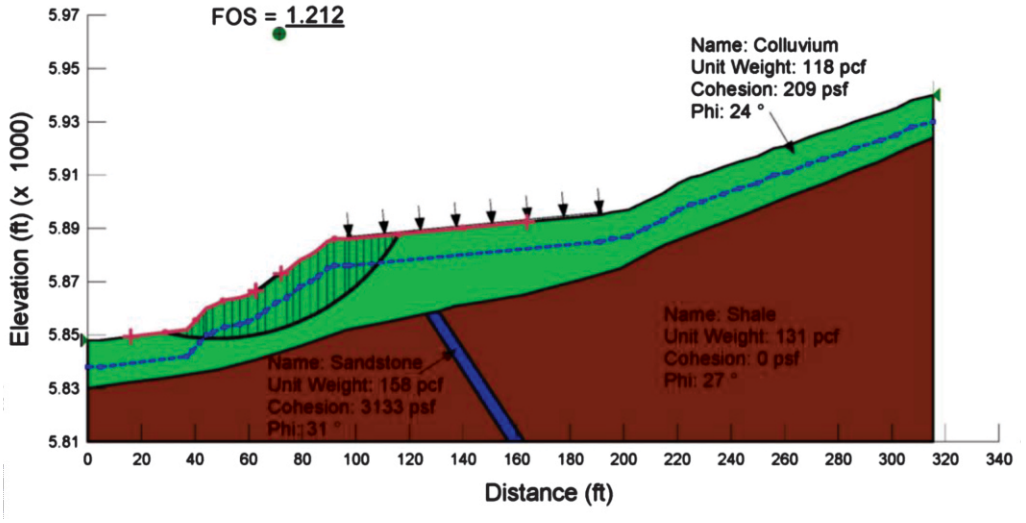


Figure 4: Slope Stability Analyses – Partially Saturated Slope under Static Loading

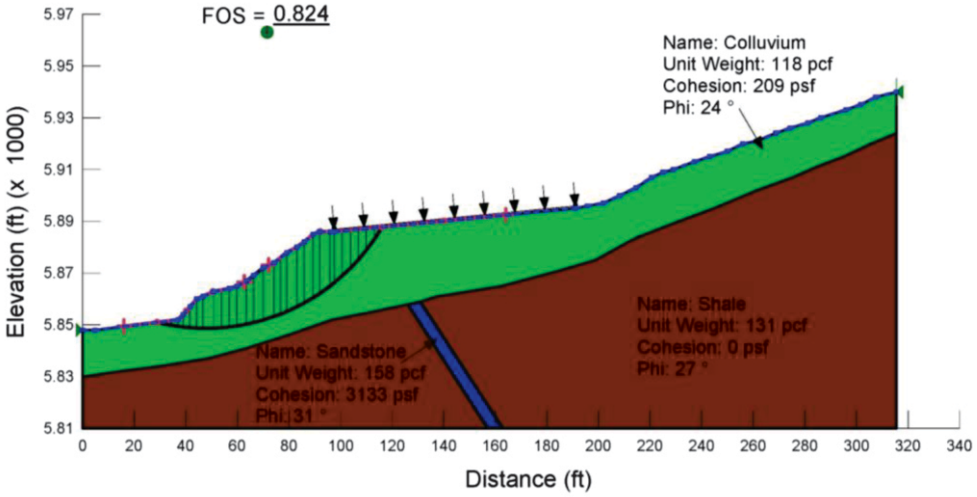


Figure 5: Slope Stability Analyses – Wet Slope under Static Loading

Table 2: Results of Slope Stability Analyses

Slope Condition	Without Surcharge		With Surcharge	
	FOS Static	FOS Pseudo-Static	FOS Static	FOS Pseudo-Static
Natural Slope - Dry Condition	1.539	1.048	1.489	1.034
Natural Slope - GWT @ 10 ft (Partially Saturated Slope)	1.246	0.833	1.212	0.826
Natural Slope - GWT @ 0 ft (Wet Slope)	0.839	0.574	0.824	0.572

5. REINFORCED EARTH EXTENSION OF TERRACE

There was a special requirement of the owner to provide forest-friendly look for the proposed development. Therefore green face Reinforced Earth (R.E.) walls were used to retain the fill material instead of conventional masonry or Reinforced Concrete (R.C) walls. The lower parts of Terrace-1 and Terrace 2 were extended with R.E. to increase the parking capacity. **Figure 6 (a, b)** shows the location of proposed R.E. wall at Terrace 1 and 2.

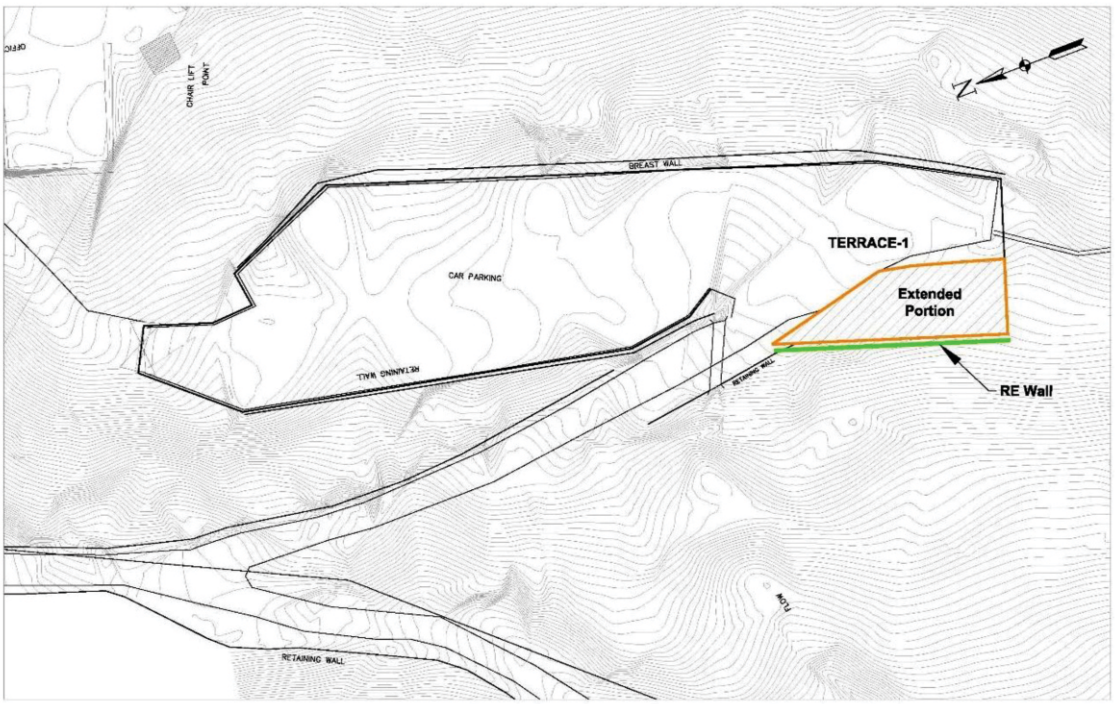


Figure 6 (a): Location of RE wall and the proposed extension at Terrace – 1

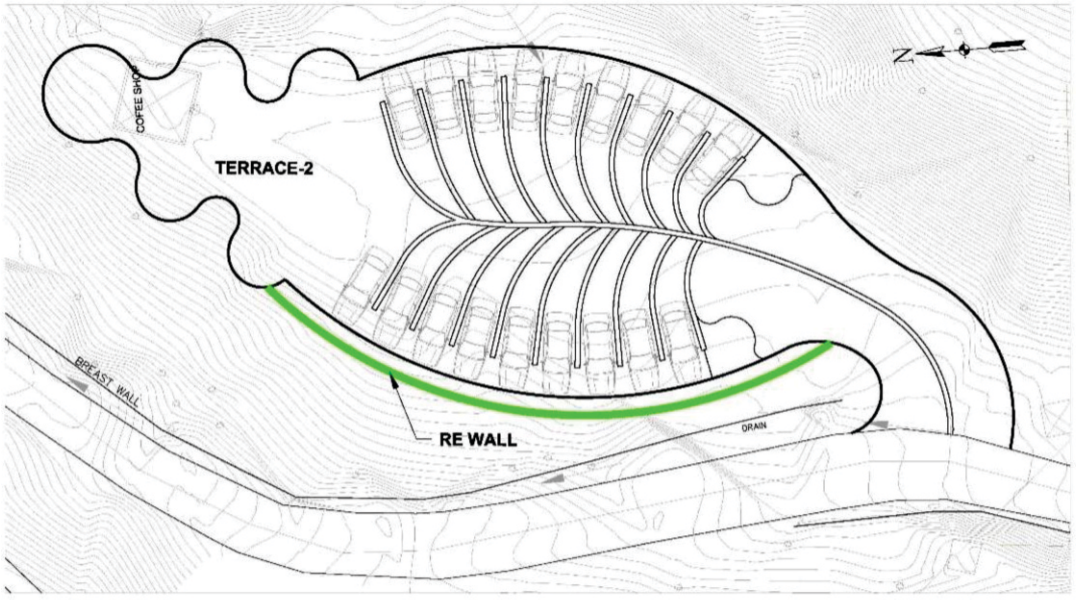


Figure 6 (b): Location of RE wall at Terrace – 2

The reinforcing system of M/s Freyssinet (a subsidiary of M/s Reinforced Earth) was used as earth retention system. **Figure 7** shows a typical x-section of reinforced earth systems adopted for the development of Terrace-1 and 2.

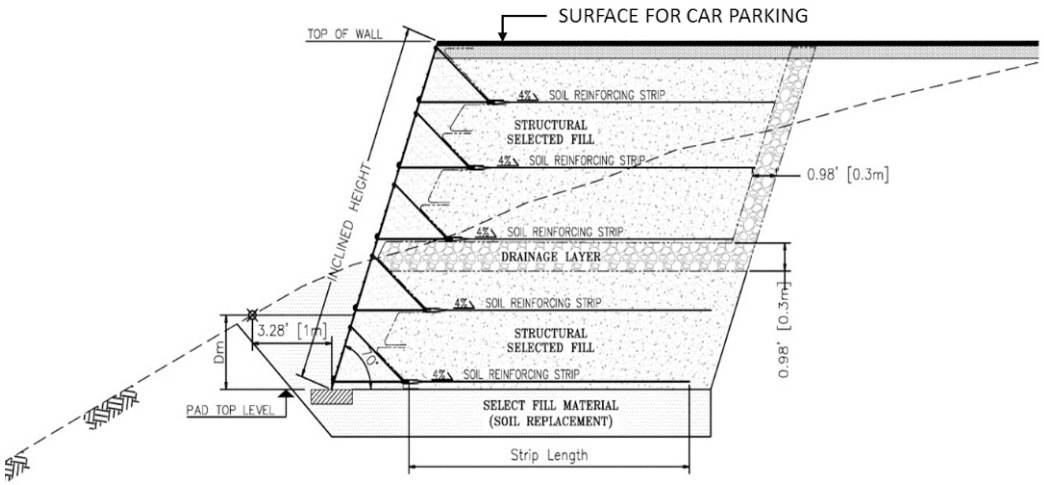


Figure 7: Typical X-section of R.E. System adopted at Bansara Gali Parking Terraces

6. PROVISION OF DRAINAGE SYSTEM

Considering the topographical, geological and hydrological features of the site, adequate surface and subsurface drainage system was designed and implemented at site. The drainage system comprised a network of surface drains, subsurface drains, seepage holes, spring catcher along with other allied drainage structures.

7. SLOPE MOVEMENTS AT AND AROUND SITE

Reinforced Earth was constructed on the edge of Terrace-1 (approximately 7% of total terrace area) in July 2014. It stood the test of one rainy season as well as snowfall for one full year. The first signs of slope movement occurred in the form of cracks, toppling of stones and slope movements were observed in the downslope area (located along the exit road) during the month of March 2015.It was also noted that a tree leaning towards the exit road was also about to fall. As an immediate measure, these cracks were filled with impervious material to avoid ingress of water into the subsoil and the owner was requested to take necessary action for requisite engineering studies to determine the root cause and subsequent design of remedial measures. These cracks widened up in June 2015, and a big boulder moved down the hill slope at exit road and breaking a breast wall, it fell on exit road. Subsequently, a crack appeared on the interface of the extended part of Terrace-1 with the old part, during the month of July 2015. **Figure 8** shows the location of cracks developed at the Terrace-1 and on the downslope area leading towards exit road.

The possible causative factor for these slope movements may be the possible change in the upslope drainage regime due to the following reasons:

1. Some local interventions/constructions of houses etc.
2. Blockage of stormwater nullahs on the hill slopes with stones/debris etc., thus increasing seepage water in the slopes.

3. Clogging of culverts/drains in the area, to take the seepages into valley.
4. Continuous seepage from an old water tank on the upslope, as noted during the site visit.

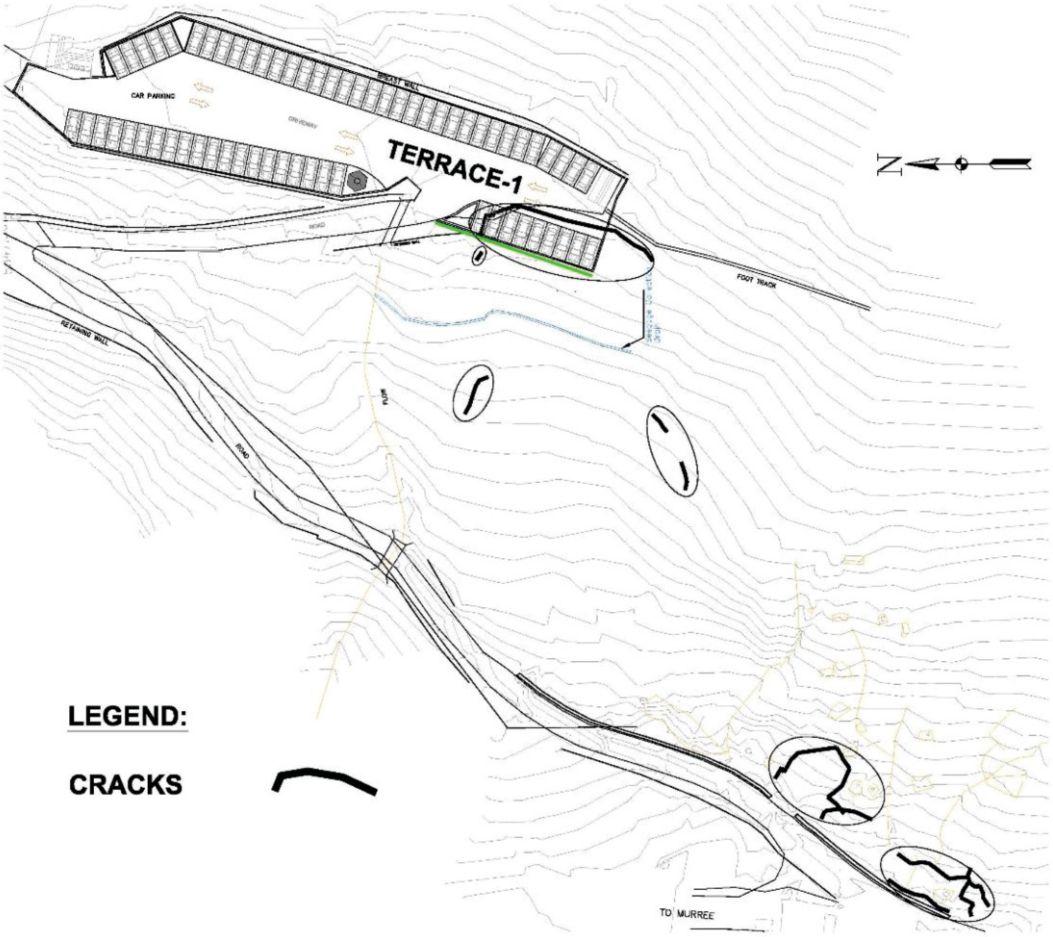


Figure 8: Location of Cracks at Terrace-1 and on the Downslope area (the encircled portion indicates cracks).

8. MONITORING OF SLOPE MOVEMENTS

To monitor the movement of slope, surface settlement markers were installed on upslope and downslope areas of Terrace-1, to the exit road. **Figure 9** shows the location plan of about 70 settlement markers installed at the site to monitor the magnitude, rate, and direction of slope movements.

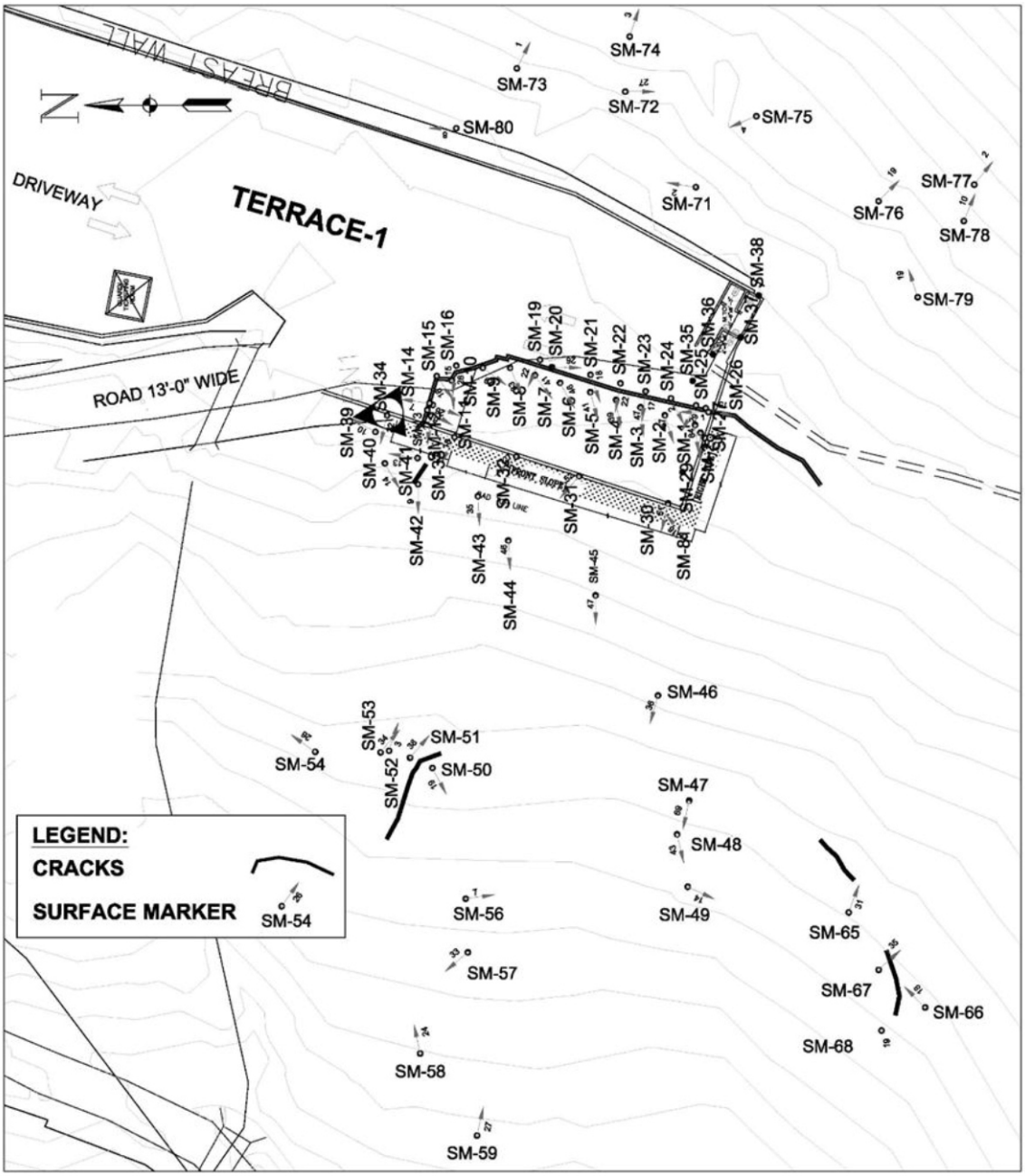


Figure 9: Location plan of the Installed Settlement Markers

9. REMEDIAL MEASURES ADOPTED AT SITE

After the development of cracks, the cracks were immediately filled with impervious material. Cleaning of chocked weepholes and chocked drains/culverts was carried out to make the existing drainage system fully functional. Also, the following additional drainage measures were provided which played an important role in draining out the trapped seepage water.

1. Construction of horizontal drainage holes and vertical seepage wells to drain out entrapped water

2. Construction of cascading drains in the breast wall of Terrace-1 and filling of free-draining material behind breast wall of Terrace 1 and exit road
3. Construction of additional weepholes in the retaining walls and breast walls
4. Construction of seepage collector drains in the upslope and downslope area of Terrace-1 and exit road.

Figure – 10 shows the plan of the additional drainage measures implemented at site. The details of the additional drainage works is presented in **Figure 11 (a, b) and Plate 1 – Plate 3.**

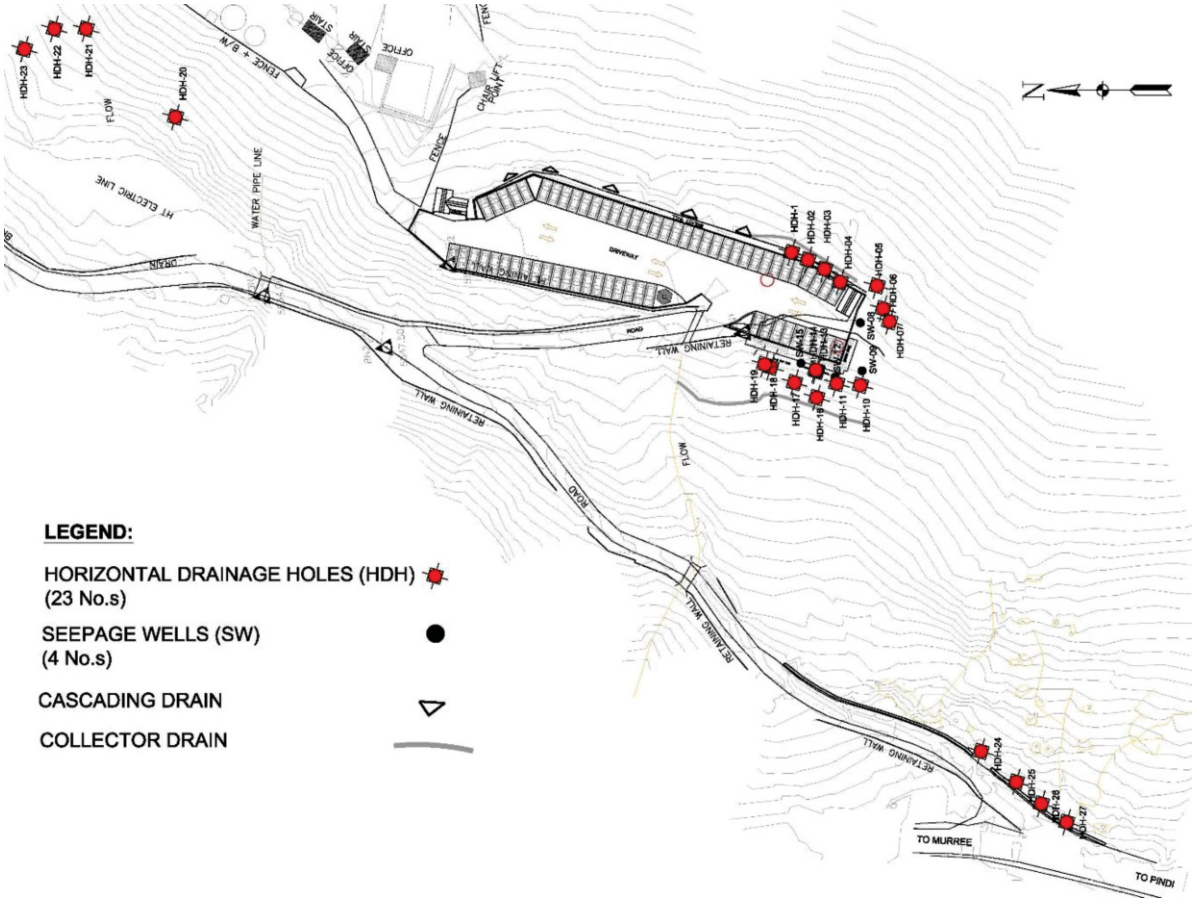


Figure – 10: Additional Drainage Measures Implemented at Site, (i) Horizontal Drainage Holes– 23 No., (ii) Seepage Wells–4 No., (iii) Cascading Drains and (iv) Collector Drains

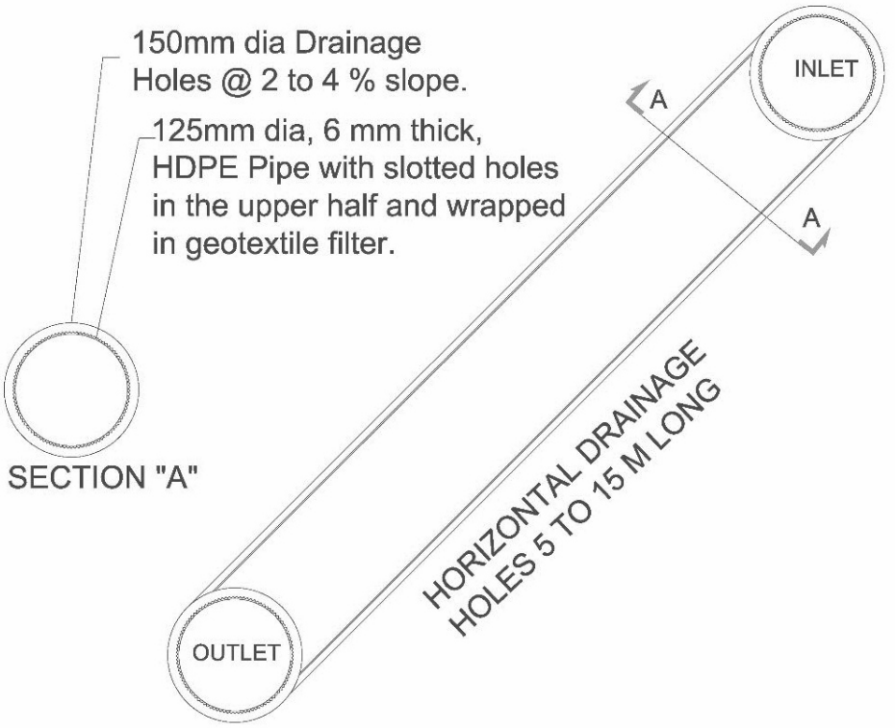


Figure 11(a): Additional Drainage Measures – Details of Horizontal Drainage Holes

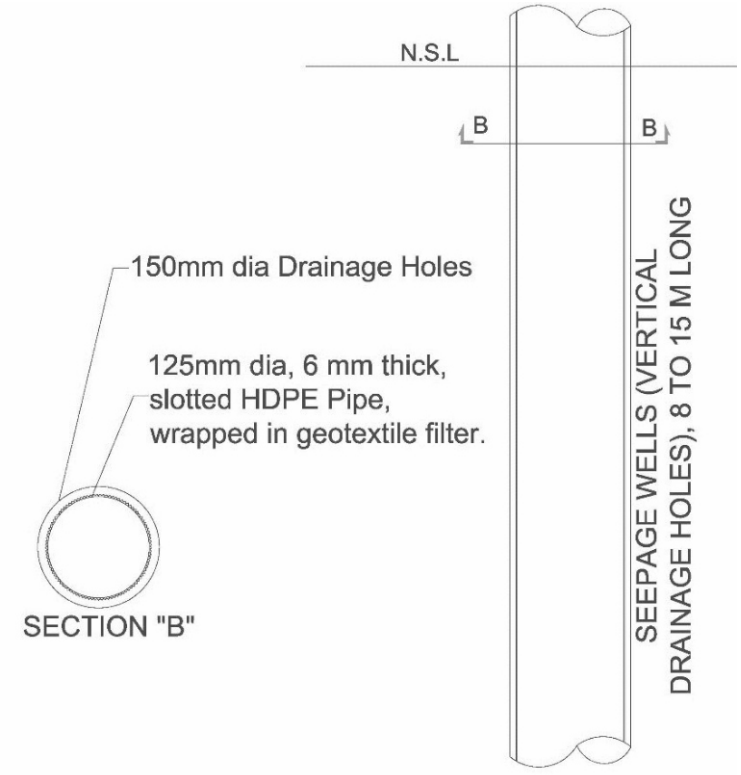


Figure 11(b): Additional Drainage Measures - Details of Seepage Wells



Plate – 1: Additional Drainage Measures Implemented at Site, (i) Horizontal Drainage Holes (HDH), (ii) Weepholes in Breast Wall, and (iii) Collector Drain at the Toe



Plate – 2: Additional Drainage Measures Implemented at Site, Seepage Well (SW)



Plate – 3: Additional Drainage Measures Implemented at Site, Cascading Drain and Weepholes

10. STOPPAGE OF SLOPE MOVEMENT

The settlement markers monitoring data was plotted to determine the rate and magnitude of slope movement. **Figure 12 and Figure 13**present the slope monitoring record of horizontal and vertical movements, respectively. The record shows that initially after the development of cracks, the rate of movement was substantially high. However, with the implementation of remedial measures, the rate of movement gradually decreased and even the maximum movement in the markers below the constructed terrace edge stopped in a matter of two to three (2 – 3) months.

Higher movement values were recorded in the settlement markers installed on the Terrace-1 and the immediate downslope area of Terrace-1. However, the settlement markers located in the upslope area of Terrace-1 and downslope area leading towards exit road, showed lesser movement.

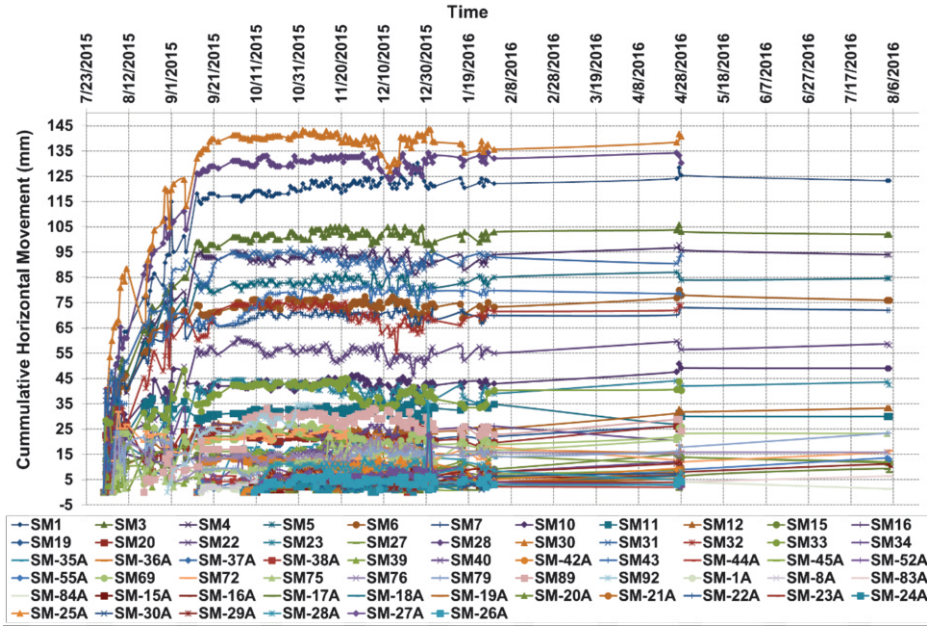


Figure 12: Slope Movement Monitoring Record – Plot of Horizontal Movement

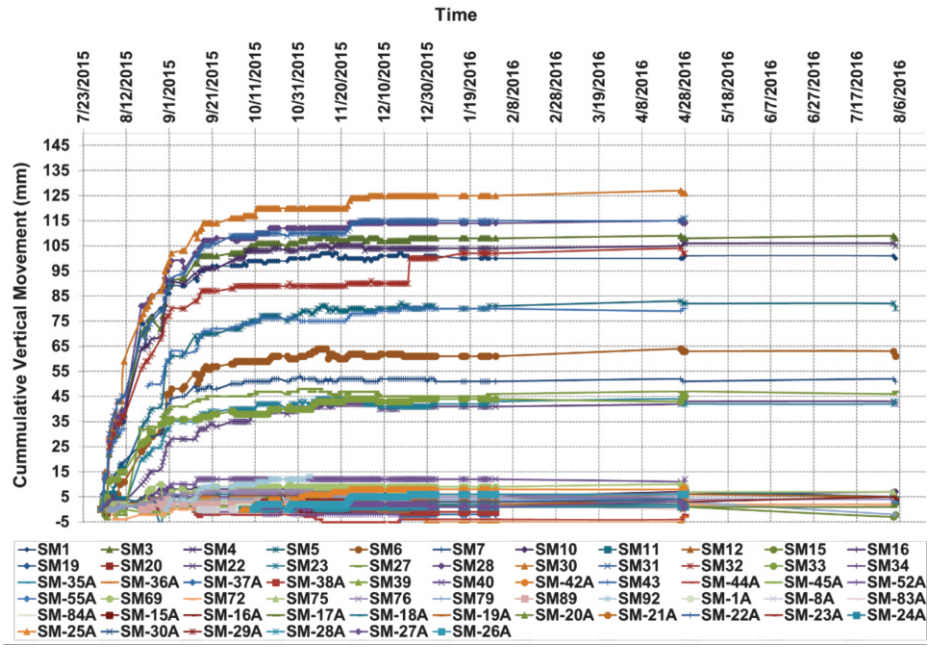


Figure 13: Slope Movement Monitoring Record – Plot of Vertical Movement

11. CONCLUSIONS AND RECOMMENDATIONS

1. Almost, whole Murree is considered in a quasi-stable condition, and as such, the slopes exist at the threshold of stability. Where rock is present at shallow depths, stability of slopes improves, and where rock is present at deeper depths, the thick soil cover (colluvium) is just stable in dry conditions. The existing vegetation also helps in augmenting the stability of slopes against landsliding.

2. Sometimes seepages from distant sources emerge from the slopes, due to several reasons, and cause instability issues in the thick cover of colluvium. The movements in slopes at Bansara Gali are best explained by the above mechanism.

3. Improving drainage is a cheap, effective and indigenous solution to quickly improve the slope stability.

4. Drainage measures were implemented as the sole remedy to curb the slope movements, which proved miraculously effective at this site.

5. It is believed that similar solutions for improvement of drainage on slopes, can substantially improve the stability of slopes at very low cost, very little effort and time. Periodic inspection and maintenance of drainage system can further augment the stability of quasi-stable slopes in Murree and its surroundings.

12. REFERENCES

Building Code of Pakistan, Seismic Provisions – 2007.

Geotechnical Investigation Data/Report of Bansara Gali Murree Parking Site (2012).

Slope Movements, Instrumentation and Drainage Details/record from Bansara Gali Forest Park Murree Project Construction Supervision/Monitoring Data Record (2015 ~ 2016).

Miscellaneous Details from Construction Drawings of Bansara Gali Forest Park Murree (2014).

Paper No. 795

ELECTRIFICATION OF KARACHI-LAHORE SECTION OF ML-1 UNDER CPEC

Abdul Rehman Chaudhry

ELECTRIFICATION OF KARACHI-LAHORE SECTION OF ML-1 UNDER CPEC

By

Abdul Rehman Chaudhry[1]

Abstrat

Pakistan Railway Main Line-1(ML-1) starts from Karachi in the south, extends toward the northeast, passes through Hyderabad, Multan and Lahore, and then turns to the northwest, passes through Rawalpindi and ends at Peshawar. The overall length of existing ML-1 is 1,726 km and it carries more than 80% of the total passenger and freight traffic of Pakistan Railways.

A Framework Agreement was signed in 2015 between the National Railway Administration of China and the Ministry of Railways of the Islamic Republic of Pakistan to overhaul/up-grade the existing infrastructure of ML-1, to increase its line capacity and to raise the running speed of the passenger trains up to 160 km/hr under China Pakistan Economic Corridor (CPEC).

A Contract for Consultancy Services for carrying out the feasibility study for the above referred upgradation was accordingly signed between Pakistan Railways and Joint Venture comprising China Railway Eryuan Engineering Group Co. (CREEC), China (Lead Partner), National Engineering Services Pakistan (NESPAK) and Pakistan Railways Advisory and Consultancy Services (PRACS), hereinafter referred to as Consultants.

The Consultants submitted their Final Feasibility Study Report December, 2015, but did not recommend in this report the electrification of ML-1 as part of its above referred up-gradation under CPEC, on the grounds that due to lack of electricity in Pakistan, the demand of electricity for railway traction cannot be satisfied within the short term of CPEC.

It is considered that the above stated recommendation of the Consultants is not supported by the situation on ground because they did not keep in view, in their Report, the current serious limitations of diesel traction on Pakistan Railways and also did not carry out a realistic assessment of the availability of the electricity in Pakistan for the proposed electrification of Karachi-Lahore section of ML-1 under CPEC.

According to the position brought out in the paper, the proposed electrification of Karachi - Lahore section of ML-1 should be carried out as an essential component of the of current plan of up-gradation of existing infrastructure of ML-1 under CPEC, to derive its full benefits.

1.1 Introduction

1.1.1 Brief Description of Pakistan Railways Main Line-1 (ML-1)

Pakistan Railways Mainline-1(ML-1), located in Sindh, Punjab and Khyber-Pakhtunkhwa provinces, is the main channel of railway transportation in Pakistan. It starts from Karachi in the south, extends towards the northeast, passes through Hyderabad, Multan and Lahore, and then turns to the northwest, passes through Rawalpindi and ends at Peshawar. The overall length of existing ML-1 is 1,726 km and it carries more than 80% of the total passenger and freight traffic of Pakistan Railways entire network.

A map showing the railway sections/segments of Pakistan Railway network falling in ML -1 is given below:

[1] Advisor ILF Pakistan (Pvt) Ltd. Lahore, Ex. Federal Government Inspector of Pakistan Railways

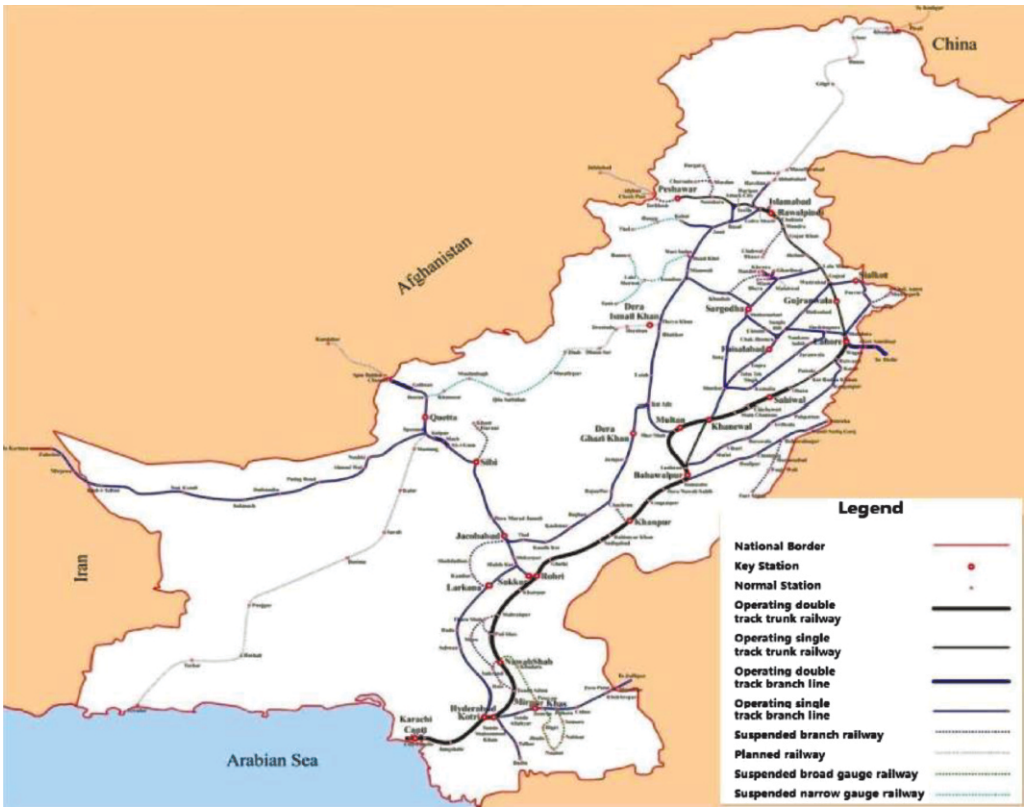


Figure 1: Pakistan Railway Network including ML-1

1.1.2 Upgradation of Infrastructure of ML-1 under CPEC

A Framework Agreement was signed in 2015 between the National Railway Administration of China and the Ministry of Railways of the Islamic Republic of Pakistan to overhaul/up-grade the existing infrastructure of ML-1, to increase its line capacity and raise the running speed of the trains up to 160 km/hr under CPEC (China Pakistan Economic Corridor). A Contract for Consultancy Services for carrying out the feasibility study for the above referred up-gradation was accordingly signed between Pakistan Railways and Joint Venture comprising China Railway Eryuan Engineering Group Co. (CREEC), China (Lead Partner), National Engineering Services Pakistan (NESPAK) and Pakistan Railways Advisory and Consultancy Services (PRACS), hereinafter referred to Consultants.

The Consultants submitted the first draft of Feasibility Study in August, 2015, which was reviewed jointly by Pakistan Railways Administration, the Consultants and the Client from August 27 to September 25, 2015. The Consultants revised the feasibility study document according to the above referred review comments and submitted the Final Feasibility Study Report in December 2015.

1.1.3 Proposal for Electrification of Karachi-Lahore Section of ML-1 under CPEC

During the above referred review of the Draft Feasibility Study Report, the concerned officials of Pakistan Railways Administration strongly recommended that the electrification of Karachi-Lahore railway line should also be included in the Short Term Plan of above referred up-gradation of the existing infrastructure of ML-1 under CPEC, but the Consultants did not agree with this recommendation and wrote on this subject as under in their above referred Final Feasibility Study Report.

"Due to lack of electricity in Pakistan, electricity demand from railway traction cannot be satisfied within the short term. In the long term it is recommended to conduct electrification construction in due time, based on the external environment and transport demands"

It is considered that the above stated observations of the Consultants are not supported by the situation on ground, because they did not keep in view in their Report the current serious limitations of diesel traction on Pakistan Railways and did not carry out a realistic assessment of the requirement and availability of the electricity for the proposed electrification of Karachi-Lahore section of ML-1 during its upgradation under first stage of CPEC, as described in the paragraphs hereafter.

1.2 Brief Description of Steam, Diesel and Electric Traction Systems

The railway vehicle which provides the necessary traction power for the movement of a train is often referred to as a locomotive. The traction power may be steam, diesel or electric.

The first power generation system used for traction was steam. The first steam vehicle appeared in 1804 and was used for railway traction in 1830s.For more than 120 years the steam engine was the principal traction mode for railways.

Diesel traction of trains was introduced during the 1930s but was systematically developed during the 1940s and 1950s. Diesel locomotives are driven by a diesel internal-combustion engine. In comparison to steam traction, diesel traction offers far higher efficiency, a lower operating cost (by at least 50%), much better performance (power and speed), cleaner operation, improved passenger comfort and convenience and relatively less strenuous work for the driver.

The first implementation of electric power in railway vehicles was restricted to urban areas, with the development of electric tramways between 1880 and 1914 and the first metro lines. Electric traction was first introduced in railways in 1900, when it was adopted in the London and Paris metro lines and in the mountainous railway lines of Switzerland. Electric traction has been used extensively since 1920, especially after 1950. Its operating cost is almost half in comparison to diesel traction, but it necessitates a higher initial cost due to required fixed installations (contact wires, pantographs and substations etc.). Electric traction is accordingly used on high traffic density lines.

1.3 The Introduction of Diesel Traction on Pakistan Railways and its Limitations

The diesel traction was introduced on Pakistan Railways in late 1950s. The new diesel locomotives had performed very well during the initial years, but during the subsequent years the undue delays in the procurement of the spare parts and the delay in replacement of overage locomotives started having adverse effects on the scheduled train operations.

The number of imported spare parts of each type/make of diesel locomotives, the inventory of which is required to be maintained for the operation and maintenance of each type of diesel locomotive, is about 12000. With the variety of the diesel locomotives operating on the network, the maintenance of such a large inventory of spares to ensure their regular and timely supplies required uninterrupted availability of foreign exchange for the regular import of the above referred spares, which was an uphill task.

Since the required amount of foreign exchange was usually not allocated due to one reason or the other, the availability of the desired number of spares etc. for the scheduled/non-scheduled repairs was never more than 60% of the requirement. This situation adversely affected the availability of required number of fit locomotives, resulting at times in the delay/closure of some of the passenger and freight train and ultimately resulted in the closure of many trains particularly freight trains.

The situation worsened when most of the available locomotives became overage but could not be replaced in time and their spares were also generally not available on account of non-allocation of requisite funds. Such a situation was first experienced in late 90s and again in 2007, when the train operation particularly freight train operation almost came to a stop. The situation was controlled on both occasions by emergent imports of new locomotives by the then governments.

The only viable solution to effectively avoid the repetition of above stated situation is to plan gradual switching over to electric traction as early as possible as electric locomotives do not require very large inventory of spare parts in addition to their clear operational advantages listed under paragraph 1.2 above. In the meanwhile Pakistan Railways should evolve some viable system to ensure timely availability of required spare parts for the available operative diesel locomotives.

1.4 The Limited Introduction of Electric Traction on Pakistan Railways

Electric Traction was introduced and operated for the first time on Pakistan Railways in 1969, between Lahore and Khanewal on a single line 276 km long section, with the procurement of 29 new electric locomotives. The diesel locomotives used to work trains from Karachi were detached at Khanewal, electric locomotives were attached here for their onward journey upto Lahore, and vice versa, keeping in view the requirement and availability of electric locomotives.

According to the initial plans the above mentioned electrification was to be gradually extended upto Karachi, but due to one reason or the other it could not be extended even up to Samasatta, which was considered at that time to be operationally necessary for the optimum utilization of the available 29 electric locomotives.

The operation of the electric locomotives was suspended in 2009, when the second non-electrified track between Khanewal and Raiwind was commissioned and most of the available electric locomotives had also become overage by that time after about 40 years of service.

1.5 Advantages of Electric Traction over Diesel Traction

The electric traction which is more environmental friendly has the following additional advantages over diesel traction which have been endorsed by different studies carried out on European, American and Indian Railways.

a. The thermal efficiency of electric locomotive is 85% to 90% against 25% to 27% thermal efficiency of Diesel Locomotives and thus the operating costs of electric locomotives are relatively much low.

b. It has got a very advantageous power weight ratio of 50 lbs./H.P , which is almost half of diesel locomotive.

c. It has better acceleration than diesel locomotive, particularly on grades and on high overloads.

d. It is more stable on track and causes less wear on track

e. It costs slightly less than diesel locomotive but has life of about 40 years against 30 years life of diesel electric locomotive

f. It has re-generation braking which feeds back current to the system.

g. According to an internet site "Railway Electrification and Railway Productivity-A Study Report", a seven members TRB Committee on electrification conducted study about the performance of Electric Traction on 10 different European and American railways, with the following conclusions.

   i. The average availability on Europe and North American railroads for electric Locomotives was 94% and of D.E. locomotives it was 84%.

   ii. The number of failures of electric locomotives was 50% of the failures of D.E locomotives, resulting in better reliability of electric locomotives.

   iii. Average maintenance cost of an electric locomotive for hauling same gross ton mile is 20% t0 40% as compared to D.E. Locomotives

h. The maximum axle load for locomotives to be used for normal rail traffic has been restricted to 25 tonnes in the European, Chinese and Indian bridge rules/codes. This axle load restricts the use of diesel locomotives with maximum 5000 HP, whereas electric locomotives of 6000 to 8000 HP have been manufactured with maximum axle load of 25 tonnes. This means that for the haulage of heavy trailing loads, electric locomotives are the only viable option.

It is presumably in the backdrop of the above stated clear advantages of electric traction over diesel traction that Indian Railways have already electrified more than 70% of their broad gauge main line tracks and plan to raise this figure to 90% by 2021.

1.6 Criterion for Selection of a Railway Line for Electrification

The criteria for the selection of a railway line for electrification varies from one network to the other, since particularities of each country in respect of cost of labour, cost of energy, financial investment cost, etc. are involved. The following three criteria have generally been adopted by major railways of the world for the selection of a railway line for electrification.

1.6.1 Number of trains running on the line

A criterion, which, however, can only be used to make a first approximate estimate, is the number of trains running on the line. For example, until 1973 (when the cost of energy was low), a line had to be run daily by at least 30 trains per direction to qualify for consideration of electrification cost-effectiveness. After the energy crises of 1973, this criterion became around 15 trains per direction daily in 1979.

1.6.2 Energy consumed/km of line for the train operation

Given that a train may consist of a small or a large number of vehicles, a criterion was sought which would take into account the number of vehicles. Such a criterion is the energy consumption per km of line. For instance, French Railways considered in principle an annual consumption of 70,000 kW/km of line as the electrification cost-effectiveness threshold; while the German Railways estimated this limit as

150000kw/km. The criteria, therefore, can differ significantly from one network to the other.

1.6.3 Traffic Density Gross Million Tonnes (GMT) carried per annum) on a line

Indian Railways take into consideration the calculation of operational expenses both with diesel electric locomotives and electric locomotives, as a function of the traffic density on that line, expressed in terms of Gross Million Tonnes (GMT) carried /annum. A Committee of Executive Directors of Indian Railway Board carried out a study in 1996, which was based on the then prevalent unit prices of diesel and electric energy, wherein the breakeven point for the adoption of electric traction on any of their railway line was assessed in 1996 as 49.72 GMT/year.

1.7 Proposed Electrification of Karachi-Lahore Section of ML-1 in the face of above Stated Criteria

The proposed electrification Karachi-Lahore railway line under CPEC has been examined in the following sub-paragraphs on the basis of 3 criterion referred to in paragraph (1.6) above and the train operation data provided in the Final Feasibility Study Report of up-gradation of ML-1 under CPEC, referred to earlier in the in sub-paragraph (1.1.3) above.

1. Number of Trains Running on the Line

   According to the figures given in the final feasibility study submitted by the Consultants in December, 2015 for the upgradation of ML-1 under CPEC, the projected pairs of total freight and passenger trains in year 2025 shall be 84 on Karachi-Hyderabad section and 45 on Khanewal-Lahore section of ML-1. It shall increase to 126 and 77 respectively in year 2040. These figures are far more than the above referred criteria of 30 pairs of trains per day laid down in 1973 by European Railways, when oil prices were relatively low (sub-paragraph 1.6.1 above).

2. Energy Consumed/km of Line for the Train Operation

   According to the figures given in sub-paragraph (a) above the projected pairs of total freight and passenger trains in year 2025 shall be 84 on Karachi-Hyderabad section and 45 on Khanewal-Lahore section of ML-1.

   The average consumption of electricity by a 3000 HP electric locomotive when in operation shall be about 1500 kW. In case an average of 50 pairs of trains are assumed to be on line at a time, on Karachi-Hyderabad-Lahore section the average electric energy required for these trains shall be 2x50x1500= 150,000 kW/km. This figure will increase to 2x80x1500=240,000kW by year 2040, based on the projected train pairs referred to in sub-para (a) above. The above stated figures of energy consumed/km are much more than the above stated criteria of 150,000KW/km laid down by French Railways (sub-paragraph 1.6.2 above).

3. Traffic Density (GMT carried per annum) on a Line

   According to the figures given in sub-paragraph (a) above, the projected number of passenger and freight trains on Karachi-Hyderabad and Khanewal-Lahore sections of ML-1 in year 2025 will be 84 pairs and 45 pairs respectively, with an

average of about 65 pairs of train on the entire Karachi-Hyderabad-Lahore section.

When the above stated figures of total number of trains are converted in to gross million tonnes of traffic carried per annum (GMT /annum), it will work out to about 69.50 and 50 .40 GMT/year respectively. These figures are higher than the breakeven figure of 49. 72 GMT/year referred to in paragraph 1.6.3 above.

Based on 3 criterion discussed in sub-paragraphs (a), (b), and (c) above, the electrification of Karachi-Lahore section of Ml-1 is considered fully justified during the current short term stage of CPEC.

It is considered that about 150 MW of electricity which shall be required for the operation of all the freight and passenger trains by electric traction by year 2025 on Karachi-Hyderabad-Khanewal-Lahore Section of upgraded ML-1 can be provided from the National Grid.

1.8 Detailed Feasibility Study before taking decision for Electrification of a Line

According to the procedure specified by major railways when the traffic load or the energy consumption on a particular line exceeds the limits indicated in paragraph 1.6 above, a detailed feasibility study should be conducted before any decision to electrify that line is made.

For feasibility analysis two cost factors are taken into consideration:

i. Construction expenses, including transmission lines and substations, which do not depend on traffic,

ii. Operating and maintenance expense, which increase with the traffic volume

The quantity commonly studied is the total annual expense as a function of line's traffic, an index of the latter being the energy expended annually per kilometre of line.

The period of analysis is usually the following 20 to 25 years, and expenses as a whole (initial construction expenses and annual operating expenses) are converted for each traction system to constant prices by the present value method.

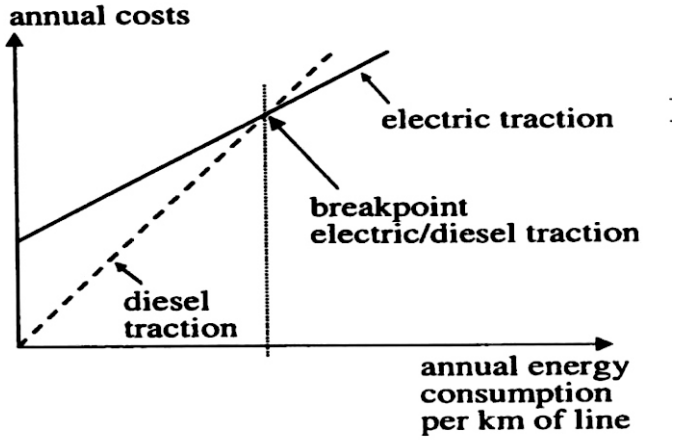


Figure 2: Annual costs as a function of energy consumption per kilometre of line for diesel and electric traction

The feasibility analysis of electric traction involves many uncertainties, particularly with respect to the price of liquid fuel in the next 20 to 25 years, the actualization interest rate whereby the various expenses are converted to constant prices, the length of the feasibility analysis period, etc. It is accordingly advisable to also perform a sensitivity analysis (which aims to examine the impact of the variation of one parameter to the result of the feasibility analysis)

1.9 Conclusions & Recommendations

1. The electrification of Karachi-Lahore railway line as an essential component of up-gradation of infrastructure of ML-1 under short term plan of CPEC is fully justified on the basis of international criterion established for this purpose. It is more environmental friendly and is considered unavoidable to derive maximum benefits from the proposed up-gradation of ML-1
2. A detailed feasibility study may be carried out for the proposed electrification of Karachi-Lahore section of ML-1 on top priority, before making it part of short term plan of up-gradation of infrastructure of ML-1 under CPEC.
3. In order to make the best use of the heavy investment which is proposed to be made for the up-gradation of existing infrastructure of main line-1 (ML-1) under CPEC, the following other measures are also recommended.
    a. A viable and workable long term solution should be evolved on priority basis to ensure the timely procurement and supply of the spares required for the operation and maintenance of all available to be procured diesel electric locomotives/electric locomotives.
    b. In the preliminary design of up-gradation of existing infrastructure of ML-1 under CPEC, provision should be made in the design for the proposed electrification.
    c. Pakistan Railways must involve more effectively its two subsidiary consultancy and construction companies, Pakistan Railways Advisory and Consultancy Services i.e. PRACS and Railway Constructions Pakistan, (RAILCOP) respectively, in all stages of implementation of the project of proposed up-gradation of ML-1 under CPEC and its subsequent operation and maintenance. However, for assigning such a broader and long term role to the above named two subsidiary companies need to be restructured and strengthened on the lines of similar subsidiary companies of other major railways of the world.

    1.10 Breakeven Traffic Density for the Adoption of Electric Traction on Karachi-Lahore Section of ML-1

Paper No. 796

CONTOURS OF THE FIRST EVER NATIONAL WATER POLICY OF PAKISTAN

Dr. Qazi Tallat, M. Siddiqui

CONTOURS OF THE FIRST EVER NATIONAL WATER POLICY OF PAKISTAN

By

Dr. Qazi Tallat M. Siddiqui[1]

ABSTRACT

By the grace of Almighty, Pakistan has one of the largest contiguous irrigated systems in the World. The snow-clad peaks of the mountain ranges in the North continuously recharge the system. The descending snow-melt and monsoon waters flow into the country's Indus River System and its tributaries. After passing through the plateau and the vast plains across the Indus Valley, the rivers join up to form the Indus that eventually drains into the Arabian Sea in the South. Irrigated agriculture is the backbone of the country's economy, and consumes around 95 percent of the nation's water resources, the balance is used for domestic and industrial requirements. With rapidly growing population, Pakistan is heading towards a situation of water shortage and by corollary, a threat of food insecurity. Per capita surface water availability has declined from 5,260 cubic meters per year in 1951 to around 1,000 cubic meters in 2016 .Water resources are inextricably linked with climate and the impending climate change scenario has serious implications for Pakistan's water resources. The continuing increase in population at an annual rate of over 2% combined with rapid and un-regulated urbanization has already pushed Pakistan into the category of water stressed countries. The changing and unpredictable precipitation patterns may have serious consequences, including flash floods in the north and increasingly prolonged droughts in the south. As the glaciers retreat, more glacial lakes will form, increasing the risk of Glacial Lake Outburst Floods (GLOF), which are already becoming increasingly common and hazardous in the Northern parts of the country. Only by devising and implementing appropriate adaptation measures will it be possible to ensure water, food and energy security for the country as well as minimize the impact of natural disasters. The situation calls for rapid development and management of the country's water resources on a war footing.

Taking cognizance of the emerging water crisis, the federal government has announced first ever National Water Policy (NWP) to provide an overall policy framework and guidelines for a comprehensive plan of action. On this historical occasion, Pakistan Water Charter was also signed by Federal and Provincial governments to mark political commitment for the water sector development throughout the country. Pakistan has a federal system of government and the provinces enjoy a considerable degree of autonomy under the 18th Amendment to the Constitution. Therefore, the National Water Policy is a national framework within which the provinces can develop their master plans for sustainable development and management of water resources. The water resource is a national responsibility but irrigation and agriculture, as well as rural and urban water supply, environment and other water related sub-sectors are provincial subjects.NWP is an enabling document and provides comprehensive guidelines for water resources management and development as per international practice. It also contains a development action plan till 2030, the terminal year of SDG era. NWP has an elaborate implementation mechanism at the national level and will pave way for improved, sustainable and integrated water resources management in the country.

[1] DEPUTY ENGINEERING ADVISER, OFFICE OF CHIEF ENGINEERING ADVISER, MINISTRY OF WATER RESOURCES

CONTOURS OF THE FIRST EVER NATIONAL WATER POLICY OF PAKISTAN

1. BACKGROUND

In Pakistan, the development and management of water resources has received considerable attention in many national and international studies and reports in the past three decades. These include:

a. The Report of the National Commission on Agriculture,(1988).

b. Report of the Inter-Provincial Committee on the Apportionment of the Indus Waters (1991).

c. Water Sector Strategy by the Asian Development Bank (2002).

d. WAPDA's Vision 2025 Report (2003)

e. Pakistan's Water Economy Running Dry by John Brisco (2005).

f. Development of Integrated River Basin Management for Indus Basin: World Wildlife Fund (2012).

g. A Productive and Water Secure Pakistan: Report by Friends of Democratic Pakistan (2012).

h. Pakistan Vision 2025: Pillar IV: Energy, Water and Food Security; Planning Commission, Government of Pakistan (2014)

These Reports and Studies stimulated considerable debate in professional circles and may have led to some useful projects and initiatives but the overriding objective of evolving an integrated Water Resources Management Strategy which can promote the coordinated development and management of water and land resources in a sustainable and equitable manner, has not yet been achieved. This is partly because any crisis that is creeping slowly does not normally attract high level political attention. But in Pakistan, concerns about future water shortages have been moderated at the farm level, by expanding abstraction of ground water in Punjab and Sindh. Currently 1-million tube wells are pumping about 55 million acre feet of underground water for irrigation, which is 20% more than that available from the canals.While the continuing increase in population at an annual rate of over 2% combined with rapid and un-regulated urbanization has already pushed Pakistan into the category of water stressed countries, the phenomenon of climate change is causing faster melting of the high altitude glaciers, on which the Indus Basin system is dependent and is also increasing sea levels. Pakistan is located in one of the three most vulnerable regions in the world in terms of climate change, threats of increasing frequency and intensity of floods, prolonged droughts and the frightening possibility of the melting of the Himalayan Ice cap.

This National Water Policy can provide a major response to the emerging water crisis if:

- It receives high level political support, as a national imperative.
- It provides a set of agreed national targets for water conservation, water storage, water treatment and clean drinking water.
- It leads to a sustained national commitment to substantially increase public and private resources for the water sector.

- It creates an institutional framework that can address present deficiencies in project management and cost effective maintenance on a war footing to revive the technical capacity and efficiency of the system that achieved such remarkable progress between 1950 and 1990.

It has become a national imperative to ensure water security for the people of Pakistan, through a National Water Policy (NWP) laying down the outlines of an integrated water management strategy that can optimize the economic, social and environmental returns on water resources, ensure equitable allocation among its competing demands as well as its judicious use by consumers and safe disposal of post-use effluents.

2. ISSUES AND CHALLENGES IN WATER SECTOR OF PAKISTAN

Some of the specific issues concerning the water sector are:

- Water scarcity can adversely affect the health and well-being of the people of Pakistan and must be resolutely addressed especially since it has serious implications for the nation's food and energy security;
- Fresh water being a finite resource is progressively becoming more scarce due to persistent increases in its competing demands;
- The geographic location of Pakistan places the country in the heat surplus zone on Earth, putting it high on the vulnerability scale of climate change with considerable increase in frequency and intensity of extreme weather events and erratic monsoon rains (as demonstrated by the unprecedented floods of 2010)
- Existing and planned trans-boundary developments on the Western Rivers could further impact water availability to the disadvantage of Pakistan;
- The "Indus Basin Replacement works" (dams in particular) are approaching the end of their designed life span due to siltation. requiring replacement storages;
- Different regions in the country are endowed differently with water in terms of precipitation, surface flow and ground water and there is increased stress on the sharing of water resources;
- Lack of equity in water allowances of various canal commands is causing water and salt imbalances at a regional level;
- Salt balances in irrigated lands are already negative and with the passage of time the soil quality will deteriorate resulting in reduced yields.
- Bulk of drinking water requirement is met by groundwater which is depleting and its quality is deteriorating;
- It is necessary to avoid growing conflicts and social unrest in the country due to water scarcity;
- The mandate and roles of the federal and provincial water related agencies need to be reviewed in view of the 18th Amendment to the Constitution;
- Concentrated efforts are needed tore-use treated sewage water in order to reduce sweet water demand;

- There is lack of awareness amongst the general public about the impending threat of water scarcity and the huge wastage of sweet water; excessive watering of crops is endemic with total disregard for efficiency and conservation;
- Desalinization of Sea water is a significant source of water, however, no effort has been made for desalinization in the *light of technology advances and international* best *practices;*
- Irrigated agriculture is indispensable for Pakistan's agriculture and low irrigation efficiency vis-à-vis water productivity is a major factor leading to lower growth of the sector;

3. NWP OBJECTIVES

The National Water Policy lays down a broad policy framework and set of principles for water security on the basis of which the Provincial Governments can formulate their respective Master Plans and projects for water conservation, water development and water management. The National Water Policy is based on the concept of Integrated Water Resources Management primarily aimed at the following policy objectives:

- Promoting sustainable consumption and production patterns throughout the water sector from exploitation to utilization;
- Augmentation of the available water resources of the country through judicious and equitable utilization via reservoirs, conservation and efficient use;
- Improving availability, reliability and quality of fresh water resources to meet critical municipal, agricultural, energy, security and environmental needs;
- Improving urban water management by increasing system efficiency and reducing non revenue water through adequate investments to address drinking water demand, sewage disposal, handling of wastewater and industrial effluents;
- Promoting behavioral change to reduce wastage of water by raising public awareness through media campaigns and incorporating water conservation lessons in syllabi/curricula at primary, secondary and tertiary levels;
- Hydropower development to increase the share of renewable energy;
- Providing food security and expanding water availability to help adapt to climate change, population and other large-scale stresses;
- Treatment and possible reuse of waste water - domestic, agricultural and industrial;
- Upgrading water sector information systems for improved asset management and to derive evidence and data driven decision making;
- Improving watershed management through extensive soil conservation, catchment area treatment, preservation of forests and increasing forest cover;
- Restoring and maintaining the health of the environment and water related eco-systems.
- Flood management to mitigate floods and minimize their damages;

- Drought management with emphasis on long term vulnerability reduction;
- Security of benefit streams of the water related infrastructure for sustained provision of services;
- Promoting appropriate technologies for rain water harvesting in rural as well as urban areas;
- Regulating groundwater withdrawals for curbing over-abstraction and promoting aquifer recharge;
- Adequate water pricing (Abiana) for irrigation and proper operation and maintenance of the irrigation system as well as other user sectors;
- Promoting measures for long term sustainability of the Irrigation System;
- Encouraging beneficiary participation and public private partnerships;
- Strengthening and Capacity building of water sector institutions;
- Profitable use of flood water towards promotion of local irrigation practices;
- Exploitation of vast potential of water generated through hill torrents;
- Protection of wet lands and Ramsar Sites for the prevention of wild life, flora and fauna;
- Stoppage of further sea water intrusion into Sindh (upstream from coastline) for the sustainability of coastal environment, flora and fauna and mangrove growth including the use of skimming dug- wells in coastal areas ;
- Establishment of Hydro-meteorological disaster risk reduction complied integrated water resources management regime;
- Enhancing water productivity through infrastructure development and adoption of improved technologies in a sustainable manner;
- Climate change impact assessment and adaptation for sustainable water resources development and management;
- Promoting research on water resources related issues of national importance and building capacity/delineating roles and responsibilities of Federal research institutions and promoting coordination among them;
- Setting major national targets for the water sector including those for water conservation, water storage, Irrigation, water treatment and drinking water. These targets can be firmed-up in consultation with the Provincial Governments and reviewed periodically for inclusion in the 12th and 13th Five Year Plans and future plans;
- Secure Katcha areas and economy thereof;
- Preserve delta area by providing sufficient supplies regularly;
- Rainwater management in plains where it cannot be disposed of or diverted to the river;

- Effective implementation of the 1991 Water Apportionment Accord in letter and spirit.

4. WATER USES PRIORITY SET IN NWP

The priorities set in NWP for the consumptive and non-consumptive uses of water shall be as follows:

a. Drinking and Sanitation (WASH)
b. Irrigation including land reclamation
c. Livestock, fisheries and wildlife
d. Hydropower
e. Industry and mining
f. Environment, river system, wetlands, aquatic life
g. Forestry including social forestry
h. Recreation and sports
i. Navigation

5. STRATEGIC AREAS OF NWP

National Water Policy (NWP) is based on a set of principles aimed at promoting greater national interest and the welfare of the people of Pakistan. In NWP seven strategic areas have been identified that will be taken-up at the Federal and Provincial levels, since they are of critical importance to the water, energy and food security of Pakistan. These include,

5.1 Conservation and Efficiency: More than 50 per cent of canal water diverted from the Indus system does not reach the farm level. While the main canals cannot and should not be lined, a crash programme for lining the water courses can reduce the seepage by at least one third. Similarly conservation measures can be adopted for ground water by regulating its extraction and use. Both conservation and efficiency must be highlighted for Demand Side Management (DSM) of water resources. The current policies have a supply side bias. It is important to make the distinction between efficiency, which means reducing waste and doing more with less and conservation, which refers to restricting use.

5.2 Storage: The most important instrument of mitigation against the impact of climate change on water resources is storage. If the pattern of rainfall becomes erratic with more than average rain in one year and a drastic reduction in the next years' rainfall, the only way to conserve the surplus rainwater in wet years is to store it and release it in dry years, when required. For storage and new irrigation projects a national master plan must be developed which must cater for storage, floods, arid areas, irrigation, urban water and tariff rationalization. In addition there are vast possibilities of small and medium size dams, enhancing the life of existing storages and remodeling and rehabilitation of existing infrastructure in the country. Expansion of water storage will expand irrigation and also increase the proportion of hydro-power in the energy mix, reducing the need for thermal power.

5.3 Leveraging Technology: Adoption of new technologies is urgently needed for (i) sea water utilization and water recycling (ii) preparation of an inventory of water resources through remote sensing and Geographic Information System (GIS) technologies (iii) accurate monitoring of irrigation water delivery. Home grown innovation in the water sector should be encouraged as

much as possible, including investments aimed at start-up companies that promote remote sensing, demand side management and agricultural productivity.

5.4 **Renewable Energy**: Sustainable water resources development has a close nexus with renewable energy. Large, medium and small dams not only generate cheap and clean energy but also provide reliable source of water for agriculture and other human needs. With appropriate policies and subsidies, a large percentage of tube wells in Pakistan, can be converted to solar energy especially in areas where water table is not very low, to provide additional water at lower cost. Solar energy can also be used for day-time de-salinization of sea water, particularly in the coastal areas of Baluchistan.

5.5 **Integrated Water Resource Management**: The management of water resources is shifting from sectoral to a more integrated approach in different parts of the world. Under IWRM, (i) the interests of all upstream and downstream stakeholders can be protected against mining and contamination. (ii) Watershed and catchment areas can be protected to prolong the life of water storage facilities. This revolutionary IWRM concept will however require strengthening institutional and management capacity at all levels.

5.6 **Comprehensive Regulatory Framework**: The Federal government must play a leading role in facilitating regulations to ensure the efficient and sustainable utilization of ground water, industrial uses, and waste water management. Food security, water security and energy security being inextricably linked, so the regulatory framework must address all the associated issues comprehensively, including ground water contamination, waste treatment, open defecation Water Sanitation and Hygiene (WASH).

5.7 **Planning Principles**: The process of planning, development and management of water resources at the Federal and Provincial level, including the development of this policy will be guided by the following set of principles:

- Equity and participatory decision-making; Water sector activities shall be participatory and consultative at each level and decisions will be taken by consensus
- Water is a strategic resource and access to affordable and safe drinking water is a fundamental human right of all citizens
- Efficiency and conservation will be promoted at all levels
- Environmental Sustainability must be ensured
- Practicability and Innovation will be encouraged and ensured
- Command area development shall be the responsibility of farmers with government support in respect of small land-holdings

Within these broad parameters of water security, the provincial governments can formulate more detailed policies and guidelines on other subjects like (i) water pricing (ii) drinking water, (iii) water quality and (iv) water treatment, keeping in view the national environment policy 2005, the national sanitation policy 2006 and the national drinking water policy 2009 and the overall agricultural priorities.

6. NWP PROVISIONS

Salient features of NWP include; Water Uses and Allocation of Priorities, Integrated Planning for Development and use of Water Resources, Environmental Integrity of Basin, Impact of Climate Change, Trans-boundary Water Sharing, Irrigated as well as Rain-fed Agriculture, Drinking

Water and Sanitation, Hydropower, Industry, Ground Water, Water Rights/Obligations, Stakeholder's Participation, Sustainable Water Infrastructure, Water-Related Hazards, Quality Management, Information Management, Research, Economic and Financial Sustainability, Demand Management, Conservation of Water, Legal Framework and Capacity Building of Water Sector Institutions.

7. NWP TARGETS

Our river flows are heavily dependent on glacial melt (41%), snowmelt (22%) and rainfall (27%). The Indus River System receives an annual influx of about 138.4 Million Acre Feet (MAF) of water. Pakistan receives snowfall only in the Northern Areas of the country during winter. Rainfall is markedly erratic in magnitude, time of occurrence and aerial distribution. The mean annual precipitation ranges from less than 100 mm in parts of the Lower Indus Plain to over 750 mm near the foothills in the Upper Indus Plain.

Pakistan is mainly dependent on the three western rivers of the Indus (including Kabul, Jhelum and Chenab). Post-Tarbela (1976-2008) flows (Indus at Kalabagh, Jhelum at Mangla and Chenab at Marala) were 137 MAF. The three eastern tributaries of the Indus – Ravi, Sutlej and Beas – were allocated to India for its exclusive use. Currently about 1.4 MAF of water flows from India to Pakistan through these eastern rivers. Pakistan is extracting 50 MAF from the aquifers and already crossed the sustainable limit of safe yield. This over-mining and pollution of aquifers has resulted in secondary salinization and the presence of fluorides and arsenic in water, which in turn is degrading the quality of agricultural lands.The Indus Waters Treaty led to the construction of multiple hydraulic structures. These enabled Pakistan to enhance water availability at canal head works to about 104.0 MAF. However, this has now started decreasing because of the lack of surface water development since construction of Tarbela dam and the significant loss of on-line storage capacity through sedimentation. Of the 104.0 MAF of annual canal diversion, only 58.3 MAF reaches the farm-gate, while remaining 46.7 MAF seeps into the ground water.

Water Availability can be enhanced through reduction in water loss, additional water storage through large, medium and small dams, cycling used waters, desalinization of sea water and more efficient water use. An important aim of the National Water Policy is to fix quantifiable targets in each of these sub-sector with a timeline and estimated resources required over the next twelve years i.e. by 2030.

Main Targets proposed for 2018-2030 can be summarized as follows:

- Reduction of 33 percent in the 46 MAF river flows that are lost in conveyance, through accelerated programme of water course lining specially in saline or semi saline areas.
- In order to augment the dwindling irrigation deliveries into the existing canal systems on account of ever decreasing existing storage capacity of Mangla and Tarbela due to sedimentation and to develop new cultivated area on canal irrigated water, the existing water storage capacity of 14 MAF shall be increased by immediately starting construction of the Diamer-Basha Dam Project having 6.4 MAF live storage on which consensus of all the federating units has already been achieved in 2009 at CCI level. The existing water storage capacity will be increased up to 10 MAF including Diamer-Basha Dam.
- Increase of at least 30 percent in the efficiency of water use by producing "more crop per drop". This will require use of new technologies like drip and sprinkler

irrigation and more realistic water pricing policy. The present average rate of water charges per acre is only one fourth of what the farmer pays for tube well water in the ground water market.

- Gradual replacement and refurbishing of decades old irrigation infrastructure in accordance with an adequate asset management plan.
- Real-time monitoring of river flows by IRSA is to be ensured through inter alia telemetric monitoring to maintain transparent water accounting system and to check the increasing trend of unaccounted-for water in the Indus System of Rivers. This task should be completed before the end of 2021.
- In order to establish and maintain a reliable assessment of water resources in the country, federal and provincial water sector organizations would develop a standardized and uniform mechanism for data collection of various parameters of water resources including but not limited to rivers/canals gauge and discharge, rainfall/snowfall, depth to groundwater table, surface/ subsurface water quality parameters, river/canal and reservoirs sedimentation.

The tentative targets proposed in this policy will be firmed-up in consultation with the Provinces and incorporated in the 12th Five Year Plan (2018-2023) and 13th Five Year Plan (2023-2028).In addition to these over all national targets, the Provincial Governments can formulate their own targets for watershed management, aquifer recharge, ground water extraction and drainage as a part of their respective Master Plan for Water.

8. NWP INVESTMENT REQUIREMENTS

The root cause for the current water crisis is lack of adequate allocations in the Public Sector Development Programme for the Water Sector. As a result there has been virtually no increase in the total cropped area of 55 MA in the past two decades.National Water Policy recognizes the need to ensure that water sector receives at least 10 percent of Federal PSDP allocation in 2018-19, gradually increasing to 20 percent by 2030. Correspondingly the Provincial Governments may also increase their development expenditure for this sector. Sub-sector wise estimates of investment needed by 2030 are given in the table below

(Rs. Billion)

Sub Sector	Investment	Major Projects
Storage	1,600	Diamer-Basha Dam, Mohmand Dam
Conservation	800	HEIS Projects, lining of distributaries and minors, telemetric monitoring, improvement of conveyance efficiency
Drainage	150	RBOD-I, RBOD-II and RBOD-III, new reclamation projects
Flood Control	186	National Flood Protection Plan-IV (NFPP-IV)
Rehabilitation of Irrigation System	300	Rehabilitation of barrages, head-works and canals
Research 1% of total	30	IWASRI Research Program, GMRC, Hi-AWARE

Besides above, sectors that can benefit from Public Private Partnership (PPP) modalities and private sector participation (like urban water and sewage for example) should immediately be opened up for investment through appropriate policies. The introduction of private capital and discipline in project execution will not only introduce cost savings and efficiency during implementation but will also save time and create a competitive environment. However, it will have to be ensured that a public utility like water is not exploited for profit and the strictest regulatory standards are maintained. Fortunately, Pakistan has successfully undertaken private investment in the power sector so there is a readily available model that can be emulated.

9. NWP IMPLEMENTATION MECHANISM

The integrated management of water resources requires the highest level of skills and knowledge to effectively address the looming water crisis. In fact, the real challenge is not just listing "*what*" needs to be done, because that is well known, but "how" to do it and "who" will do it, with a clear time lines. This is exactly what this policy has aimed to achieve. Capacity Building of all water related Public Sector Organizations at Federal and Provincial level shall be given high priority to equip and improve their performance in order to generate capacity for:

- Design, develop, upgrade, maintain and manage the water resources infrastructure according to national needs and optimum standards.
- Meet future challenges of increased demand and finite water resources.
- Meet challenges of climate change and demographic constraints;
- Ensure Integrated Water Resources Planning, Development and Management.

It is of paramount importance that an effective and responsive institutional structure is decentralized for implementation of this Policy that supports linkages between policy, practice, science and decision making, so as to facilitate at various levels, the sustainable solutions for water resources planning, development and management. The new priorities for the water sector that will be spelled out in the proposed increase in financial allocations for the water sector will be of limited value unless and until the institutional capacity for policy formulation and management capacity for project implementation is upgraded in a holistic manner. It is recognized that an effective institution is one that has a clear mandate, a legal framework, a well-structured organization with clear responsibilities and accountability at various levels, professionally competent engineers and other professionals with a clear mandate and operational autonomy. New and vibrant institutions are required at four levels i.e. planning, regulation, development, coordination and management. The following institutional framework will be adopted and gradually strengthened:

9.1 National Water Council: **A national body named as "National Water Council" (NWC) shall be established with the following composition:**

1.	Prime Minister of Pakistan	Chairman
2.	Federal Minister for Water Resources	Member
3.	Federal Minister for Power	Member
4.	Federal Minister for Finance	Member
5.	Federal Minister for Planning, Development & Reform	Member
6.	Chief Ministers of Provinces and one Provincial Minister nominated by the CMs	Members

7.	5 Private sector members from water related disciplines	Members
8.	Secretary, Ministry of Water Resources	Secretary

(Note: The Prime Minister AJK and Chief Minister G.B. will be invited to the meetings of NWC.)

The National Water Council shall meet at least once a year and perform the following functions:

i. Review and coordinate implementation of the National Water Policy and National Water Sector Strategy in the country and periodic updating of the same;

ii. Recommend legislation, policies and strategies for water resources development and management in the country;

iii. National planning and coordination for water resources development and management activities among concerned organizations at federal as well as provincial government level to achieve objectives of NWP;

iv. Review all major interprovincial water-related projects and activities in the fields of irrigation, drainage, flood control and hydropower where federal funding is involved to ensure optimal and economical use of water resources;

v. Create an enabling environment that shall promote broader multi-stakeholders' participation and integrated water resources management with due consideration for environment and ecology;

vi. Review in consultation with concerned organizations the progress in controlling pollution of water bodies including rivers, streams, lakes and groundwater;

vii. Coordinating water resources database service at different level;

viii. Any other functions, which the Council of Common Interest(s) (CCI) may assign to the Council.

9.2 **A Policy Steering Committee** on water will assist the National Water Council (NWC) by ensuring inter-provincial coordination and reviewing policy papers and monitoring reports before submission to NWC. The composition of the Steering Committee will be as follows:

(i)	Federal Minister for Water Resources	Chairman
(ii)	Secretary, Ministry of Water Resources	Member
(iii)	Secretary, Ministry of Power	Member
(iv)	Secretary, Ministry of PD & Reform	Member
(v)	Secretary, Ministry of Finance	Member
(vi)	Chairman WAPDA	Member
(vii)	Chief Engineering Advisor	Member/Secretary
(viii)	Chairman NDMA	Member
(ix)	Surveyor General of Pakistan	Member
(x)	Chairman Pakistan Engineering Council	Member

(xi)	Provincial Irrigation Secretaries	Members
(xii)	Secretary (Works), PWD, Govt. of Gilgit-Baltistan	Member
(xiii)	Addl. Chief Secretary Fata Secretariat	Member
(xiv)	Secretary, (Irrigation & Small Dams), Govt. of AJ&K	Member

(Note: Depending upon the agenda other stakeholders can be invited)

The Steering Committee shall meet twice in a year or more, frequently whenever deemed necessary.

10. Pakistan Water Charter

The looming shortage of water in our beloved country has now become a grave threat to our food, energy and water security. Today, Pakistan's water economy is in acute danger of running dry. The prevalent water scarcity is inching towards a full-blown water crisis and is likely to become an existential threat, unless we act decisively. The remarkable progress made by Pakistan in the first four decades from 1950 to 1990 increased the availability of water withdrawn from the Indus River System making Pakistan self sufficient in food. But the progress we have made is now under threat. It is high time that we harness the opportunities that are within our reach, in order to ensure a sustainable supply of water for food and energy security and to meet the challenges of climate change.

This extraordinary situation requires extra ordinary measures. Business-as-usual is simply no longer an option. We need to focus all our energy and acumen, not only to avert an anthropogenic water crisis but to mitigate the impacts of climate change, as Pakistan is considered by experts to be one of the most climate vulnerable countries on the planet. If the glacial melt which accounts for 40 percent of our river flows accelerates, we will face heavy flooding in some years and as the snow cap shrinks, the annual river flows will begin to decline. This, combined with the more than usual variations in rainfall, can play havoc with the country's agriculture sector and threaten its food security system.

Taking cognizance of this grave state of affairs, it was deemed necessary to sign a Charter in the broader interest of the present and future generations of this country, and political leadership forged a consensus that:

- The demand-supply gap of freshwater is broadening on account of the population explosion, rapid urbanization and sub-optimal use of this precious resource in all sectors;
- sustainable consumption and production patterns need to be adopted by law as a water intensive foot-print is no longer an option;
- since there is no additional water available to inject in the Indus River System, a holistic and aggressive management regime for the judicious use of available resources is mandatory;
- being a single basin country lying in a Monsoon region, Pakistan needs to build a number of reservoirs so as to conserve some of annual surplus flows that escape into the sea keeping in view the effects of sea water intrusion, importance of conserving aquatic ecosystem and to act as a shield against water related disasters and climate change;

- conservation and scientific management of water is as important as augmentation; It is unacceptable and ironic that a substantial portion of the water diverted to canals is lost in the conveyance system;
- contamination of water has taken its toll on public health and 80% diseases are water borne, responsible for billions of rupees in lost productivity and medical and social costs.

With the commitment and intent to achieve water security for the people of Pakistan, it was pledged that;

1. Top most priority will be given to water sector and development spending will be increased significantly with judicious distribution among all sub sectors including disaster management and WASH
2. Inter provincial coordination will be fostered to implement transformational infrastructure development in an equitable and amicable and harmonious manner
3. Transfer of political power from one regime to the other does not affect water sector development in any way and that approved projects shall continue as per agreed time and cost stipulations
4. Water resources planning and development will be entrusted to high level qualified professionals.

"We firmly resolve that dedicated efforts will be made and all resources will be utilized to avert the water crisis and mitigate the anticipated impact of climate change on water security. We believe that sincere efforts made today will translate into a water secure future for the coming generations of Pakistan, and we pledge to leave no stone unturned in this endeavor. This Charter is a Call to Action and the declaration of a *water emergency*. We must now look beyond our differences and come together as a nation to rise to the challenge that is before us. We have done so before, and we can do it again. We will seize the day and secure our collective future. This is our promise to the coming generations". Signed by the Prime Minister and four Chief Ministers on 24 April 2018.

11. WAY FORWARD TO A WATER SECURE PAKISTAN

Upon approval of NWP, a national body named as "National Water Council" (NWC) has been established under chairmanship of the Prime Minister of Pakistan with Federal Minister for Water Resources, Federal Minister for Finance, Federal Minister for Power, Federal Minister for Planning, Development & Reform and Provincial Chief Ministers as members. The prime function of the NWC shall be to oversee the implementation of the Policy and issue directions where appropriate. A Steering Committee has also been notified to oversee and monitor the policy implementation guidelines given by the NWC through Policy Implementation Cell. The Steering Committee shall be headed by the Federal Minister for Water Resources with representatives from federal and provincial governments and concerned organizations. The Steering Committee shall have its meeting twice in a year or whenever deemed necessary. NWP is an enabling document and provides comprehensive guidelines for water resources management and development as per international practice. It also contains a development action plan till 2030 the SDG ERA. However, fund distribution among the stake holders is yet to be decided. First meeting of NWC was headed by the Prime Minister of Pakistan in Oct. 2018. It is strongly believed that NWP will pave way for improved sustainable and integrated water resources management in Pakistan.

Paper No. 797

IMPACT OF EXCESS GROUNDWATER PUMPING AND ITS REMEDIAL MEASURES IN IRRIGATED AREA OF BARI DOAB, PUNJAB, PAKISTAN

Engr. Dr. Muhammad Saeed, Engr. Dr. Muhammad Basharat, Engr. Muhammad Jawad

IMPACT OF EXCESS GROUNDWATER PUMPING AND ITS REMEDIAL MEASURES IN IRRIGATED AREA OF BARI DOAB, PUNJAB, PAKISTAN

By:

Engr. Dr. Muhammad Saeed[1], Engr. Dr. Muhammad Basharat[2], Engr. Muhammad Jawad[3]

Abstract:

Bari Doab: It is a piece of land between two rivers i.e. Ravi and Sutlej. It is the most rapidly groundwater depleting area of Pakistan. The causes of rapidly depleting groundwater is due to the stoppage of surface water supplies in both rivers after Indus Water Treaty (IWT) in 1960 between Pakistan and India. It created acute shortage of surface water supplies in this area. It generated maximum stress on groundwater to meet the crop water requirement.

This study was carried-out with an objective to predict the future groundwater availability and impact of climate change in this area with the overview of change in pumping cost. In this regard water balance of the area was determined and it was found that surface supplies are less by about **1027** mm/year. As a result the average groundwater mining is determined as @ 0.34 to 0.6 m/year in the area.

The results of the study revealed that acute shortage of groundwater in the central and lower parts of Bari Doab and it is moving in the direction from east to west. This was due to heavy pumping rate from upper to lower part of Bari Doab as currently the farmers are compelled to install their tube wells with varying depth i.e. 46 to 79 m from head to tail of Lower Bari Doab Canal. Similarly the study results showed high tube well installation cost as well as pumping and operating cost with electricity.

It is, therefore, recommended to construct artificial recharge channels in the area in order to maintain groundwater levels and to avoid enhanced pumping cost. In this regard old bed of Sukh-Beas River can be used for artificial recharge. A discharge of 156.3 m3/s (5518 cfs) can be diverted in Sukh-Beas channel.

1. Introduction:

Climate change is defined as certain degree of change in climate with time, it can be natural or due to certain anthropogenic activities. The net impact is in the form of uncertainties to the available water resources. Although climate change is well recognized internationally and locally, its impact on groundwater can be seen obviously in Pakistan. Groundwater resources are related to climate change through the direct and indirect interaction with surface water resources, such as lakes and rivers, and the groundwater recharge process. Due to high temperatures, increase in evaporation and transpiration would increase the water requirements. In contrary, the water availability is expected to decrease due to higher incidences of flooding and more prolonged and severe droughts. Consequently, these changes would influence intensity and timing of precipitation. This will certainly impact surface storage and groundwater

[1] Director General, IWASRI, WAPDA, Lahore, Email: engrsaeed_47@yahoo.com, Mobile: +92 333 4431183

[2] Addl. Chief Engineer, Drainage, IWASRI, WAPDA, Lahore.

[3] Junior Engineer, Drainage, IWASRI, WAPDA, Lahore.

recharge. The ultimate impact would be groundwater depletion and reduction in the net water availability in contrary to increasing water requirements.

There could be many impacts of climate change namely: change in monsoon pattern, increase in temperature and ET rates, increase in rainfall intensity, decrease in number of rainy days, decrease in snow fall, increase in glacier melt and retreat, change in runoff pattern, decrease in groundwater recharge, increase in extreme events, sea level rise and deterioration in water quality.

Reduced water availability in Indus Basin is expected due to the following:

- Decline in on-line water storage due to sedimentation;
- Increasing domestic and industrial water demands;
- Required increases in environmental flows or in other words deteriorating water quality in rivers;
- Depleting groundwater resources leading to increasing river losses;
- Potential impact of climate change on water resources in the mountains.

1.1 Water Resources Development in Bari Doab:

Until recently water resource development mainly focused on diverting water from rivers channels to where and when it was needed most, a supply-side management based on fragmented approach i.e. without integration of other parameters of importance. Nowadays the potential of diverting surplus river flows has nearly exhausted and there are signs that surface water resource availability is dwindling. This is due to decreasing online storage, population increase and larger per capita water use with passage of time. Until a few decades earlier, in addition to surface water utilization, increased groundwater use provided a big boom for meeting additional water requirements. The exploitation of groundwater, mostly by private farmers, has brought numerous environmental and economic benefits to the agriculture sector in Pakistan. Share of groundwater is now almost half of all crop water requirements in the irrigated environment.

Although there is clear evidence of groundwater over exploitation, in the form of falling watertables, even then thousands of new wells are being installed every year without knowing the sustainability of the aquifer for meeting this increased demand. This problem has become more acute in recent past due to the continued and extended drought faced by the country in the early part of last decade. But unplanned and unevenly distributed large scale groundwater pumping in canal commands is causing unequal distribution of depth to watertable (DTW).

Consequently this has given birth to a number of adverse interactions, such as abnormal lowering of watertable, increase in energy cost for pumping deeper groundwater and potential lateral migration of saline water into sweet water zones leading to groundwater quality problems. There is a strong need to conduct research to improve the existing scientific knowledge regarding relationships between climatic patterns, land use and the hydrologic systems, particularly the groundwater. This, in turn, will help of irrigation planners and system operators to re-examine current operational principles.

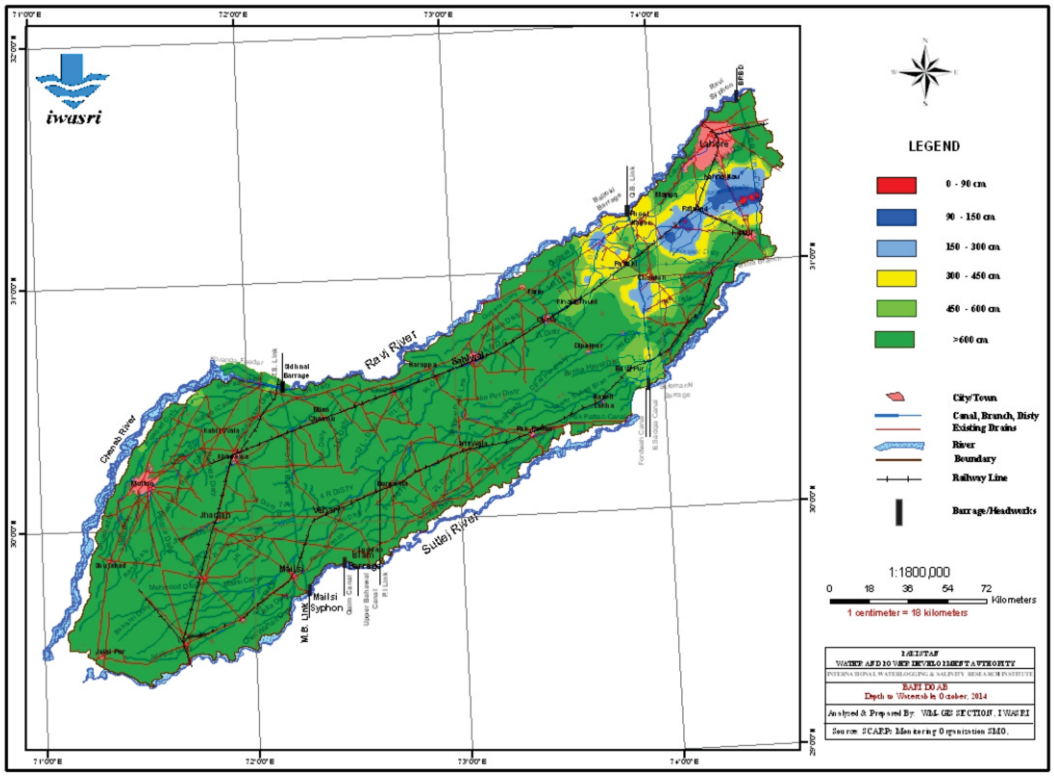


Figure 1: Depth to Watertable Map of Bari Doab-Pakistan, Oct-2014

The map showing different watertable depth ranges percentage during 2014 in Bari Doab. It shows depth to watertable was less than one percent in the range 0-150 cm, 2.74% in the range of 150-300 cm, 4.79% in the range of 300-450 cm, 5.30% in the ranges 450-600 cm, 27.31% in the range of 600-1200 cm 59.10% in the range of > 1200 cm in Bari Doab.

1.2 Integration of Water Resources

Conjunctive water use refers to simultaneous use of surface water and groundwater to meet crop demand. Each day, majority of the farmers in canal irrigated areas mix canal water with groundwater. They do so individually at farm level, uncontrolled by any scheme or irrigation system level entity. Whereas, integration of water resources in its real sense can best deal with variability of water in space and time and, therefore, can be implemented by simultaneously managing surface and groundwater resources at the watercourse, canal commands and basin levels to optimize productivity, maintain equity, and environmental sustainability. In many canal commands themselves and IBIS system level, such planning is needed to raise crop water productivity by reducing misuse of water where rainfall and canal water have higher combined availability. That means conjunctive water management can better occur when system administrators control ground and surface water simultaneously. It can be achieved by modifying the configuration of the surface system and/or its operating procedures. Already, it is less widespread at IBIS and rather absent at canal commands level, because it requires new thinking at institutions level and re-evaluation of crop water requirements. However, this type of conjunctive management is complex; nevertheless, it can play a dominant role, particularly in water scarce regions and in times of drought (avoid mining at tail end) and wet years (avoid

waterlogging and salinity at head end), because failure to integrate conjunctive water resources can result in either of the two problems or both at the same time.

Human economic activities and population growth have led to a sharp decrease in per capita water availability, as well as decrease in surface runoff and lowering of groundwater level in many parts of the world. Canal irrigation in Pakistan is supply-driven with inadequate releases from Tarbela, Mangla dams & Chashma reservoirs to regulate fluctuations in natural river flows in response to water demand. Canal water available to meet consumptive use requirements is the diversion quantities further minimized by conveyance and application efficiencies of about 46%. Major portion of these losses adds to the aquifer, which is developed by the users without any management intervention by the government at local or basin scale. The country is changing in its status of a water-stressed to a water-scarce region and is continuously approaching the low level limits of its water resources. Present per capita water availability has attained the figure of 1000 m^3 per year as projected by Briscoe et al. (2005), due to gradual increase in population @2.03% per annum (World Population Day, 2011). Water productivity is low as well, compared to other countries; crop yields both per unit of land and water are low. All the aforementioned facts demand innovative measures to efficiently manage scarce water resources.

Generally, groundwater potential for irrigation use diminishes over the alluvial aquifers of IBIS in downstream direction. The reasons are two fold, i.e. either the groundwater is highly mineralized for use or the depth to groundwater increases from head to tail of canal commands. On the other hand, demand for supplemental irrigation supplies increases towards south in downstream direction of canal systems in IBIS, particularly in upper parts of IBIS (upper and central parts of Punjab Province). The reason being that climate becomes more arid in this direction. Although solar radiation, wind and temperature, all affect evapotranspiration demand, rainfall is often the most important determinant of irrigation demand. The mean annual precipitation ranges from about 100 mm in parts of the Lower Indus Plain to over 1000 mm near the foothills in the Upper Indus Plain (Figure 1.1). On the other hand, lake evaporation increases in north-south direction from 1270 mm at Peshawar to 2800 mm at Thatta (Ahmad, 1982).

To meet the deficit in crop water requirement and rainfall, the IBIS supplies canal water, this too was designed to partially fill this gap. This deficit has increased over time due to increased cropping intensity, compelled by growing population. But, irrigation duties in upper Indus Basin are based, in general, on equitable canal water distribution, particularly within a canal commands, in spite of the aforementioned anomalies regarding irrigation water requirement. As a result, groundwater levels are falling at unprecedented rates in tail end areas with low rainfall. Also the centrifugal pumps are facing suction limits due to successive groundwater mining, thus limiting access to only those who can install turbine pumps primed by electricity at very high costs. Thus, imparity of supply versus demand is inducing cost and quality inequity of irrigation water use within the same canal commands. To face this challenge a new pragmatic approach is needed, based upon integrated and conjunctive use of canal and groundwater resources which takes account of climatic, economic and environmental factors.

Canal water reallocation depending upon spatial climate variability will also result in increased water use efficiencies along with improved irrigator behaviour towards efficient irrigation management. At least no or minimal waterlogging and salinity in the head end area even during high wet years would be expected. At the same time, no groundwater mining in the tail end and less overall pumping cost will be an additional benefit. If adopted at country level, the proposed approach of canal water distribution will result in economic optimization of the available land and water resources.

2. Causes of Groundwater Depletion Bari Doab:

Following are the reasons for groundwater depletion Bari Doab Area:

2.1 Stoppage of Surface Water Flows in Ravi and Sutlej Rivers:

The Indus Waters Treaty is a water-distribution treaty between India and Pakistan, brokered by the World Bank to use the water available in the Indus System of Rivers located in India. The Indus Waters Treaty (IWT) was signed in Karachi on September 19, 1960 by the first Prime Minister of India Pandit Jawaharlal Nehru and then President of Pakistan Ayub Khan.

According to this agreement, control over the water flowing in three "eastern" rivers of India the Beas, the Ravi and the Sutlej with the mean flow of 33 million acre-feet (MAF) was given to India, while control over the water flowing in three "western" rivers of India, the Indus, the Chenab and the Jhelum with the mean flow of 80 MAF was given to Pakistan. More controversial, however, were the provisions on how the waters was to be shared. Since Pakistan's rivers receive more water flow from India, the treaty allowed India to use western rivers water for limited irrigation use and unrestricted use for power generation, domestic, industrial and non-consumptive uses such as navigation, floating of property, fish culture, etc. while laying down precise regulations for India to build projects. The preamble of the treaty declares that the objectives of the treaty are recognizing rights & obligations of each country in settlement of optimum water use from the Indus System of Rivers in a spirit of goodwill, friendship and cooperation contrary to the fears of Pakistan that India could potentially create floods or droughts in Pakistan, especially at times of war since substantial water inflows of the Indus basin rivers are from India. With the stoppage of surface water supplies in Ravi and Sutlej rivers the underground reservoir suffered badly due to stoppage of seepage from river bed which rendered Bari Dob as most depleted area of Pakistan.

2.2 Enhanced Groundwater Pumping for Agriculture and Domestic Usage:

Extensive groundwater development facilitated the increase in cropping intensity by addressing shortages in canal supplies and also lowering the watertable which also resulted in declining soil salinity. The BARI DOAB is, therefore, a conjunctive use farming system, however without any regulation by the government for long term aquifer management. Estimated number of tubewells in the BARI DOAB commands, based on Agriculture Extension Services data and Consultants' field check in 1994, was about 20,000. Groundwater abstraction estimates were 2,710 MCM per year towards supplementing canal irrigation supplies (NESPAK-NDC-AHT, 1995). There has been an exponential growth of tubewells in Punjab within the last decade. A comprehensive tubewell census in BARI DOAB commands was carried-out in 2005 by the Punjab Irrigation Department (PID) through its field staff under the guidance of NESPAK as consultants. The census provides the latest information on the numbers of tubewells, total operating hours and the total groundwater abstraction in both Rabi and Kharif on distributary commands basis for the whole of BARI DOAB Commands. According to the survey the reported number of tubewells in the BARI DOAB commands was 48,102. The data was analyzed by NESPAK (2005) and the total groundwater abstraction in BARI DOAB commands has been estimated as 4674 MCM (3.78 MAF) by NESPAK.



Figure 2: Turbine pump with PTO arrangement in Chak No. 60/12L in Bari Doab Region

The data (NESPAK, 2005) regarding type and power of prime mover for tubewells by the Divisions are summarized in Table-1. The data reveals that about 62% tubewells in BARI DOAB Commands are diesel operated with a horse power ranging between16-23. The highest percentage (94%) of diesel operated tubewells are in Okara Division. About 28% tubewells are tractor operated. The horse power of tractor ranges between 45-65 HP for centrifugal pumps. The proportion of tractor operated tubewells is highest (45%) in Sahiwal. The electricity powered tubewells were only 10% with a horse power between 15-20 HP. The reasons for least number of electric tubewells are high cost of installation compounded by expensive electricity to operate the tubewell. Tubewell density varies from division to division, the highest in Okara division (1 tubewell per 25 acres) the lowest in Khanewal (1 tubewell per 49 acres), however, the spatial distribution of tubewells is more difficult to establish definitively with a lack of mapped tubewell locations.

Table-1: Distribution of tubewells, type of prime mover and horse power range.

Type of Prime Mover	Balloki			Okara			Sahiwal			Khanewal		
	T/W Nos.	%	HP	TW Nos.	%	HP	T/W Nos.	%	HP	T/W Nos.	%	HP
Diesel Engine	1555	77.0	16 - 20	13113	94.1	16 - 20	8163	42.6	16 - 24	6849	52.8	16 - 23
Electric Motor	167	8.3	10 - 20	485	3.5	15 - 20	2320	12.1	15 - 25	1964	15.1	10 - 25
Tractor Operated	297	14.7	45 - 50	341	2.4	45 - 50	8692	45.3	45 - 50	4156	32.0	45 - 50
Total	2019	100		13939	100		19175	100		12969	100	
Area (acres)/ one T/W	41.7			25.1			34.4			49.1		

Source: NES Pak, 2005.

2.2.1 Population Growth and Limitation of Groundwater Resources

Pakistan is arid to semi-arid country with an average rainfall of about 240 mm per year. The ever increasing population of the country and the economy are both heavily dependent on the

annual river flows of about 180 BCM (146 MAF) of water. In arid and semi-arid regions like Pakistan, during hot and dry periods, impact of economic activities has a pernicious effect on water resources and the level of water supply. The usual canal supplies after seepage losses cannot fulfil the entire crop water requirements. Triggered with the shortage of canal water supplies particularly during drought period (1999-2002), groundwater resources development started with an accelerated pace. Now the farmers are to rely on tubewell water when needed at a critical time of crop requirements. These increasing crop water requirements due to ever increasing population has shifted the dependence from canal supplies (at the time of irrigation system design) to both the canal water supply and groundwater pumping at present. Replenishment of groundwater also relies on canal water seepage and rainfall recharge. This has created a situation where integrated use of all the water sources i.e. rainfall, canal and groundwater has become the important aspect to sustain the present agricultural growth and production.

Increasing urban and rural population is causing substantial pressures on surface and groundwater resources. While addressing a function at the eve of World Population Day, the then, Prime Minister of Islamic Republic of Pakistan, Syed Yousaf Raza Gilani said it was very important to make a plan to balance population growth with the country's resources, equitably and prudently. The Prime Minister said that Pakistan was the sixth most populated country in the world with the population growth rate at 2.03 % amongst the SAARC countries, resulting in an annual increment of 3.6 million people. He said "it was projected to reach 210.13 million by the year 2020 and would double in next 34 years" (World Population Day, 2011). With this scenario of population increase along with degradation of water quality, and competition between agriculture and growing industrial and municipal demands, it is vitally important that the water resources of the country be managed pragmatically and holistically. Groundwater is now being over developed in many areas, and its quality deteriorating possibly due to lateral movement of brackish water to the sweet water aquifers with the potential to make existing sweet water aquifers unusable. Over the past 40 years, the exploitation of groundwater, mostly by private farmers, has brought numerous environmental and economic benefits. A laissez-faire approach could be appropriate during this era. But groundwater now meets for about half of all irrigation requirements. Now, although, there is clear evidence in the form of falling watertables that groundwater is being over exploited, yet thousands of additional tubewells are being installed every year. This problem has become more acute in recent years due to the continued and extended drought faced by the country. In rain fed (barani) areas of Balochistan, farmers are pumping from depths of hundreds of meters and in sweet water areas of Indus Basin, depletion is now a fact in almost all canal commands. The situation is even more serious in large cities, and urban areas are facing the problem of receding watertable due to heavy groundwater extraction for piped water supply. The depth to watertable in Lahore has gone beyond 40m in central parts of the city, a few years back it was less than 27m, whereas it was about 5 m deep in 1960 (Basharat and Rizvi, 2011). Furthermore, there are serious and growing concerns with groundwater quality, a reality that is most likely to get worse if the present trend of declining watertable continues. Pakistan has thus entered into an era in which laissez-faire becomes an enemy rather than a friend.

If the over-exploitation of water resources, particularly the groundwater, is not controlled by avoiding over pump-age and misuse of the same, the decreasing groundwater level will naturally aggravate the current conflict on water shortage amongst the provinces as well as among various users' at all local levels. Also there is another danger of rapid declining groundwater levels which can cause salt-water intrusion due to up-coning from underlying saline aquifer or lateral movement from saline to fresh zones. To keep up with the pace of agricultural growth rate comparable to population growth, the need is to bring additional lands under

cultivation. Since no additional water is expected to be available, it is better to improve the efficiency of existing water resources system and land capabilities, otherwise Pakistan will be facing acute shortage of food, fibre and edible oil in near future. The major issue facing Pakistan in the coming years can be lack of management regime for groundwater, leading to rapidly falling groundwater levels and pollution of both surface and groundwater. All these issues have impact on agricultural production, food security and the overall ability of the Nation to improve the economic performance of irrigated agriculture sector. According to Perry (2001), the apparent misuse and waste of irrigation water, especially in the context of low and subsidized prices for water and deterioration of irrigation systems, suggest that charges should be increased to cover the costs of system operation, and that pricing mechanisms should have a prominent role in encouraging more efficient resource use. He further concludes that water is a complicated economic and political resources and its value varies sharply across time, space and use. In his opinion, the objective of increased water use efficiency will be better served by volumetric allocation of water rather than expecting markets to achieve the desired balance among competing objectives in production, environment, and social equity.

The drop in aquifer level also means that irrigators will be facing increasing cost of pumping and in some areas, will need to upgrade the pumping plant to cope with higher lifts. The groundwater may become out of reach of poor farmers. According to Punjab Private Sector Groundwater Development Project (PPSGDP, 2000), these areas with deeper groundwater levels are generally located in tail reaches of the canal systems. The reason being that there is a relatively big shortfall between crop water requirement and irrigation water supplied in comparison to head reaches. With dramatic increase in the intensity of groundwater exploitation in the last three decades, according to Steenbergen and Oliemans (1997), the policy landscape for Pakistan has changed i.e. “the main policy issues now relate to environmental sustainability and welfare”. They stressed the need “to avoid declining groundwater tables and deteriorating groundwater quality in fresh groundwater areas”, and also “to ensure equal access to this increasingly important natural resource”. According to Shah (2006), “sustaining the massive welfare gains that groundwater development has created without ruining the resource is a key water challenge facing the world today”. So there is an urgent need to develop pragmatic policies and approaches for bringing groundwater withdrawals into balance with recharge, a difficult process which is going to require action by government and by informed and organized users. Since much groundwater recharge in the Indus Basin is from the irrigation system, this requires an integrated approach to surface and groundwater management.

3. Impact of Groundwater Depletion in Bari Doab:

The groundwater depletion in the area of Bari Doab especially in lower bari doab has caused many severe problems in this area which are listed below:

- Increased pumping costs;
- Deterioration of water quality;
- Reduction of water in streams and lakes;
- Land subsidence.

3.1.1 Increased pumping costs

Although there is clear evidence of groundwater over exploitation, in the form of falling watertable, even then hundreds of new wells are being installed every year without knowing the sustainability of the aquifer for meeting this increased demand. This problem has become more acute in recent past due to the continued and extended drought faced by the country during 1998-2002. But unplanned and unevenly distributed large scale groundwater pumping in canal

commands of Bari Doab is causing unequal distribution of depth to watertable (DTW) in the area.

3.1.2 Deterioration of water quality

With the increase in groundwater depletion rate throughout Bari Doab area groundwater quality is also suffering badly, which can be seen in Figure 3. More than 50% of the area is not falling in the range of usable quality.

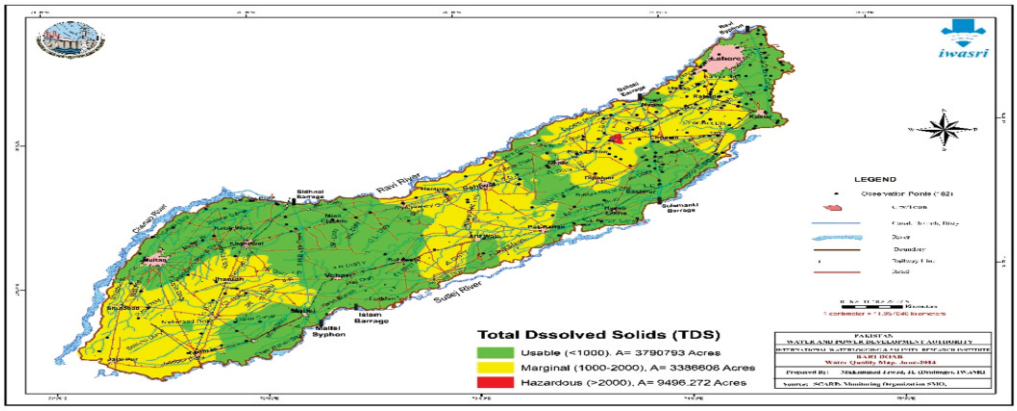


Figure 3: Groundwater Quality in Bari Doab Area, June-2014

4. Different Artificial Recharge Options in Bari Doab:

Following groundwater recharge options can be adopted in the area of Bari Doab.

4.1 Developing Sukh Beas as Artificial Recharge Channel:

International Waterlogging and Salinity Research Institute (IWASRI), WAPDA Pakistan carried out a research on abandoned Sukh-Beas channel and published a report on it in 2016 as publication # 305. According to which, at the Punjnad Barrage, where the extra flows from Jhelum, Chenab, Ravi and Sutlej join together, the downstream discharge and volume at 50% AEP were 31100 cfs and 10.28 MAF, respectively. Similarly, at 75% AEP, discharge was 7000 cfs and volume was 11.04 MAF. Thus, 50% exceedance probability being more dependable and a volume of 10.28 MAF is available at Punjnad Barrage which can be utilized for groundwater recharge subject to its appropriate management during its routing in the river system.

Also, the results showed that extra releases going downstream of Kotri Barrage were 78600 cfs and 17100 cfs at 50% and 75% exceedance probability, with corresponding flow volumes being 22.64 and 24.75 MAF, respectively. Thus, flood flows released from Punjab through Punjnad River remain excess to the irrigation demand of Lower Indus due to extra water flowing in Indus River during July to September.

Now its well established that extra surface water is available in the form of flood flows in the Chenab River at Punjnad, Trimu and Qadirabad Barrages. During the period from July to August, the expected discharges at 50% exceedance probability, are 31,800 and 29,200 cfs at Trimu and Qadirabad Barrages, respectively. Also, at 65 % exceedance probability, the expected discharges are 15000 and 15700 cfs, whereas at 75% exceedance, the corresponding figure are 7,600 and 10,600 cfs. Thus, these extra flows are available for diversion to

Qadirabad-Balloki and Trimu-Sidhnai Canals for its conveyance to Ravi River and ultimately recharging the groundwater via the Sukh-Beas bed.

However, thousands of acres of farmland of tehsils of Kabirwala (Khanewal), Shorkot (Jhang) and Pirmahal (Toba Tek Singh) area covering almost 200 villages were found already waterlogged from the seepage occurring due to Trimu Sidhnai and Havlei Canals. The farmers of the area already demand that the TS link canal should not be operated for more than 4000 cfs discharge; otherwise underground water level rises and severely damages the crop production in the area. Therefore, conveying extra water through the TS Link without its lining is out of question. Therefore, the only option of diversion of this extra flood water to the Ravi River remains through the QB Link, UCC Link or MR Link canals. Once conveyed into the Ravi River, it can then be diverted to the SB Channel (Sukh Beas) through the Balloki-Suleimanki and Sidhnai-Mailsi Link canals. However, the capacity enhancement of these link canals might be required, in coherence with the maximum discharge capacity of SB channel which can be accommodated for conveyance and recharge to the groundwater.

At Balloki Barrage, discharge at 50% probability of exceedance (during July to September) was 9300 cfs and the corresponding volume going downstream was 2.53 MAF. Also, the corresponding figures for Sidhnai downstream were 5700 cfs and 1.89 MAF. Thus, substantial volume of water is available at these two Barrages which can be diverted to Sukh-Beas channel during July to September. Even excluding half of the discharge flowing downstream of the Balloki Barrage for diversion to Cholistan area, through BS Link canal (currently being planned by the Punjab Irrigation Department), half of this volume i.e. 1.26 MAF would still be available for diversion to Sukh-Beas channel. However, these meager flood flows available in Ravi River can be substantiated by diverting extra flood flows available in Chenab and Jhelum rivers.

The flood flows to the Sukh-Beas channel can be released from Balloki-Sulemanki (BS) and Sidhnai-Mailsi-Bahawal (SMB) link canals, for recharge purpose. Therefore, it is concluded that stopping and reversing the declining groundwater tables in Bari Doab would be possible by diverting flood flows to Sukh-Beas channel. Equity amongst the farmers regarding groundwater availability, will be improved, resulting in improved agricultural yields in the area. Specific conclusions regarding diversion of flood flow and recharge are as follows:

- In total a discharge of 156.3 m3/s (5518 cfs) can be diverted and accommodated in Sukh-Beas channel i.e. 113 m3/s (4000 cfs) from BS Link (Balloki-Sulemanki) Canal and 43 m3/s (1518 cfs) from SMB Link canal;
- Out of this diverted water about 808 cfs is expected to recharge to the aquifer at its own under gravity;
- It is also possible that neighboring farmers will use channel water for irrigating their crops by pumping directly from the channel by using peter engines and centrifugal pumps. Thus, this would further enhance the net harvesting of the flood water and recharge to groundwater from Sukh-Beas channel;
- Operating mechanism of the escape gates would have to be rehabilitated, especially electric motors would have to be installed for their easy and frequent operations;
- All the three reaches of Sukh-Beas channel be rehabilitated to the maximum possible level for accommodating extra flood water during wet season;
- All the three reaches of Sukh-Beas channel be used for groundwater recharge with flood water conveyed through BS Link and SMB Link canals;

- Most of the bridges and other structures are having enough capacity for passing this flood water, may be very newly built bridges like the one near Muhammad Pura would need widening in order to avoid flooding of few acres of land on upstream side.

5. Conclusions and Recommendations:

Based on the above information and facts following conclusions/recommendations can be drawn:

- Climatic patterns increase in severity in head-tail end direction of the Bari Doab Commands over its length. At prevailing pattern and average cropping intensity is 159.7%, the annual crop consumptive use requirements increases from 1051 mm to 1152 mm from head to tail end respectively, with 9.6% increase. Annual normal rainfall decreases from 615 mm at head end to 212 mm at tail end with 55.1% reduction. Net crop consumptive use requirement (after accounting for rainfall contribution) is 25.2% larger at tail end of the commands as compared to head end.
- The canal irrigation supply is fairly uniform at distributary head i.e. about 655 mm without any trend in head tail end perspectives. Balance of crop water requirement is largely met by groundwater pumping to the tune of 492 mm at head to 518 mm at tail end of the commands. Groundwater recharge from canal supplies and rainfall reduces from 430 mm at head end to 285 mm at tail end. These conditions attributed to spatial climate variability.
- Excessive lowering of watertable has made groundwater pumping 2.37 times and overall irrigation cost 2.19 times expensive in tail reach areas of the Bari Doab commands in comparison to head reach. With continued equitable canal water supply, the presently prevailing irrigation cost inequity is projected to further aggravate with the passage of time. After 50 years from now, tail end farmers will be bearing 3 to 4 times of irrigation costs than their counterparts at head end with the expected canal supplies.
- Groundwater mining balance can be reduced or even made zero by supply and demand side management. Cost-effective rainwater harvesting and groundwater recharge schemes can help to stabilize groundwater levels.
- Through appropriate adoption of regulation policy and strategic actions such as building recharge structures in Ravi bed for groundwater recharge during wet years, the current worrying situation can be reversed to preserve and improve the groundwater quality and to ensure its availability on equitable and sustainable basis.
- Sukh-Beas bed should be used as artificial recharge channel in order to maintain groundwater depth at not normal level especially in central and lower parts of Bari Doab.

6. References:

ADB, 2006. ADB, 2006. Punjab Irrigated Agriculture Development Sector Project DRAFT FINAL REPORT; Annex 12 - Upgrading of Balloki Barrage July 2006. Prepared for Asian Development Bank by Halcrow Pakistan (PVT) Ltd In. association with Halcrow Group UK Ltd and Integrated Consulting Services.

Alam K. 1994. Groundwater flow modelling of the Lahore city and surroundings. A thesis submitted to the Centre of Excellence in Water Resources Engineering, University of Engineering and Technology Lahore for the partial fulfilment of the requirements of the degree of M. Phil in Hydrology.

Basharat M. and Tariq A.R. 2011. Climatic variability and its impact on irrigated hydrology in a canal command in Punjab, Pakistan. Under publication by Arabian Journal for Science and Engineering, Published by Springer.

Bennett G.D. Ata-UR-Rehman, Sheikh I.J. and Ali S. 1967, Analysis of Aquifer Tests in the Punjab Region of West Pakistan. Geological Survey Water-Supply Paper 1608-G.

DLR 2007. Surface water quality monitoring in Punjab, annual report 2007 by Directorate of Land Reclamation, irrigation and Power department Punjab, canal bank Moghalpura, Lahore.

GoP, 2007. Punjab Urban Water and Sanitation Policy by Government of Punjab. Available at http://202.83.164.26/wps/wcm/connect/499447004189d27895f79f71b08de1d3/Punjab+urban+water+and+sanitation+policy.pdf?MOD=AJPERES&CACHEID=499447004189d27895f79f71b08de1d3&CACHEID=499447004189d27895f79f71b08de1d3&CACHEID=499447004189d27895f79f71b08de1d3&CACHEID=499447004189d27895f79f71b08de1d3 accessed on September 15, 2010.

Greenaman D. W., Swarzenski W. V. and Bennett G. D., 1967. "Groundwater Hydrology of the Punjab, West Pakistan with emphasis on problems caused by canal irrigation. West Pakistan Water and Power Development Authority, WASID Bulletin 6.

Mehta, M. 2006. Status of Groundwater and Policy Issues for its Sustainable Development in India. In: Proceedings of IWMI- ITP- NIH International Workshop on "Creating Synergy between Groundwater Research and Management in South and Southeast Asia" February 8-9, 2005, Roorkee, India.

NESPAK and BINNE & Partners, 1988. Groundwater resources evaluation and study of aquifer under Lahore; Groundwater Model. Prepared by National Engineering Services Pakistan (Pvt) Limited for Water and Sanitation Agency, Lahore Development Authority.

PCRWR 2004 *'Water Quality Status' Third Report 2003-2004,* Pakistan Council of Research in Water Resources, Islamabad, Pakistan.

Punjab Private Sector Groundwater Development Project. 1998. Canal seepage analysis for calculation of recharge to groundwater; Technical report No. 14, Prepared for PMU, I & P, Government of Punjab by a Consortium of Arcadis-Euroconsult, NESPAK, NDC, & Halcrow.

Romani, S. 2006. Central Groundwater Authority-Past Experience and Future Strategies for Regulating the Development and Utilization of Groundwater in India. In: Proceedings of IWMI- ITP- NIH International Workshop on "Creating Synergy between Groundwater Research and Management in South and Southeast Asia" February 8-9, 2005, Roorkee, India.

Sheikh I. A. 1971. Long term values of specific yield in Bari Doab WAPDA, WASID Publication No. 95.

Steenburgen Van F. and Olienmans W. 1997, "Groundwater resources management in Pakistan" In: ILRI Workshop: Groundwater Management: Sharing Responsibilities for an open access Resource, Proceedings of the Wageningen Water Workshop.

Paper No. 798

WATER QUALITY EVALUATION OF KHANPUR DAM THROUGH PHYSICOCHEMICAL AND MICROBIAL ANALYSIS

Sohaib Zia, Imran Hashmi

WATER QUALITY EVALUATION OF KHANPUR DAM THROUGH PHYSICOCHEMICAL AND MICROBIAL ANALYSIS

By:

Sohaib Zia, Imran Hashmi[1]

ABSTRACT

In Pakistan, drinking-water supplies are generally obtained from surface water sources (such as rivers, canals or lakes) or the underground aquifers. The quality of surface water is deteriorating as a result of disposal of untreated municipal and industrial wastewaters and saline drainage effluent from agricultural areas. Among the ongoing water scarcity issues in Pakistan, current study involves evaluation of water quality in Khanpur Dam. Khanpur reservoir is a significant water source for consumption, fulfilling daily needs of the community residing within Rawalpindi, Islamabad and some areas of Hazara Division. Grab samples were collected as per standard protocols from three different locations i.e. Upstream (Khanpur Dam Island), Midstream (WAPDA Rest House Khanpur Dam) and Downstream (Khanpur Dam viewpoint). Samples were analyzed for Physico-chemical and microbial parameters which include pH, Temperature, Turbidity, Dissolved Oxygen, Chemical Oxygen Demand, Total Dissolved Solids, Electrical Conductivity, Nitrate, Nitrite, Total Phosphorus, Total Kjeldahl Nitrogen, Total Hardness and Alkalinity whereas for Escherichia coli; Most Probable Number (MPN) method was performed. The study reveals that all parameters were within WHO Permissible limits with the exception of Turbidity and Total Hardness. pH ranged from 7.70 to 7.31, temperature from 17.9 °C to 19.1°C, turbidity exceeded WHO limit at upstream with a value of 5 NTU and decreased to 3.5 NTU downstream. Dissolved oxygen varied from 7.89 mg/L to 7.82 mg/L, COD from 21.33 mg/L to 22.40 mg/L and Nitrate from 4.48 mg/L to 4.49 mg/L. Nitrite, TKN and Total Phosphorus were below detectable limit. Total Alkalinity decreased from 158 mg/L of $CaCO_3$ to 150 mg/L of $CaCO_3$. Total Hardness exceeded the WHO limit and ranged from 199 mg/L to 221mg/L. TDS ranged from 302 mg/L to 308 mg/L whereas

EC varied from 604 µS/cm to 622 µS/cm. Presence of Escherichia coli in all the samples reflects poor water quality rendering it unfit for human consumption.

Key Words: Khanpur Dam, Water Quality, Physicochemical Analysis, Microbial Analysis

1. Introduction

Pollution of freshwater reservoirs is a worldwide concern; untreated wastewaters are released into reservoirs due to their easy availability since they normally comprise urbanized areas with inappropriate living standards (Genthe et al., 2018; Giri and Singh, 2014). Consequently, the water quality is deteriorating by several pollutants, including excessive amounts of various toxic/heavy metals in the aquatic reservoirs thus making it unsuitable for drinking, irrigation, domestic, industrial and recreational purposes (Li and Zhang, 2010; Nawab et al., 2018; Pertsemli and Voutsa, 2007; Saha et al., 2017; Titilawo et al., 2018; Varol, 2013). In Pakistan, drinking water is provided from groundwater and surface water resources such as rivers, lakes and reservoirs. The untreated waste from agricultural, industrial and domestic effluents into

[1] ***Corresponding Author: imranhashmi@iese.nust.edu.pk*** Institute of Environmental Sciences and Engineering (IESE) School of Civil and Environmental Engineering (SCEE) National University of Sciences and Technology (NUST), Sector H-12, Islamabad, Pakistan

natural water reservoirs result in serious surface and groundwater pollution (Azizullah et al., 2011; Majidano et al., 2010; Muhammad et al., 2010; Tariq et al., 2008). Runoffs from agricultural land and industrial areas pollute the reservoirs, so the freshwater lakes become highly impacted. The toxic chemicals are washed away by excess irrigation water, which enters the freshwater reservoirs through streams (Ahad et al., 2005). Human intervention and pollution has led to progression in deterioration of water quality due to which approximately 80% of freshwater ecosystems are suffering from water security issues (Bunn, 2016).

Khanpur Dam is one of the major sources of drinking water for the inhabitants of Rawalpindi and Islamabad along with some areas of the Hazara Division. Therefore, it is paramount to monitor the water quality of reservoir for a better understanding of its physicochemical and biological characteristics. Hence, this study was designed to evaluate the effects of contaminated water on its consumers. Significant objectives of the study included physicochemical analysis and microbial analysis to monitor if the water is fit for human consumption. Statistical analysis in terms of Anova and Pearson Correlation would be applied to assess the contribution from various anthropogenic sources.

This study may serve as a reference to evaluate water quality of other similar ecosystems facing contamination due to recreational activities, industrialization and urbanization.

1.1. Study area

Khanpur dam was built in 1983 and is situated in district Haripur, province Khyber Pakhtunkhwa; 48 km (25 miles) from the federal capital Islamabad, on Taxila-Haripur Road and lies between 33.801 8°N 72.9305°E. The reservoir stands 167 feet tall with catchment area of 308 sq. miles and gross reservoir capacity of 107000 AF. It supplies 33 MGD water to Islamabad and 69.50 MGD to Rawalpindi. Khanpur dam has been built on Haro river which is a tributary of the Indus. Haro rises to above 9000 feet above sea level in the mountain regions of Nathiagali and Murree. Khanpur dam also serves as a popular picnic spot due to its scenic location. It provides recreation facilities like boating, sailing, fishing and waterskiing. Untreated domestic wastewater effluents, agricultural and road runoffs, and pollutants released during recreational activities are among major contamination sources in this reservoir.



(Source: Google Maps)

Fig. 1. Satellite image of Khanpur Dam

2. METHODOLOGY

2.1. Collection of samples

Autoclaved glassware rinsed with distilled water was used for collection of samples. Surface water samples were collected in triplicates from 3 locations of the reservoir i.e. Upstream (Khanpur Dam Island), Midstream (WAPDA Rest House Khanpur Dam) and Downstream (Khanpur Dam viewpoint) during November 2018. The samples were placed in a storage box and transported to laboratory immediately for analysis. (Kannan et al., 2008; Nemati et al., 2011; Saleem et al., 2013)

2.2. Analysis of samples

Parameters	Units	Instrument and Methods	References
pH	-	HACH 156 pH meter	APHA, 2017
Temperature	°C	HACH session 1	
Turbidity	NTU	Turbidity meter (HACH 2100 P)	
Dissolved Oxygen	mg/L	Crison Oxi 45 DO meter	
Electrical Conductivity	μS/cm	Conductivity meter (Ino Lab 720)	
Total Alkalinity	mg/L of $CaCO_3$	Titration Method	
COD	mg/L	Closed Reflux Method	
Total hardness		Titration Method	
TDS		Potentiometric Method	
Total Kjeldahl Nitrogen		Velp Scientifica	
NO_3-N		UV Spectrophotometer Specord 200 plus Analytikjena Germany)	
NO_2-N			
PO_4-P			
PMN	CFU/100 ml	MPN Method	

Table: 1 Methods and Equipment for Physicochemical Parameters

Analytical grade reagents and distilled water were used in sample processing and standards preparation. The physical parameters like pH, temperature, Electrical Conductivity (EC), Total Dissolved Solids (TDS) and Dissolved Oxygen (DO) were determined in situ using a HACH 156 pH meter and Crison Oxi 45 DO meter. Turbidity was measured using HACH 2100 P turbidity meter. All the samples were analyzed for major anions i.e., Nitrate (NO_{3^-}), Nitrite (NO_{2^-}) and total phosphorus (PO_4^{3-}) using a UV-VIS spectrophotometer (Specord 200 plus Analytikjena Germany). Before analysis, the system was calibrated with known multiple standards using standard stock solutions for each parameter. Samples were analyzed for Total Kjeldahl Nitrogen (TKN) using automated Velp Scientifica. Chemical Oxygen Demand (COD), Total alkalinity and Total hardness was analyzed through titration method. Most Probable Number (MPN) was performed to detect the presence of Escherichia coli. This technique was used with 10 fermentation tubes each containing 10 mL sample portion and an inverted durham tube. In presumptive phase, lauryl tryptose broth (LTB) was used, dehydrated ingredients were mixed well in distilled water to dissolve. The mixture was poured in test tube having inverted durham tubes covering them at least two thirds. The medium was sterilized and then incubated at 37°C overnight. The sample was vigorously shaken before dispensing into test tubes. These tubes were kept in the incubator for 24 ± 2 hours. A positive presumptive reaction is shown by production of gas in the tubes, while absence of gas represents a negative test.

Tubes having a positive presumptive reaction were put forward to the confirmed phase. Brilliant green lactose bile broth (BGLB) was used as medium, the tubes were prepared using the same procedure. The presumptive tubes were slightly shaken and a small portion of positive presumptive mixture was transferred to fermentation tube containing BGLB. The tubes were placed in an incubator at 37° for 24 ± 2 hours. Formation of gas in the inverted durham tubes inside BGLB symbolizes a positive confirmed phase.

The third phase is known as the completed phase. The broth used in this phase is called *E. Coli* (EC) broth. Previous phase confirms the presence of *total coliforms* while completed phase is to check the occurrence of *fecal coliforms*. The tubes were prepared having inverted durham tubes, were sterilized and then used after incubating overnight at 37°C. Positive tubes from confirmed phase were gently shaken and the fluid was transferred to the prepare completed phase tubes. The tubes were again placed in incubator under uniform conditions for the same interval of time. (Eaton et al., 1995)

2.3. Statistical analysis

Descriptive statistics such as range values, means and standard deviations were calculated using Microsoft Excel®. Anova and Pearson correlation analysis was performed using IBM Statistical Package for Social Sciences (SPSS) Statistics 20 to determine relationship between physicochemical parameters.

3. Results and Discussion

The permissible values for various water quality parameters as per World Health Organization (WHO) and Pakistan Standard and Quality Control Authority (PSQCA)are given in Table: 2

Parameters	Units	WHO	PSQCA
pH	-	6.5-8.5	6.5-8.5
Temperature	°C	-	-
Turbidity	NTU	<5	<5
Dissolved Oxygen	mg/L	-	-
Electrical Conductivity	μS/cm	750	400
Total Alkalinity	Mg/L of $CaCO_3$	500	-
COD	mg/L	-	-
Total Hardness		100	150
TDS		500	1000
Total Kjeldahi Nitrogen		0.5	-
NO_3-N		10	
NO_2-N		3	
PO_4-P		0.3	
MPN		0	0

Table 2: Guidelines for Drinking water quality

The results of physico-chemical analysis (mean ± standard deviation, minimum, maximum values) are indicated in Tables 3.

Parameters	Upstream	Mid-stream	Downstream	Min	Max	Average	STD
PH	7.70	7.17	7.31	7.17	7.7	7.39	0.27
TDS	302	311	308	302	311	307	4.58
EC	604	622	616.67	604	622	614.22	9.24
Turbidity	5.54	4.11	3.50	3.50	5.54	4.38	1.04
Temperature	17.9	18.9	19.1	17.9	19.1	18.63	0.64
DO	7.89	8.08	7.82	7.82	8.08	7.93	0.13
COD	21.33	20.27	22.40	20.27	22.4	21.33	1.06
Nitrate	4.48	4.51	4.49	4.47	4.513234	4.49	0.01
Nitrite	-	-	-	-	-	-	-
TKN	-	-	-	-	-	-	-
Total Phosphorus	-	-	-	-	-	-	-
Total Alkalinity	158	154	150.7	150.7	158	154.22	3.67
Total Hardness	199	219.7	221.9	199	221.9	213.53	12.63
MPN	10	10	10	10	10	10	0

Table 3: Descriptive statistics for water quality parameters in Khanpur Dam

	pH	Temp	Turb	DO	COD	NO_3	NO_2	TKN	PO_4^{3-}	T.A	T.H	TDS	EC	MPN
pH	1													
Temp	-.924	1												
Turb	.851	-.987	1											
DO	-.495	.125	.035	1										
COD	.252	.137	-.294	-.966	1									
NO3	-.898	.661	-.532	.827	-.653	1								
NO_2	a	a	a	a	a	a	a							
TKN	a	a	a	a	a	a	a	a						
PO_4^{3-}	.a	.a	.a	.a	.a	.a	.a	.a	.a					
T.A	.748	-.945	.985	.206	-.454	-.379	.a	.a	.a	1				

T.H	-.941	.999*	-.978	.172	.090	.696	.a	.a	.a	-.928	1			
TDS	-.997*	.892	-.809	.560	-.325	.929	.a	.a	.a	-.695	.913	1		
EC	-.999*	.910	-.832	.525	-.286	.913	.a	.a	.a	-.724	.929	.999*	1	
M PN	.a	.a	.a	.a	.a	.a	.a	.a	.a	.a	.a	.a	.a	.a

**Significance level is at 0.05*

Table 4: Pearson Correlation for water quality parameters in Khanpur Dam

3.1. pH

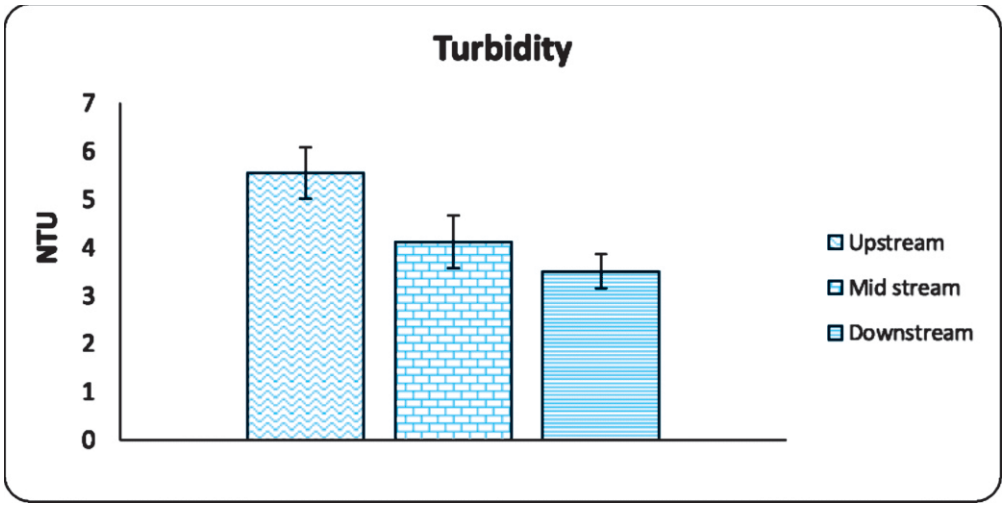
The pH of water samples decreased from slightly alkaline at upstream (7.70) to neutral at downstream (7.17). The average pH of water samples in study area was 7.39 which is well within the WHO permissible limit. pH showed a significantly strong indirect relation with total dissolved solids and electrical conductivity. Gerla (2013) reported large range and distinctive patterns of pH and EC suggesting that hydro geochemistry is related to processes affecting the water, including (a) reaction of water with organic carbon near the water–soil interface, (b) reaction of water with carbonate minerals in the underlying substrate.

3.2. EC and TDS

Electrical conductivity (EC) and Total dissolved solids (TDS) are generally influenced by human intrusions in the catchment areas (Siosemarde et al., 2010). EC value of samples increased from 604 µS/cm at u^{p}stream to 616.67 µS/cm at downstream . Similarly, TDS

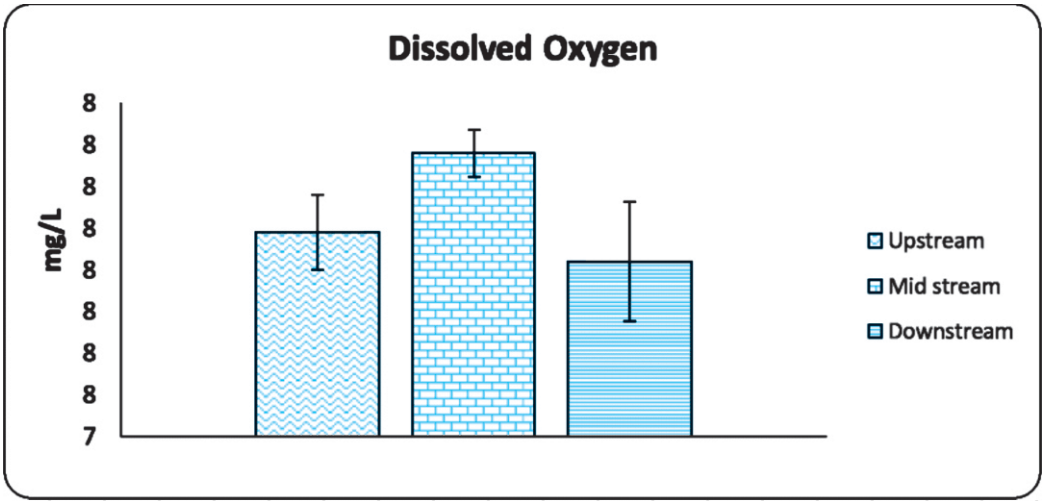
3.3. Turbidity

Turbidity exceeded the WHO permissible limit at upstream with value of 5.54 NTU and decreased to a safe limit of 3.50 NTU. Microorganisms (bacteria, viruses and protozoa) are typically attached to particulates. As a consequence, turbid waters can be microbiologically contaminated and indirectly constitute a health issue. Furthermore, high levels of turbidity can protect microorganisms from the effects of disinfection, giving rise to a significant chlorine demand and reducing the performance of some disinfection treatments, like Solar Water Disinfections. Thus, turbidity could represent a key issue regarding the microbiological quality and disinfection of water. (Hoko et al., 2018)



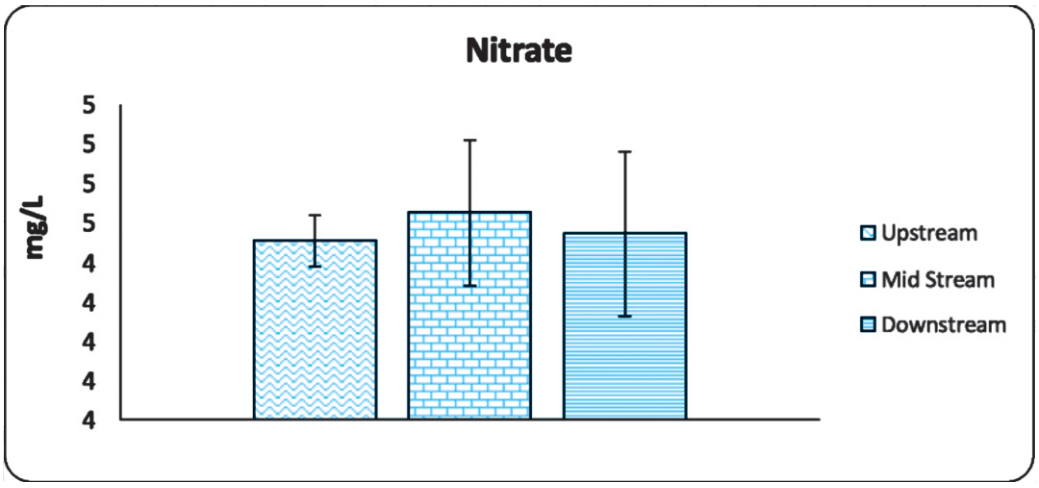
3.4. Dissolved oxygen

Dissolved oxygen showed minimal fluctuation between 7.82 and 8.08. Reiser and Bjornn (1979) report that low dissolved oxygen concentrations during egg incubation may delay hatching, increase anomalous development, stimulate premature hatching, and ultimately lead to weaker, smaller fry. They further state that coho salmon and steelhead survival drop off dramatically when dissolved oxygen concentration falls below an average of about 8 mg/l . (Davis et al., 1975)



3.5. Nitrate

Nitrate remained stable with an average value of 4.49 mg/L. The factors influencing the spatia distribution of NO_3 are diverse, including non-point sources e.g. chemical fertilizers and point sources e.g. wastewater irrigation (Jing and Li et al., 2014)



3.6. Nitrite

Nitrite (NO_2^-) is not usually present in significant concentrations except in a reduing environment because of unstable oxidation state. Nitrite was below detectable limit of 0.066.

3.7. Total Kjeldahl Nitrogen

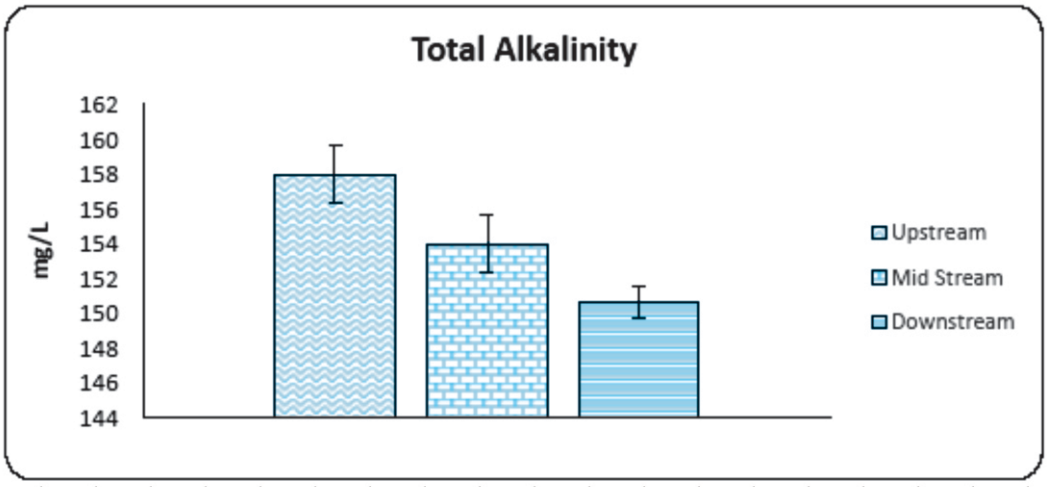
TKN was below detectable limit of 0.3.

3.8. Total Phosphorus

Total Phosphorus was below detectable limit of 0.061.

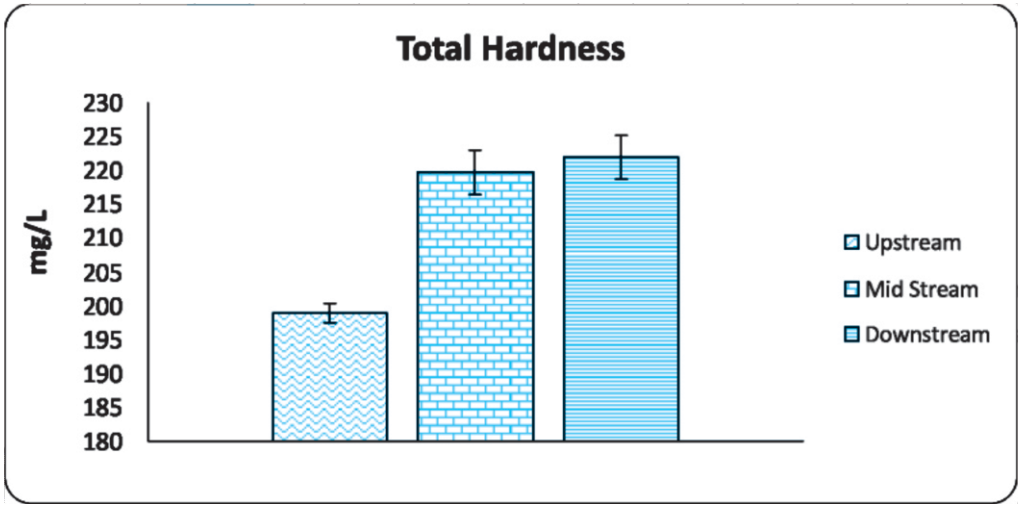
3.9. Total Alkalinity

Total alkalinity was measured at 158 mg/L of $CaCO_3$ at upstream and 150.7 mg/L of $CaCO_3$ at downstream. Average value was 154 mg/L of $CaCO_3$ which is within the WHO permissible limit.



3.10. Total Hardness

Total Hardness exceeded the WHO permissible limit at upstream, mid-stream and downstream with respective values of 199 mg/L, 219.7 mg/L and 221.9 mg/L with an average of 213 mg/L. A significant positive correlation was observed between hardness and temperature.



3.11. Most Probable Number

All the samples for most probable numbers were positive and depicted a Most Probable Number index/100 ml of greater than 23 rendering it unfit for human consumption.

4. Conclusions and Recommendations

There is a dire need to improve water quality of our freshwater reservoirs to make safe drinking water accessible to all. Current study indicates that all of the samples analyzed were

microbiologically contaminated. The Presence of *Escherichia coli* indicates fecal contamination which is the root cause of gastrointestinal disorders in humans. The major source of bacterial contamination was open defecation, improper hygienic conditions as well as poor sewage disposal. Total hardness exceeded the WHO permissible limit at upstream, midstream and downstream. The possible sources of hardness are calcium and magnesium which are present in industrial products, common constituents of food with a minor contribution from polyvalent ions such as zinc, manganese and iron.

Following are the recommendations to achieve the safe drinking water goals for Khanpur dam

i. National Drinking Water Quality Standards should be fully enforced.

ii. Regular water monitoring of Khanpur dam should be carried out to identify the issues.

iii. Fines should be imposed on littering and garbage disposal during recreational activities in the dam. Furthermore, mass awareness programs should be conducted by a small dam organization for visitors to mitigate pollution.

vi. Direct municipal discharge into t h e dam from the surrounding villages should be cut off.

6. References

Ahad, K., Mohammad, A., Mehboob, F., Sattar, A., Ahmad, I., 2005. Pesticide residues in Rawal Lake, Islamabad, Pakistan. Bulletin of Environmental Contamination and Toxicology 76, 463–470.

Azizullah, A., Khattak, M.N.K., Richter, P., Hader, D.P., 2011. Water pollution in Pakistan and its impact on public health — a review. Environment International 37, 479–497.

Bunn, S.E., 2016. Grand challenge for the future of freshwater ecosystems. Front. Environ Sci. 4, 21. https://doi.org/10.3389/fenvs.2016.00021.

Davis, J.C. 1975. Minimal dissolved oxygen requirements of aquatic life with emphasis on Canadian species: a review. Journal of Fisheries Research Board Canada. 32(12), 2295-2332.

Eaton AD, Clesceri LS, Green Berg AE (1995) Standard methods for the examination of water and wastewater, 19th edn. American Public Health Association, Washington

Genthe, B., Kapwata, T., Roux, W.L., Chamier, J., Wright, C.Y., 2018. The reach of human health risks associated with metals/metalloids in water and vegetables along a contaminated river catchment: South Africa and Mozambique. Chemosphere 199, 1 9 .

Gerla, P. (2013). Can pH and electrical conductivity monitoring reveal spatial and temporal patterns in wetland geochemical processes? [online] Hyd rol-earth-syst-sci-d iscuss. net. Available at: http ://www. hydrol-earth-syst-sci-d iscuss. net/10/699/201 3/hessd- 10-699-2013-print.pdf [Accessed 22 Aug. 2019].

Giri, S., Singh, A.K., 2014. Risk assessment, statistical source identification and seasonal fluctuation of dissolved metals in the Subarnarekha River, India. J. Hazard Mater. 265, 305314.

Hoko, Z., An assessment of quality of water from boreholes in Bindura District, Zimbabwe. *Phys. Chem. Earth, Parts A/B/C* 2008, *33,* 824–828.

Kannan, S.K., Batvari, B.P.D., Lee, K.J., Kannan, N., Krishnamoorthy, R., Shanthi K.Jayaprakash, M., 2008. Assessment of heavy metals (Cd, Cr and Pb) in water,sediment and seaweed (Ulva lactuca) in the Pulicat Lake, South East India.Chemosphere 71, 1233–1240.

Li, Jing & Li, Fadong & Liu, Qiang & Yoshimi, Suzuki. (2014). Nitrate pollution and its transfe in surface water and groundwater in irrigated areas: A case study of the Piedmont o South Taihang Mountains, China. Environmental science. Processes & impacts. 16 10.1 039/C4EM00200H.

Li, S., Zhang, Q., 2010. Spatial characterization of dissolved trace elements and heavy metal in the upper Han River (China) using multivariate statistical techniques. J. Hazard Mater. 176, 579588.

Majidano, S.A., Khuhawar, M.Y., Channar, A.H., 2010. Quality assessment of surface an groundwater of Taluka Daur, district Nawabshah, Sindh, Pakistan. Journal of th Chemical Society of Pakistan 32, 744–752.

Muhammad, S., Shah, M.T., Khan, S.,2010. Arsenic health risk assessment in drinking wate and source apportionment using multivariate statistical techniques in Kohistan region northern Pakistan. Food and Chemical Toxicology 48, 2855–2864.

Nawab, J., Khan, S., Xiaoping, W., 2018. Ecological and health risk assessment of potentially toxic elements in the major rivers of Pakistan: general population vs.Fishermen. Chemosphere 202, 154164.

Nemati, K., Kartini, N., Bakar, A., Abas, M.R., Sobhanzadeh, E., 2011. Speciation ofheavy metals by modified BCR sequential extraction procedure in differentdepths of sediments from Sungai Buloh, Selangor, Malaysia. J. Hazard. Mater.192, 402–410.

Pertsemli, E., Voutsa, D., 2007. Distribution of heavy metals in lakes Doirani and Kerkini, Northern Greece. J. Hazard Mater. 148, 529537.

Saha, N., Rahman, M.S., Ahmed, M.B., Zhou, J.L., Ngo, H.H., Guo,W.S., 2017. Industrial metal pollution in water and probabilistic assessment of human health risk. J. Environ. Manag. 185, 7078.

Saleem, M., Iqbal, J., Shah, M.H., 2013. Study of seasonal variations and riskassessment of selected metals in sediments from Mangla Lake, Pakistan. J.Geochem. Explor. 125, 144–152.

Siosemarde M, Kave F, Pazira E, Sedghi H and Ghaderi S J 2010 Determine of constant coefficients to relate total dissolved solids to electrical conductivity Int. J. Environ. Chem. Ecol. Geol. Geophys. Eng. 4 457–459

Tariq, S.R., Shah, M.H., Shaheen, N., Jaffar, M., Khalique, A., 2008. Statistical source identification of metals in groundwater exposed to industrial contamination. Environmental Monitoring and Assessment 138, 159–165

Titilawo, Y., Adeniji, A., Adeniyi, M., Okoh, A., 2018. Determination of levels of some metal contaminants in the freshwater environments of Osun State, Southwest Nigeria: a risk assessment approach to predict health threat. Chemosphere 211, 834843.

V€a€an€anen, K., Lepp€anen, M.T., Chen, X.P., Akkanen, J., 2018. Metal bioavailability in ecological risk assessment of freshwater ecosystems: from science to environmental management. Ecotoxicol. Environ. Saf. 147, 430446.

Varol, M., 2013. Dissolved heavy metal concentrations of the Kralkızı, Dicle and Batman dam reservoirs in the Tigris River basin, Turkey. Chemosphere 93, 954962.

Paper No. 799

WATER RESOURCE MANAGEMENT IN PAKISTAN NATIONAL AND PROVINCIAL PERSPECTIVES ON INSTITUTIONS AND POLICIES

Dr. Mahmood Ahmad, Tabeer Riaz

WATER RESOURCE MANAGEMENT IN PAKISTAN NATIONAL AND PROVINCIAL PERSPECTIVES ON INSTITUTIONS AND POLICIES

Dr. Mahmood Ahmad[1], Tabeer Riaz[2]

1. Introduction

Water sector in Pakistan has a long history of its development with policy and strategy documents being published. Similarly, proliferation of institutions increased to a point that there are 18 water related institutions serving the sector. The Federal Government last year in consultation with provinces came up with National Water Policy, 2018, the purpose of which is to take cognizance of emerging water crisis and provide an overall policy framework and guidelines for a comprehensive plan of action. The National Water Policy (NWP) was approved on April 23, 2018. Although there are some issues with its merit and quality, nonetheless the document represents a historic milestone given the lingering, perennial disputes between the Punjab and Sindh provinces which had impeded the formulation of a NWP. The much awaited water policy document took a decade to complete, it is another document in the long list to carry the ingredients for much needed change of mind set to move further with shifting challenges. The most vocal critics point out that NWP fails to clearly prioritize actions for short to long term interventions, thus failing to fully take account of issues and challenges being faced at National and Provincial levels. This paper would try to bring about key areas of gaps/actions needed based on global experience and ground realities in Pakistan – outlining policy options and their tradeoff in terms of supply enhancement versus demand management and short versus long term. Further, water resource management is a national/federal responsibility but irrigation and agriculture, as well as rural and urban water supply, groundwater administration, environment and other water related sub-sectors are provincial subjects. It will briefly trigger a debate looking at NWP from provincial lens.

2. Historical Perspective

Pakistan has a huge volume of documentation on water, spanned over two and a half centuries, that can be divided into major Federal and Provincial Legal Instruments before and after Partition. During 17th and 18th century an extensive system of inundation dug with weir-controlled irrigation has started. Before partition in late 1900s, Canal and Drainage Act and Irrigation Act were important milestones. According to (Basharat. M, Ahmad. S, 2016) regular irrigation in IBIS (Indus Basin Irrigation System) began in 1875 with the completion of the Upper Bari Doab Canal (UBDC) from Madhopur Headwork (now in India) on Ravi River. The last inundation canals were connected to weir-controlled supplies in 1962 with the completion of Guddu Barrage. In 1960, a major institutional reform was seen with creation of Water and Power Development Authority (WAPDA) and Environmental Protection Acts as shown in Figure 1, also depicting a comprehensive history of Irrigation and Drainage Development in IBIS. At provincial levels decentralization of water management was a major policy shift in early 1990s and thereafter hardly any notable water reform was enacted.

---

[1] Dr. Mahmood is presently working as Senior Visiting Researcher at Center for Water Informatics & Technology (WIT) at Lahore University of Management Science (LUMS) and Advisor to Shahid Javeed Burki Institute of Public Policy at NetSol, Lahore. He retired from FAO as Senior Policy Officer (Water), FAO Regional Office, Cairo, Egypt after serving 24 years in FAO/UN providing policy support in agriculture and water to most water scarce countries in the Near East.

[2] Research Assistant, Center for Water Informatics & Technology (WIT) at Lahore University of Management Science (LUMS)

Major Policy and Institutional reforms were enacted after 1960s with the Indus Waters Treaty in Pakistan as reflected in Figure 1. Water and Power Development Authority (WAPDA) established in 1958 with SCARP (Salinity Control & Reclamation Programme (Pakistan) projects were major institutional reforms.

Major land reforms and creation of flood commission were also significant supporting institutions / laws in the water sector. With large irrigation system developed, twin problem of waterlogging and salinity began to appear in many areas. In consequence to this large-scale water diversion, water table came close to land surface, within a few decades.

During 70s, 80s and 90s major focus was to address problem of waterlogging and salinity by taking extensive surface drainage and canal lining, public wells privatized and more than 200,000 private wells installed, enhancing groundwater use and drainage. A major work was initiated on Left Bank Outfall Drainage (LBOD) project in Sindh. The combined effect of all these projects were reduction in water table and soil salinity survey in 1977-79 showed reduction as compared to 1950's.

It is well documented in SCARP how Pakistan met it's water-logging and salinity challenges, which few thought capable of resolution. The above efforts still point to the fact that job is half done, as waterlogging and salinity still make agriculture an unsustainable practice in these areas. In Lower Indus, SCARP tubewells and tile drainage is hardly functioning. Water logging and salinity problems persist on wider areas.

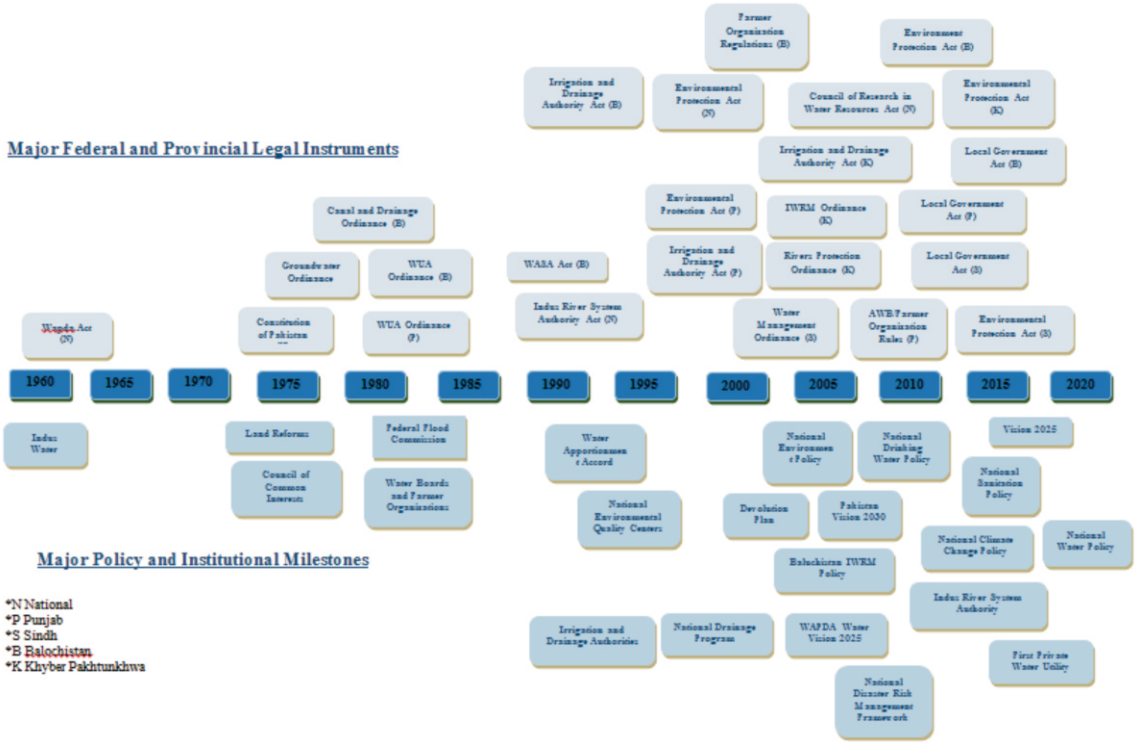


Figure 1. Major Federal and Provincial Legal Instruments before Partition and before and after the Indus Water Treaty in Pakistan, 1860 to Present and Major Policy and Institutional Milestones before Partition and before and after the Indus Waters Treaty in Pakistan, 1940 to Present

Note: AWB = area water board; IWRM = Integrated Water Resources Management; WUA = water user association; WASA = water and sanitation agency; IWRM = Integrated Water Resources Management; WAPDA = Pakistan Water and Power Development Authority.

While old, these studies do bridge the data gap till 1980s. Following this period, several good analytical studies have been conducted, so the water sector is well documented and sufficient information was available to draft a water policy. The most recent document among these is the World Bank report titled "Pakistan's Water Economy: Running Dry", which clearly highlights key water-based issues, challenges and possible solutions, and offers a balanced outlook on the supply and demand side of water management in Pakistan. Prior to this, in 1995, the World Bank supported significant water policy reforms by the Government of Pakistan, aimed at decentralizing operations and maintaining the irrigation and drainage systems. Consequently, this initiated a program of institutional reforms meant to establish autonomous organizations at the level of the four provinces, of the 43 canal systems, and at the distributaries and minor canal level. These institutional reforms envisaged the formation of autonomous, self-accounting and self-financing Provincial Irrigation and Drainage Authorities (PIDAs); Area Water Boards (AWBs) along canal commands; and Water User Associations (WUAs) at the watercourse level. However, implementation has proceeded slowly, and to different extents in different provinces. Some aspects, such as AWBs, proceeded satisfactorily for some years, but then deteriorated with time mainly due to the lack of political, financial and technical support.

The Pakistan Water Partnership proposed the Water Vision 2025 and followed it up with 'The Framework for Action (FAA) for Achieving the Pakistan Water Vision 2025' in 2001. This document became the frame of reference for much of the debate on the water sector and showed how different stakeholders viewed its development. While concerns about climate change were noted briefly as an economic driver, much of the detail was left out from the documentation for clear direction. After this huge water sector development which often touted as largest contagious irrigation system in the world with major investment in the water/irrigation sector. However, there is another side to this debate that such a huge investment could have been much better returns as we have failed to add potential value per unit of extra water generated. Further, there are alarming facts that are related to water sector – declining availability, stagnant or lower farm productivity, poor environmental records of these investments and very week preparation for climate change with too much (floods) or too little (drought) water being a norm. However, despite this shortcoming, the document gave civil society a clearer understanding of the link between climate change and water resources.

To wind up this brief historical perspective, two issues are of paramount dimensions, first the groundwater now a major source of water supply for all competing uses is being depleted at an alarming rate. In Upper Indus, pumping for irrigation is larger than recharge, leading to declining ground water levels to various extents. Second, with the climate change happening, we need to integrate climate change aspects into specific policy areas of newly crafted NWP. These aspects should be incorporated at planning and development levels; at competing demand levels (agriculture, domestic, industrial and environments needs); water allocations and most important to emphasize the economic and social costs associated with climate change in the medium to long term.

3. A Brief Review of National Water Policy-2018

National Water Policy, 2018 is a national framework within which the provinces can develop their master plans for sustainable development and management of water resources. The National Water Policy also addressed the need for capacity building of water related public sector organizations at federal and provincial level to ensure integrated water resources planning, development and management. As part of institutional and functional arrangements,

the National Water Policy also calls for the establishment of Groundwater Regulatory Authorities in all provinces in order to regulate water safety, pricing, sustainability etc.

The current water policies regarding Pakistan are briefly summarized in Figure-2 below;

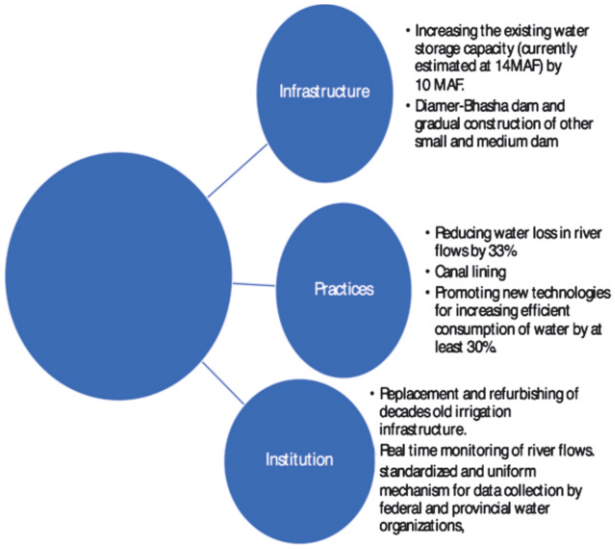


Figure 2: Current Water Policies

4. Gaps in National Water Policy Formulations

The paper identifies key areas that water experts deem as priority intervention and as a guideline for implementation of the national water policy at national and provincial levels.

We need a clear and prioritized focus of new water policy:

Formulation of Pakistan Water Policy for the 21st century requires a major shift from the classic paradigm used in water resource management (supply enhancement, command and control water allocation) to a more adaptive new paradigm (based on demand management and economic incentives). Right now, supply actions are only available for long term, the demand management option are far more cost-effective to save or reallocate water, yet water demand management policies are not promoted, Pakistan is the leader in this blind policy, and only it is matter of time when we would be forced (as has been the case of energy) the hard way to opt for difficult choices. As part of NWP implementation, there is need to rationalize water use among sectors and also to formulate a set of incentives, regulations and penalties along with proper accountability mechanism and monitoring oversight has to be built for maintenance of water standards, regulation of surface and ground water use and equitable distribution of water resources. In short, a proper and credible water accounting and auditing is required.

4.1 Rationalize water use in agriculture is central:

Agriculture uses 95% of water (FAO Stat 2019), supports the argument that water shortage solutions lies in a drastic shift in agriculture policy. It is well documented that agriculture sector uses most of water, pays the least and wastes the maximum. The water planners should spearhead a policy shift in the provincial department of Agriculture from 'yield optimization per unit of land' to 'yield optimization per unit of water.' Only such a paradigm shift can help country's agriculture survival in an era of water scarcity. When water is used for production, low water costs may permit the cultivation of water intensive crops (rice and sugarcane), which cannot be economically grown if water commands a high cost or its opportunity cost. Thus, the cost of water may be a factor which determines the cropping pattern of an irrigated area, and farmers' capacity to produce certain crops, particularly popular food-crops. Sugarcane is a

prime example. Farmers are switching to sugarcane cultivation because their net profits are larger, year 2018 was not a typical year. Considering, our national requirements for cotton and wheat, and excessive water use in sugarcane cultivation, the Government should discourage its cultivation, in particular in Southern Punjab as these crops require large amounts of water, and often produced where the cost of irrigation water is low.

4.2 Improving Water Governance:

There are 18-agencies serving the water sector yet there is no single organization responsible for the integrity of water resources in the Indus River Basin. The institutional reform needs a change in mindset, it must move from a business-as-usual scenario to benefit sharing mechanisms between provinces so that the needs and priorities of all provinces are met by the new water management legislative and institutional frameworks.

The irrigation and drainage systems have been deteriorating due to deferred maintenance and the country is finding it difficult to mobilize financial resources to maintain the large investments in the water sector. Huge budget deficits, rising cost of maintenance and over extended institutions are widening the gap of resources needed and the current level of expenditures. A major policy reform that can address the water scarcity issue is to redefine in terms unbundling land and water rights, of head, middle, and tail farmlands in irrigated areas and in terms of other ways of water resources management in non-irrigated rain-fed and arid areas where ground water use is critical. Nontraditional sources of water such as water harvesting, recycling wastewater and use of solar energy to desalinize water along coastal belts where tourism is expected to grow with CPEC. (China Pakistan Economic Corridor)

4.3 Water Quality issues are equally important:

Water quality, of both surface water and groundwater, is a major issue. While there are laws governing disposal of waste water into the rivers, their enforcement has been ineffective. Access to clean domestic water is limited. Large part of the country's population is deprived of improved access to safe drinking water and sanitation, 27.2 million do not have access to safe water. Access to proper sanitation facilities is low and only about 1% of the total wastewater generated in the municipal sector is treated before being discharged into the rivers. Further 52.7 million do not have access to sanitation, moreover 39,000 children under five die every year from diarrhea caused by drinking unsafe water and poor sanitation (UNDP 2010). Agricultural drainage is also an issue, from the perspective of sustainability of irrigated land as well as the environment. Waterlogging and salinity, ground water depletion, sedimentation and degradation of water quality for agriculture and other uses are critical water resource management issues. The solution lies in better regulations and their implementation for point and non-point pollution --- proper treatment of sewage and industrial toxic waste necessary to improve the water quality. There are cost effective ways to treat water which can be used for economic activities. Secondly, a proper groundwater management and drainage system are key to solving the issues. However, education and public awareness especially young people are needed to prevent pollution at the source.

4.4 Environmental externalities and Climate Change:

We need to monitor if NWP embraces the recommendations of the National Climate Change Policy (2012) to counter the adverse effects of climate change, in particular extreme weather events such as floods, prolonged droughts, and heatwaves as well as the rising sea level inundating coastal land and aquifers. Climate change poses a huge challenge to agriculture with a significantly high deleterious impact on production and productivity. The Department of Agriculture Punjab estimates a loss in income of PKR 1-trillion from decreased productivity of 5% per annum due to climate change. The agriculture sector will need to adapt to higher

temperatures and varying availability of water resources, through different crop varieties and improved on-farm water management practices to conserve soils and moisture. Mitigating effects of agriculture on climate change by reducing GHG (Greenhouse Gas) emissions can come from helping farmers adopt sustainable and climate-friendly practices and techniques, or Climate Smart Agriculture (CSA), without sacrificing productivity. There is no safety net for small farmers to increase their resilience against climate change impact, exposing a large section of farming community to high risk. Besides the dictates of climate change, considerable change in the land use pattern since 1980s, necessitates a fresh identification and development of new Agriculture Ecological Zones (AEZ) in order to maximize the agriculture potential of Punjab/Pakistan. First, water resources conservation and management have to be reoriented to move towards a climate-smart agriculture.

We need to value water to save it? Like many countries in region, Pakistan treated water as free good. A committed policy to price water would be key to rationalize water use, generate funds for Operation & Maintenance (O&M) and new investments. The present level and structure of water charges in Pakistan do not encourage farmers to use water efficiently. Comparing prices in the water markets (opportunity cost) and irrigation tariff indicates to some degree the divergence between the private and social prices. These social prices are best discovered in prevailing water market in growing urban and semi-urban areas, where almost free water is pumped from aquifers, transported to unban and peri-urban areas and sold at a price as high Rs. 1000 per taker in small towns to as high as Rs8000 in Karachi. It is clear that farmers/ consumer is willing to pay for water as long as they get a reliable supply which public service (PID/WASA) have failed to provide (Ahmad 2016). The facts are that the private sector (water markets) is capturing the revenues, which potentially public entities should have been collecting by raising the service level. The water markets will continue to supply water, as long present water supplier fails to provide water and services needed by consumers. Box-1 show a case from Baluchistan.

Broader policy guidelines can be that in the short to medium terms price water; first to cover the O&M cost and second in the long term incrementally move towards full cost pricing. It may be noted that, to ensure full water cost recovery, user fees should be 1 percent of the value of infrastructure stock, which in Punjab works out to Rs.1,800/hectare. The actual abiana (water rate) collected is Rs.150/hectare, whereas simple operations and maintenance would require a 0.5% water tariffs for agriculture be increased to at least Rs 9000/hectare. Pakistan has stayed too long of a policy to “built- neglect- built” with escalated cost overtime.

Box-1: CPEC and Water

Although, infrastructure is given much significance under CPEC water remains a completely overlooked sector. Each province has its own set of problems which were not captured in water policy being approved and ready for implementation. The province of Baluchistan represents a case of severe water scarcity, where CPEC projects are facing serious constraints in meeting water requirements. The port of Gwadar being a flagship project -- price of tanker (water markets) around Gwadar port is in range of Rs 22,000 to 24,000 per tanker as compared to Rs 4,000 to 8,000 in Karachi and about Rs 3,000 in rural Punjab. Water is needed for different competing demands and policy should have been put in place to rationalize its use. A combination of price and non-price instruments are available – appropriate water pricing is needed not only in the province of Baluchistan but also in others provinces with policy objectives to incrementally moving towards full cost pricing including regulating groundwater use on a sustainable basis. (Ahmad, 2019)

And make sure policies do result in real water saving: Large investments have been made in lining the canal and in other so-called water-saving technologies without knowing the true benefits if water-saving is real. Taking the case of the Indus Basin that has a water efficiency of 85% implying that these investment programs were not instrumental in saving water at national levels. Why is that? In traditional approach, the so-called wasted water that seeps to groundwater was picked up by the downstream user and process continues till it reaches Kotri, with a fact we have fully utilized the available water. We also need to keep in view negative externality generated on downstream users who are getting less water with adoption of new technology. Another contradictory policy being adopted by Department of Agriculture has promoted for years the lining of canals, whereas present focus of Department of Irrigation is to promote investments for recharging groundwater. In other words, someone's gain is loss to others. We need to map water zones where real water saving can come, a policy that could determine the most profitable investments regime for on farm water management strategy.

4.5 Groundwater Depletion

Groundwater a water bank grossly mismanaged: Another serious issue is the over-exploitation of ground water through tubewells, which is becoming a severe threat not only to sustainable agriculture but also to domestic water supply. The number of tubewells in Pakistan has increased significantly from 10,000 in 1960 to over 1,100,000 in 2016.[1] Decreasing surface water has prompted increasing reliance on groundwater to meet crop requirements as well as urban domestic use. The downside is depletion, more water is being pumped out than can be recharged through natural means. The efficiency and design of these tubewells are also poor because these are not installed using any sound engineering standards. Moreover, flat rate and subsidized electricity for agriculture tubewells have further incentivized farmers to operate them round the clock. All these incentive driven policies are depleting groundwater rapidly in freshwater areas, resulting in serious salinization of productive lands. Moreover, decreasing water table[2] requires more energy to draw water, which puts pressure on already limited energy resources at the same time increase pumping cost. Low water productivity has led to continuous depletion of underground water resources, posing serious threats to agricultural production in the province. We are fast matching India where they are growing and exporting rice, using valuable groundwater amounts to exporting virtual water. Like India, it is only a matter of time that rice would not be profitable unless supported with huge subsidy.

Pakistan can learn from few good global practices? Israel where maintaining sustainable groundwater is prime target, the water supply system would shut down to a large extent for users when approaching a situation where they are pumping more than recharge. Also, a prudent policy option in case of a drought it was able to survive drought patches much better than other countries in the region. Then a number of researchers argue that the best solution is to allocate groundwater shares or quota to each farmer according to the farm size and historical cropped area. Oman's case is illustrative where 40 farms have benefitted from the installation of Intelligent Energy & Water Meters. The objectives are to reduce the cost of monitoring, to allow a weekly/monthly watching of the groundwater abstraction and send alerts to those farmers who exceed their allocated water quota in a preventive way. India provides a good example of a success story that can be of interest to Pakistan facing groundwater depletion. The successful farmer-managed groundwater systems initiative, Andhra Pradesh Farmers Managed Groundwater Systems (APFMGS), offers useful lessons on community based groundwater management that resulted in sustainable use, rise in income and poverty reduction.

---

[1] The Economic Survey of Pakistan 2015-16.

[2] Due to excessive pumping, in many areas of Punjab, water table is decreasing two feet per year.

5. Provincial Water Challenges are region specific

For Sindh, Indus River acts as a main surface water source, water issues are typically of a lower Riparian, the province diverts approximately 48 million-acre feet and largely depends on canal water, as groundwater caters only 13 % of supply. It's necessary to emphasize the significance of groundwater exploitation wherever fresh water is available. In addition, issues relating to water quality are extensive and pervasive. So far, 81 % of its irrigation area is classified as waterlogged. Sea water intrusion is a serious and growing problem. The main area of concern for Sindh is water flow below Kotri posing an ecological disaster for the coastal areas at the same time water supply shortage to agriculture and domestic use for city like Karachi.

Gilgit Baltistan is a region highlighted as the water bank of the country, as Indus River flows through this area, and is considered the main source of water for Pakistan. However, there exists water shortage for agricultural, domestic and tourism consumption. The region also provides the catchment areas, which lack proper watershed management resulting in heavy siltation downstream. If policy makers had the vision to invest in watershed management, the country would not have a serious problem of excessive siltation, and could have expected longer lives for our few dams. Now the country is ready to invest billions of dollars which could have been saved if other provinces had provided funds (cross subsidy) to reduce environmental externality. The region also needs innovative ideas like solar technology to lift water for developing climate smart agriculture and high value farming where currently no water under gravity flow is available. For example, through a highly efficient (90%) drip irrigation system to irrigate high value orchards (Cheery, Apple).

Punjab is among one of the most active provinces regarding water yet intense competition prevails for its dwindling supply. The lack of value-added per unit of water is pervasive thus loosing huge sum of benefits. Water is underpriced; wherein a huge wedge exists between the private and social price of water. The canal water is almost free and groundwater extraction need to be regulated. Ground water management is where new law needs to be enforced which aims at scrutinizing unabated extraction of water by various users and binds existing and new commercial and industrial users to obtain a permit for groundwater extraction. The Draft Punjab Groundwater Protection, Regulation and Development Bill, 2017 is currently being consulted with the relevant stakeholders and is likely to be passed by the Provincial Assembly in near future.

In Khyber Pakhtunkhwa, greatest potential for increased irrigation is from improved water management and conservation works such as small dams, diversion structures and conveyance channels and improvements in the spate irrigation – in both perennial water rights area; and flood water rights area. Water conservation structures that increase soil moisture and recharge groundwater such as mulching and creating recharging ponds. High potential to improve water use efficiency particularly by adoption on better farm-level water management – by improving productive and allocative efficiency. It is estimated that 5 to 6 million acre feet of water can be mobilized by reducing surface water run-off, and another 0.4 million acre by increased pumping of On-Farm water management. There has been no legislation in Khyber Pakhtunkhwa for the regulation of use of Ground Water.

6. The way forward

- Formulating a Pakistan Water Policy for the 21st century requires a major shift from the classic paradigm currently employed in water resource management (supply enhancement, command-and-control water allocation) to a more adaptive new paradigm (based on demand management and economic incentives).

- Agriculture using 95% of water, supports the argument that water shortage solutions lies in a drastic shift in agriculture policy. Both water policy and agriculture policy to be revisited to incorporate relevant statements, clauses and articles into the Agriculture and Water Policy documents, suggestions should be solicited from a wide array of stakeholders at federal and provincial levels before the finalization of the documents.
- Rationalizing water use in agriculture is central to policy reforms in all provinces. The well-documented knowledge that agriculture uses 95% of water, pays the least, and wastes the most, supports the argument that a drastic shift in agriculture policy is necessary for formulating water shortage solutions. Planners should spearhead a policy shift in the provincial Department of Agriculture from 'yield optimization per unit of land' to 'yield optimization per unit of water.' This is the only way to help the country's agricultural sector survive a dawning era of water scarcity.
- Policy seminars (agriculture and water) should be held at the Planning Commission and in provincial government P&D departments, involving planners, policy makers, progressive farmers, agribusiness concerns and decision makers from both government and the political arena.
- In terms of supply, Pakistan has been unable to augment water storage capacity via the construction of large and smaller dams to cope with seasonal variations in water supply. According to the Indus River System Authority, "Pakistan dumps water worth approximately $21 billion into the sea each year due to lack of water conservation system." Water storages are needed at all levels - rainwater harvesting is a potential solution, a modern technique used globally for effective water storage.
- Several economic and non-economic instruments are available to price the water. Water pricing is a critically needed reform in all provinces, but there isn't a generalized strategy or model for adopting the specific water-pricing policy of a particular country and/or province. Every province must develop its own strategy. Some basic principles for setting water prices can include (1) meeting the revenue needs of the system, (2) distributing the cost equitably, (3) incentivizing the efficient use of water and capital, (4) keeping the tariff rate structure simple so it can be well understood and implemented, and (5) protecting environments.
- Both Punjab and Sindh continue to promote rice and sugarcane, but neither of these water-thirsty crops can be justified under prevailing and imminent water scarcities, unless we rationalize water use in agriculture. Enhancing land and water productivity is key to justifying the economics of these two crops.
- The quality of both surface water and groundwater is a major problem. Existing laws governing the disposal of wastewater into the rivers are prone to ineffective implementation, and access to clean domestic water is limited. Further water shed management policy issue be addressed.
- Agricultural drainage is also posing several complications from the perspective of sustainability of irrigated land as well as the environment. The solution lies in better regulation and policy implementation for point and nonpoint pollution, including the proper treatment of sewage and industrial toxic waste. There are cost effective ways to treat water to be used for economic activities.
- A proper ground water management and drainage system are necessary, and without the relevant education and public awareness, especially among the youth, preventing pollution at the source will not be possible. Groundwater management must take

precedence over mega-dam construction for all provinces. Amongst its many recommendations, the report calls for the community management of groundwater, wherein the user community is the primary custodian of the resource and is charged with implementing management measures.

- Institutional reforms call for a change in attitudes, away from a 'business-as-usual' framework, towards benefit-sharing mechanisms between provinces, so that the needs and priorities of all provinces are met by the new water management legislative and institutional frameworks.
- The country is not prepared to face the catastrophic adversities of climate change, including extreme weather events such as floods, prolonged droughts, and heat waves, as well as rising sea levels inundating coastal land and aquifers. Of all the provinces, Sindh and Baluchistan are the most vulnerable to climate change, and a mix of adaptive, mitigation and productivity enhancement policy must be initiated at provincial levels.

References

Ahmad. M, (2015). Water Crisis in Karachi, *Business Recorder*, Pakistani News Paper, Karachi

Ahmad. M & Asif (2017), Water Planning and Policy Issues with Special Reference to Groundwater Management.

Basharat. M, Ahmad. S, (2016). Irrigation and Drainage Efforts in Indus Basin - A Review of Past, Present and Future Requirement. *2nd World Irrigation Forum*, 6-8 November, Ciang Mai, Thailand

M. Ashraf, Nasir & M.M. Saeed, Evaluation of The Existing Water Productivity in The Lower Bari Doab Canal (LBDC) Command – A Case Study - *Pakistani Journal of Agriculture Sci*ences, Vol. 47(4), 389-397; 2010, ISSN 2076-0906. Retrieved from: *http://www.pakjas.com.pk*

Koundouri, P. & Groom, B. Groundwater Management: An Overview of Hydrogeology, Economic Values, and Principles of Management. Groundwater, Vol. 3.

World Bank (1994). Pakistan Irrigation and Drainage: Issues and Options. Agriculture Operations Division Afghanistan, Maldives, Pakistan and Sri Lanka Department South Asia Region, Report No.11884-PAK, WB (1993)

Government of Khyber Pakhtunkhwa. (2017). Agriculture Policy, Ten Years Perspective.

Paper No. 800

COMPARATIVE ANALYSIS OF PHYSICAL AND NUMERICAL HYDRAULIC MODEL STUDY OF REHABILITATION AND UPGRADATION OF PANJNAD BARRAGE

Engr. Muhammad Muneeb Khan, Engr. Muhammad Mohsin Munir,
Engr. Raza-ur-Rehman Abbasi, Engr. Javed Munir, Engr. Mansoor Ali

COMPARATIVE ANALYSIS OF PHYSICAL AND NUMERICAL HYDRAULIC MODEL STUDY OF REHABILITATION AND UPGRADATION OF PANJNAD BARRAGE

Engr. Muhammad Muneeb Khan[1], Engr. Muhammad Mohsin Munir[2], Engr. Raza-ur-Rehman Abbasi[3], Engr. Javed Munir[4] Engr. Mansoor Ali[5]

Corresponding Author: mohsin_uett@yahoo.com

ABSTRACT

The Panjnad Barrage is the last barrage constructed on River Chenab, downstream of the confluence point of River Sutlej. The existing flood carrying capacity of Panjnad Barrage is 700,000 Cusec. The objectives of rehabilitation and upgrading of Panjnad Barrage are to safely pass a 100-years return period flood of 865,000 Cusecs and restoring the existing sections of the barrage to perform its designed functions. The paper envisages evaluation of barrage performance in present and post condition i.e. before and after rehabilitation using numerical and physical hydraulic modelling. Physical Hydraulic Model study of Panjnad Barrage comprise the Comprehensive and Sectional models which were referred as Irrigation Research Institute (IRI) Nandipur.

The comprehensive model of Panjnad barrage was run for flood Hydrograph of 2014 and flood water levels were noted on both sides of the embankments upstream of the barrage. Keeping in view of the results of the Physical and Numerical Hydraulic Model Study, recommendations on revision of breaching section have been formulated. The Top Level of Left and Right Guide banks and Marginal Bunds are fixed keeping in view of maintaining 7 ft. Freeboard above the HFL recorded along the respective banks in Physical Comprehensive Model Study of Panjnad Barrage.

Sectional Model of Panjnad Barrage comprising of Main weir and additional depressed bays were also built at IRI Nandipur, and weir analysis was conducted. The Coefficient of discharge for weir flow under the free and submerged hydraulic regimes were evaluated. The increase in Afflux with regard to the original HFL of 341.50 ft as obtained through sectional Model Study is 1.36 ft. and 1.45 ft. under the Average and Accreted Tail Water Level. The study will be quite useful for water experts, students who are working on such mega projects.

Keywords: Comprehensive Model, Sectional Model, Approach Velocity, Submergence, Coefficient of Discharge, HEC-RAS.

---

[1] Senior Engineer, National Engineering Services of Pakistan, Lahore E-mail: mmken_487@yahoo.com

[2] Senior Engineer, National Engineering Services of Pakistan, Lahore E-mail: *mohsin_uett@yahoo.com*

[3] Deputy Director Design (Panjnad), PMO Barrages Lahore E-mail: razaabbasi@yahoo.com

[4] General Manager /Head, National Engineering Services of Pakistan, Lahore E-mail: jm786@yahoo.com

[5] General Manager Coordination, National Engineering Services of Pakistan, Lahore E-mail: *mansoor371@gmail.com*

1. INTRODUCTION

The Panjnad barrage is the last barrage constructed on River Chenab, downstream of the confluence point of River Sutlej. The barrage was constructed during the period 1925-1929 with design discharge of 450,000 Cusec using upstream HFL RL 341.5. The off-taking canals from barrage irrigate 1.8325 million Acres area of Bahawalpur and Rahimyar Khan Districts by diverting 11,882 Cusec through Panjnad and Abbasia canals. The barrage had 4 bays as left pocket and 29 bays as the main weir with total clear waterway of 33 x 60 = 1980 ft.

In September 1929, a flood of 550,000 Cusec was received at the barrage site. Consequently, existing waterway was widened for discharge capacity of 700,000 Cusec by adding 14 bays of 60 ft. each on right side of existing barrage. New bays were separated from the existing barrage by 250 ft. wide Junction Groyne. The salient Hydraulic features of existing Panjnad Barrage is given in **Table 1.1** shown below.

Table 1.1: Salient Features of Existing Panjnad Barrage

Features	Figure
Maximum designed capacity (cusec)	700,000
Maximum recorded flood in 1973 (cusec)	802,516
Total width between abutments (ft.)	3,400
Clear water way (ft.)	2,820 (47 bays of 60 ft. width each)
Minimum U/S flood level (ft.)	RL 341.50
Minimum D/S flood level (ft.)	RL 340.30
Pond level – normal (ft.)	RL 337.50

The then off-taking canals from barrage included Panjnad and Abbasia Canal but later on, in 2002, Abbasia Link Canal was also commissioned from the same bank i.e. Left Bank. Furthermore, the PMO Barrages envisions to enhance the discharge capacity of Abbasia Link Canal to use flood flows as shortly soon. These canals irrigate cultivated area of Bahawalpur and Rahimyar Khan districts by diverting discharges of 17,478 cusecs at present and 18,978 cusecs in future from Panjnad Barrage. The salient Hydraulic features of off taking Canal Head Regulators are given in **Table 1.2** shown below.

Table-1.2: Salient Hydraulic Features of Off-taking Canals

Salient Features	Panjnad	Abbasia	Abbasia Link
Commissioning Year	1929	1929	2003
Off-taking Side	Left	Left	Left
Capacity (Cusec)	10,484	1,394	5,600 (Prev.) 7,100 (Prop.)
Crest level (ft.)	RL 332.5	RL 330.00	RL 330.00
Floor level (ft.)	RL 320.00	RL 320.00	RL 320.00
Full Supply Level (FSL) (ft.)	RL 335.70	RL 336.10	RL 335.40
No. of bays	12	2	6
Width of each bay (ft.)	18 ft. each (2 Nos.) 26 ft. each (10 Nos.)	20	25
Thickness of pier (ft.)	4	4	4

Google imaginary of Panjnad Barrage, with all different components marked, is shown in **Figure 1.1** shown below.

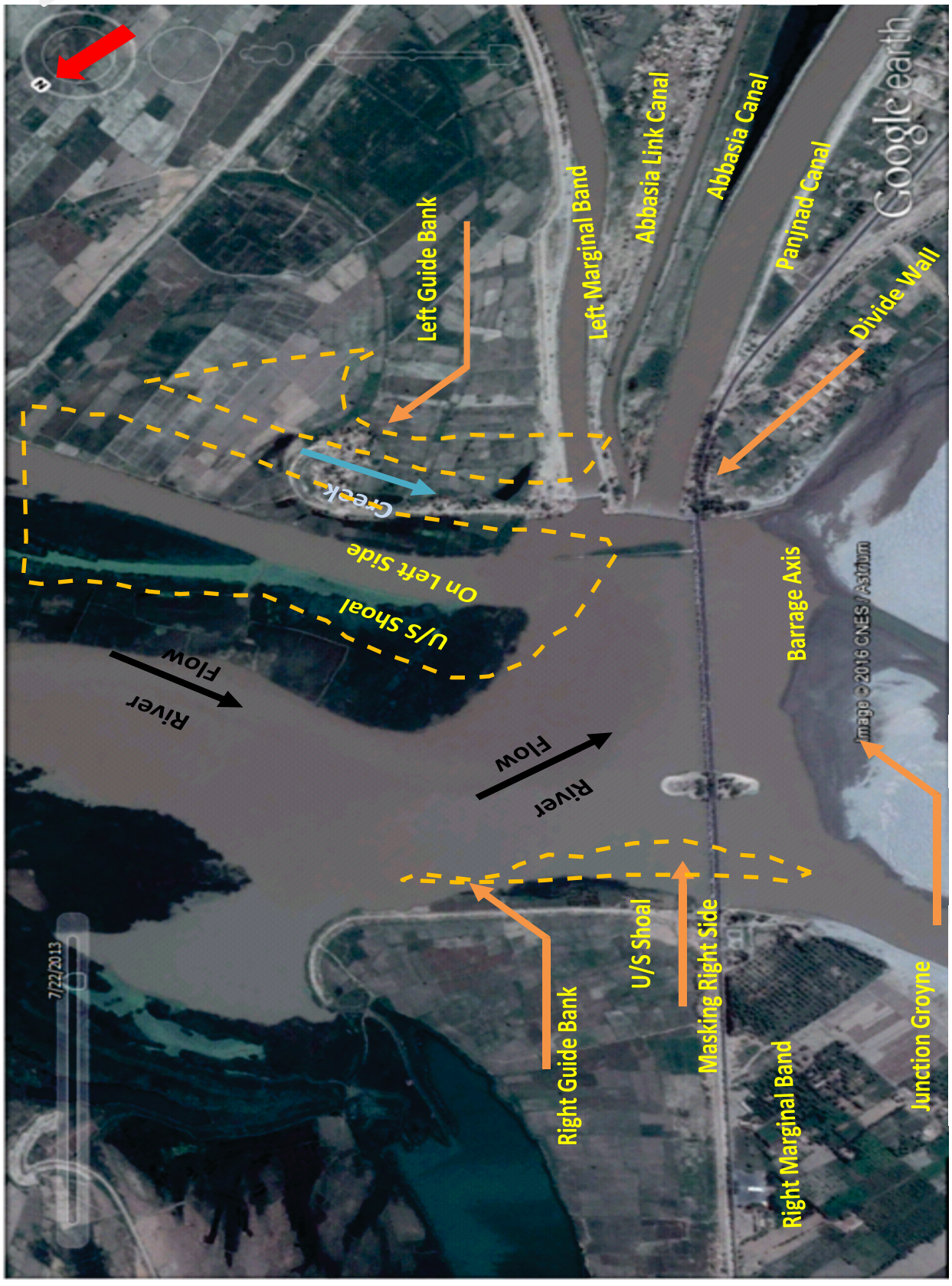


Figure 1.1: Arial View of Panjnad Barrage showing all components

1.1 History of Floods at Panjnad Barrage

The discharge classification of the barrage as given in the Flood Fighting Plan 2010 is given in **Table 1.3** shown below.

Table 1.3: Discharge Classification of Panjnad Barrage

Discharge (Cusec)	Classification	Discharge (Cusec)	Classification
Below 150,000	Normal	450,000 to 600,000	Very High flood
150,000 to 200,000	Low Flood	600,000 and above	Exceptionally high Flood
200,000 to 300,000	Medium Flood	802,516 (1973)	Super Flood
300,000 to 450,000	High flood	812,000 (1992)	Super Flood

The Punjab Irrigation Department (PID) has reported that since the construction of barrage, only on five occasions, floods have exceeded the stage of exceptionally high flood. On three occasions, floods have exceeded the design capacity of the barrage resulting in breaches in marginal bunds. The major floods reported by PID that have passed through the barrage and caused breaches in marginal bunds are given in **Table-1.4** as shown below.

Table 1.4: Major Floods at Panjnad Barrage Reported by PID

Sr. No.	Year	Flow Through Weir (cusec)	Flow Through Breaches in Embankments (cusec)	Total Discharge (1000 cusec)
1	27-09-1950	676,000	NIL	651
2	16-08-1973	762,516	40,000	803
3	12-08-1976	710,102	NIL	710
4	18-09-1992	744,000	68,000	812
5	16-09-2014	454,000	NIL	454

During Super floods of 1973 and 1992 breaches took place in left and right marginal bunds. During floods of 1973, the idea of providing breaching section at all barrages was developed and implemented after thorough discussions with the experts. Consequently, the 1725.5 ft. long breaching section and explosive stores at Panjnad Barrage were constructed on the Right Marginal Bund (RMB) upstream of the barrage during 1976 for safeguarding Panjnad Barrage structure in case of exceptionally high floods. Two breaching sections were constructed one from RD 28+000 to 30+000 of RMB and the second from RD 19+000 to 21+000 of Right Retired Embankment (RRE) upstream of Panjnad barrage. The standard operating procedure (SOP) for operating the breaching sections was fixed for either of the two scenarios mentioned below comes first:

1. Discharge at barrage exceeds 700,000 cusec
2. Water level at critical gauge (RD 15+000 of Left Marginal Bund) reaches RL 345 ft.

1.2 Necessity & Objectives of Rehabilitation & Upgrading

The necessity for and objectives of the rehabilitation and up-gradation study are to propose remedial measures for:

i) Enhancing the existing flood discharge capacity of Panjnad Barrage to safely pass 100 years return period flood discharge of 865,000 cusec determined through hydrological studies.
ii) Restoring the existing Panjnad Barrage to perform its designed functions and to ensure improved and reliable irrigation supplies for another life period.

These objectives would be achieved through effective flood management of 100 years return period floods, by rehabilitating and upgrading Panjnad barrage, besides provision of additional allied structures, structural strengthening of the existing barrage, modernizing the electro-mechanical components of the barrage; and improving operation, maintenance, and emergency preparatory arrangements.

2.0 TERMS OF REFERENCE (TOR) FOR PHYSICAL MODEL STUDY OF PANJNAD BARRAGE

Initially, to enhance the capacity of Panjnad Barrage from 700,000 Cusec to 865,000 Cusec, four new depressed bays were proposed in place of 250 ft. wide existing dividing Groyne. The adverse consequences associated with pursuing 4 depressed bays option are primarily related to the extensive dismantling and relocation of existing barrage components and unreliable connection of existing barrage floor with new floor. Considering the demerits associated with previously proposed plans from constructability and performance perspective, new plan for depressed bays is proposed. Proposed plan comprises of 3 depressed bays with 60 ft. bay width and new abutment wall at each side of the depressed bays as shown in **Figure 2.1.**

Following two Physical Hydraulic Model Study for the rehabilitation and upgrading of Panjnad Barrage were referred to Irrigation Research Institute (IRI) Nandipur.

1. Sectional Model Study for the evaluation of Discharge Coefficient under weir flow condition.
2. Comprehensive Model Study for the evaluation of remodelled barrage capacity in the light of 100-years return period flood.

2.1 Tail Water Rating Curve (1991-2015)

The tailwater rating curve has been re-established for the barrage based on the corrected documented discharge and water level data for the period 1991 to 2015, as recorded in the Barrage log book. The period has been revised to accommodate only data after the Water Apportionment Accord 1991. The Tail Water Rating Curve used to run the Comprehensive and Sectional Model of Panjnad Barrage is given in **Table 2.1**.

2.2 Flood Hydrograph 2014

Recent flood discharge of 453,570 Cusecs passed Panjnad Barrage in the year 2014 which is latest flood event. Thus, Flood Hydrograph 2014 has been prepared with evaluated peak discharge of 865,000 Cusecs and shown graphically in **Figure 2.2**. Comprehensive Model of Panjnad Barrage was run up to peak discharge of 865,000 Cusecs according to the flood Hydrograph of 2014.

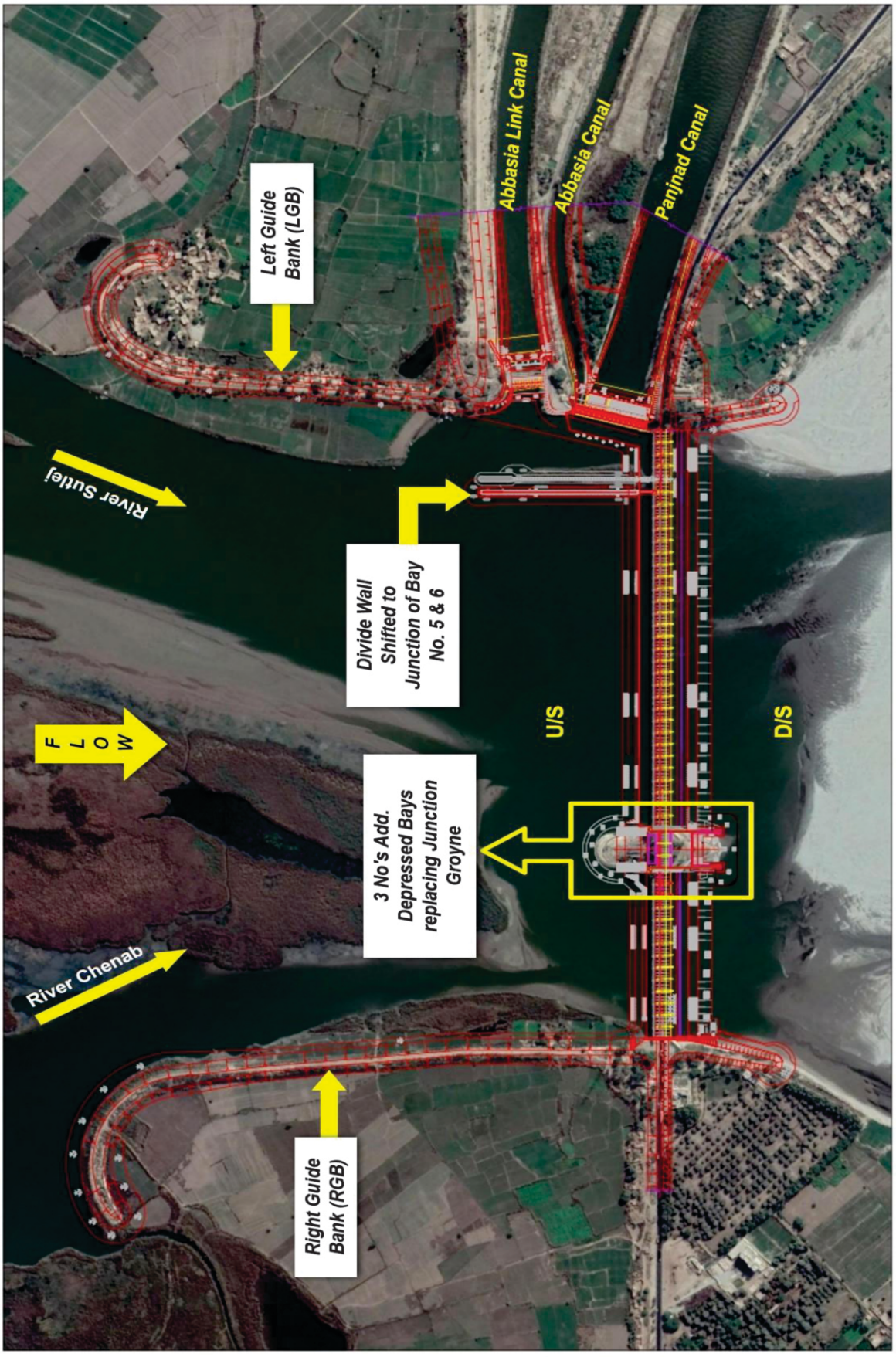


Figure 2.1: Layout Plan of Upgraded Panjnad Barrage

Table 2.1: Tail Water Rating Table of Panjnad Barrage

Sr. No.	Discharge (Cusecs)	Tail Water Level (ft)		
		Average	Retrogressed	Accreted
1	20,000	327.51	323.77	331.04
2	50,000	330.84	327.87	333.71
3	75,000	332.31	329.69	334.89
4	100,000	333.36	330.98	335.73
5	150,000	334.83	332.80	336.91
6	200,000	335.88	334.09	337.75
7	300,000	337.35	335.91	338.94
8	400,000	338.40	337.20	339.77
9	500,000	339.21	338.20	340.42
10	600,000	339.87	339.01	340.96
11	700,000	340.43	339.70	341.41
12	800,000	340.92	340.30	341.80
13	865,000	341.20	340.65	342.02

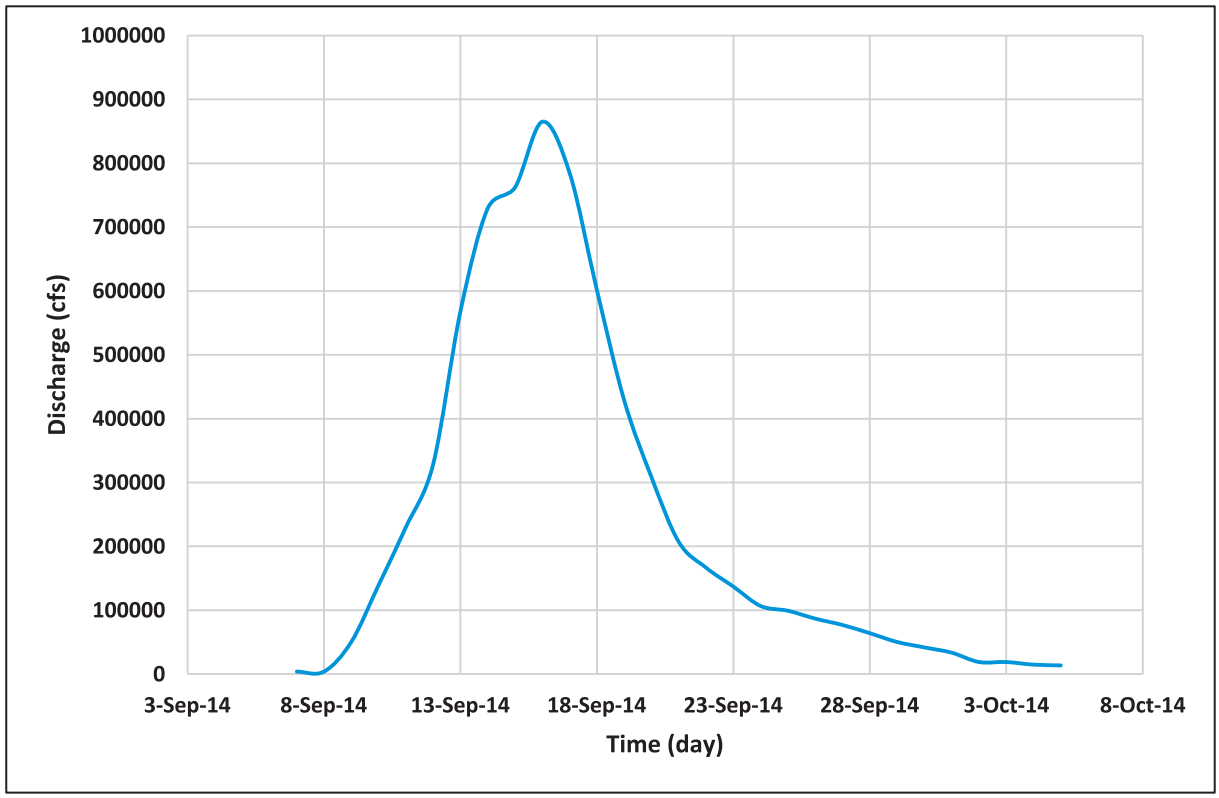


Figure 2.2: Flood Hydrograph (2014)

3.0 COMPREHENSIVE MODEL STUDY

The Comprehensive Model of Panjnad barrage including River Morphology 10 miles upstream and 3 miles downstream, existing Barrage structure and the off taking Canal Regulators were constructed at IRI Nandipur as per actual river survey and design features. The model is built on a distorted scale with horizontal scale 1:250 and vertical scale 1:50. In order to operate the hydrograph through the Chenab river reach, a discharge feeding arrangement was provided at the upstream end and Tail gate was installed at the downstream end of the model to control the tailwater level. The gauges were installed at appropriate places throughout the Chenab reach to record water levels against different discharges (Layout Plan of Gauges is shown in **Figure 3.1**).

3.1 Model Similitude

The principle of similitude forms the basis of designing models so that the model parameters can be converted into those on Prototype. In order to have similarity, it is first necessary that the model be geometrically similar to prototype. Then the movement of the fluid on model will be similar to that in the prototype if the ratios of inertial forces of the fluid, to the various other forces acting on the fluid are the same in the model as in the prototype. There are four types of forces acting on the fluid, those due to Viscosity, Gravitation Surface Tension and Elasticity.

Conversion factors for computing prototype values from model values are obtained by equating the appropriate dimensionless parameter. In gravity flow, the gravitational forces predominate. Consequently, for similitude in this case the Froude Number must be the same in model and Prototype.

Taking, $\mathrm{F_m} = \mathrm{F_p}$

Or $\frac{\mathrm{V_m}}{\sqrt{\mathrm{g_m d_m}}} = \frac{\mathrm{V_p}}{\sqrt{\mathrm{g_p d_p}}}$ Where V stands for velocity and d for depth of water

Or $\frac{\mathrm{V_m}}{\mathrm{V_p}} = \sqrt{\frac{\mathrm{g_m d_m}}{\mathrm{g_p d_p}}}$

Replacing “d” by “L” and putting $g_m = g_p$, we get

$$\mathrm{V_r} = \sqrt{\frac{\mathrm{d_m}}{\mathrm{d_p}}} = Y_r^{\frac{1}{2}} \; or \; \mathrm{L_r}^{\frac{1}{2}}$$

Similarly, $\mathrm{Q_r} = \mathrm{A_r V_r} = \mathrm{L_r}^2 \mathrm{L_r}^{\frac{1}{2}} = \mathrm{L_r}^{\frac{5}{2}}$

Time Scale is given by $\mathrm{T_r} = \frac{\mathrm{T_m}}{\mathrm{T_p}} = \frac{{}^{\mathrm{L_m}}/_{\mathrm{V_m}}}{{}^{\mathrm{L_p}}/_{\mathrm{V_p}}} = \frac{\mathrm{L_r}}{\mathrm{V_r}} = \frac{\mathrm{L_r}}{\mathrm{L_r}^{\frac{1}{2}}} = \mathrm{L_r}^{\frac{1}{2}}$

For Distorted Model

$$\mathrm{Q_r} = \mathrm{A_r V_r} = \mathrm{L_r Y_r Y_r}^{\frac{1}{2}} = \mathrm{L_r Y_r}^{\frac{3}{2}}$$

$$T_r = \frac{L_r}{V_r} = \frac{L_r}{Y_r^{\frac{1}{2}}}$$

The various Conversion being employed for the comprehensive model study of Panjnad Barrage is given in **Table 3.1** shown below.

Table 3.1: Conversion Factors for Comprehensive Model Study

Sr. No.	Features	Symbol	Conversion Factor	Scale Ratio
1	Length	L_r	L_r	1/250
2	Flow Depth	Y_r	Y_r	1/50
3	Flow Area	A_r	$L_r Y_r$	1/12500
4	Time	T_r	$L_r / Y_r^{\frac{1}{2}}$	1/35.35
5	Flow Velocity	V_r	$Y_r^{\frac{1}{2}}$	1/7.07
6	Discharge	Q_r	$L_r Y_r^{\frac{3}{2}}$	1/88388.35

3.1 Base/Calibration Test

In this test, the objective was to establish the model-Proto simulation. The Chenab River morphology existed along extreme right flank of river Khadir. Resultantly, a number of training works were constructed all along the Right Marginal Bund (RMB) whereas, the Sutlej river is at left river Khadir along the Left Marginal Bund (LMB) and no training works were constructed at the LMB except one J-Head spur tied to the LMB in the left pocket in front of Left Guide Bank. The offtakes were operated up to the barrage discharge of 300,000 Cusec by maintaining upstream Normal Pond level 337.50 ft.

For the calibration of the physical model the consultants proposed to operate the barrage for the discharge of 363,336 Cusecs as observed at site in the flood season of 2014. At site the observed Flood water level at upstream of the barrage and at RD 35+000 of RMB for the said discharge was at EL. 339.50 ft. and 345.30 ft. The model was tested for barrage discharge ranging from 100,000 Cusecs to 363,336 Cusec, the water levels recorded upstream and downstream of the barrage is given in **Table 3.1** shown below. The water levels observed in the model for the barrage discharge of 363,336 Cusec at upstream of the barrage and at RD 35+000 of RMB were same as recorded at site, thus the physical comprehensive model was found calibrated with the actual protype hydraulic conditions.

Table 3.1: Calibration Test Hydraulic Results

Sr. No.	Discharge (Cusec)	Average US Water Level (ft)	Average Tail Water Level (ft)	US Water Levels along RMB			
				RD 15+000	RD 20+000	RD 25+000	RD 35+000
1	100,000	337.50	333.40	-	-	-	-
2	200,000	337.50	335.60	-	340.00	341.30	342.20
3	363,336	339.55	338.60	341.70	344.20	345.20	345.30

3.2 Hydraulic Test for the Upgraded Panjnad Barrage

After the physical comprehensive model was found calibrated with the actual Proto conditions, the 3 No. depressed bays were incorporated at the place of junction groyne. The model was again molded according to the river cross sections provided by the consultants. The top levels of the river embankments were raised keeping 7 ft freeboard from the anticipated flood water level for barrage discharge of 865,000 Cusec. The upgraded model of Panjnad Barrage was again operated according to the Flood Hydrograph of 2014 and flood water levels were recorded upstream and downstream of the barrage according to the Gauge locations shown in **Figure 3.1** and the results are tabulated in **Table 3.2**. The photograph of the comprehensive model being run for deign flood discharge of 865,000 Cusecs is shown in **Figure 3.2**.

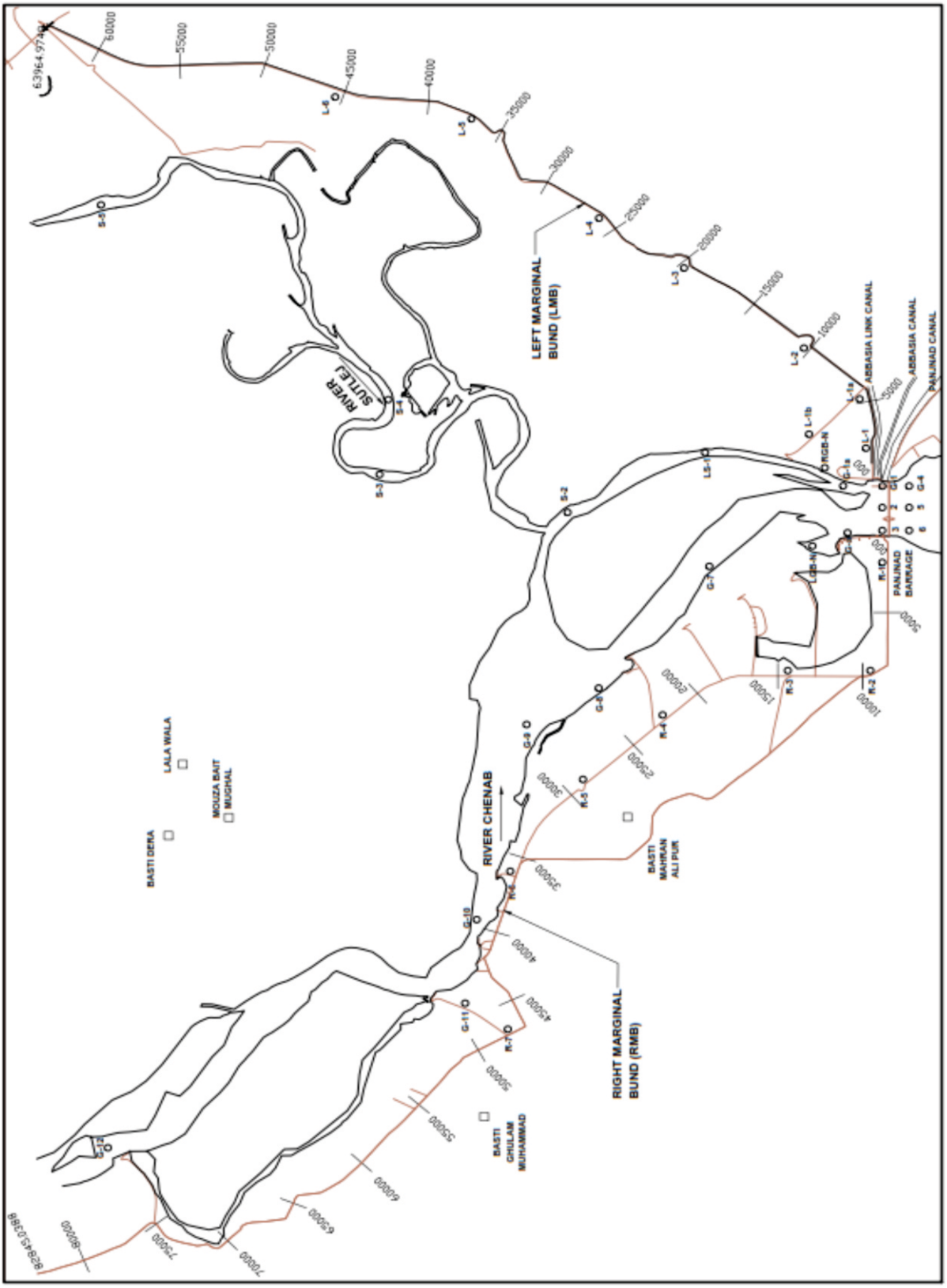


Figure 3.1: Gauge Location Layout at Comprehensive Model of Panjnad Barrage

Table 3.2: Flood Water Levels U/S & D/S of Panjnad Barrage (Comprehensive Physical Model Study)

DISCHARGE (Cusec)	Barrage U/s			Barrage U/s			Chenab Channel U/s						Sutlej Channel U/s				
	G-1	G-2	G-3	G-4	G-5 TWL	G-6	G-7	G-8	G-9	G-10	G-11	G-12	S-1	S-2	S-3	S-4	S-5
100000	338.0	338.0	338.0	333.4	333.4	333.4	338.3	339.4	339.6	339.7	340.8	344.0	339.0	339.3	339.5	343.3	345.7
200000	338.0	338.0	338.0	335.9	335.9	335.9	339.5	341.5	341.9	342.1	343.2	346.2	339.5	341.3	343.0	344.0	346.0
363336	339.0	339.0	339.0	338.5	338.5	338.5	341.5	345.0	345.3	345.5	346.0	348.5	341.9	344.5	345.5	346.1	347.1
500000	340.0	340.0	340.0	339.2	339.2	339.2	343.8	346.5	346.8	347.0	347.8	349.8	341.0	346.4	347.1	347.1	349.2
700000	342.0	342.0	342.0	340.5	340.5	340.5	346.4	348.5	349.0	349.3	350.0	351.5	346.4	348.2	348.6	348.8	349.8
800000	343.0	343.0	343.0	341.4	341.4	341.4	347.5	349.5	350.0	350.2	351.0	352.5	348.1	349.4	349.7	349.8	350.3
865000	344.5	344.5	343.8	342.0	342.0	342.0	348.7	350.3	351.0	351.2	351.6	352.8	348.7	350.3	351.0	351.1	352.0

DISCHARGE (Cusec)	LMB							RMB							Along GB		G-1-b
	RD-5			RD-10	RD-15	RD-20	RD-25	RD-5	RD-10	RD-15	RD-20	RD-25	RD-35	RD-45	LGB	RGB	
	L-1	L-1-a	L-1-b	L-2	L-3	L-4	L-5	R-1	R-2	R-3	R-4	R-5	R-6	R-7			
100000	338.5	—	—	—	—	—	—	337.9	—	—	—	—	—	—	338.6	338.5	338.4
200000	339.5	339.3	—	—	—	—	—	338.4	—	—	—	—	—	—	338.8	338.2	338.5
363336	341.0	341.3	343.0	342.5	343.5	344.2	345.7	339.5	340.0	341.5	343.5	344.8	345.0	—	340.3	339.9	339.5
500000	342.0	342.2	344.5	344.6	345.5	346.2	347.0	341.6	341.7	343.5	345.5	346.5	346.7	348.5	340.8	341.2	341.0
700000	344.3	344.3	347.3	347.4	347.7	347.9	348.5	344.0	344.3	345.7	347.5	348.6	348.7	350.3	343.8	343.0	343.0
800000	345.0	344.9	348.4	348.4	349.0	349.1	349.7	344.9	345.1	346.7	348.5	349.8	350.0	351.2	344.5	343.8	343.8
865000	346.2	346.0	349.4	349.3	349.7	350.1	350.3	346.2	346.4	347.0	349.3	350.4	350.6	351.4	345.5	344.9	344.5



Figure 3.2: Flood Discharge of 865,000 Cusecs (Comprehensive Physical Model)

4.0 HEC-RAS MODEL OF PANJNAD BARRAGE

The Hydrologic Engineering Centre's River Analysis System (HEC-RAS) software allows you to perform one dimensional steady and unsteady flow hydraulics, sediment transport/mobile bed computations and water temperature modeling. To build a HEC-RAS model of Panjnad Barrage first of river cross section at an interval of 1000 ft. were added 10 miles upstream and 3 miles downstream of the barrage. Then the existing Barrage gated weir was added in HEC-RAS as an inline structure according to standard procedure mentioned in HEC-RAS Reference Manual. Along the specified length of Right Marginal Bund Levees were added to constraint the flow in the main channel as shown in **Figure 4.1**.

After that the model was tested to run for flood discharge of 363,336 Cusec and the value of Manning's Roughness Coefficient was varied until the water level at RD 35+000 of RMB achieved a value of 345.30 ft. The water levels calculated by the software upstream and downstream of the barrage yielded the same values as recorded at site for the said barrage discharge. The value of Manning's Roughness Coefficient for the river channel came out to be 0.0275 after the model was calibrated.

After that 3 No. Depressed bays were added in the model and then the upgraded model of Panjnad barrage was operated for design flood discharge of 865,000 Cusecs under Accreted Tail Water Level of 342.02 ft. The floodwater levels calculated upstream of the barrage is tabulated in **Table 4.1.** The Longitudinal Water Surface Profile for the barrage discharge of 865,000 Cusec is shown in **Figure 4.2.**

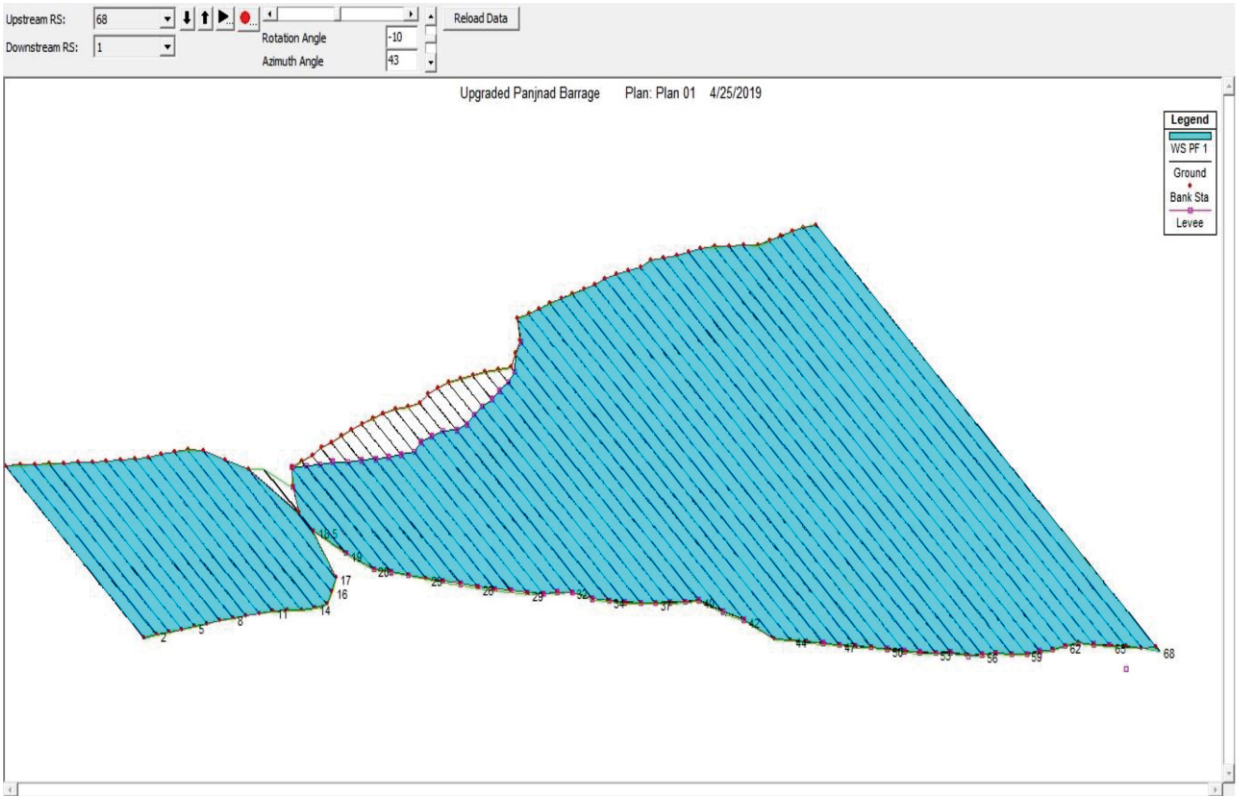


Figure 4.1: Layout Plan of Panjnad Barrage (HEC-RAS Model)

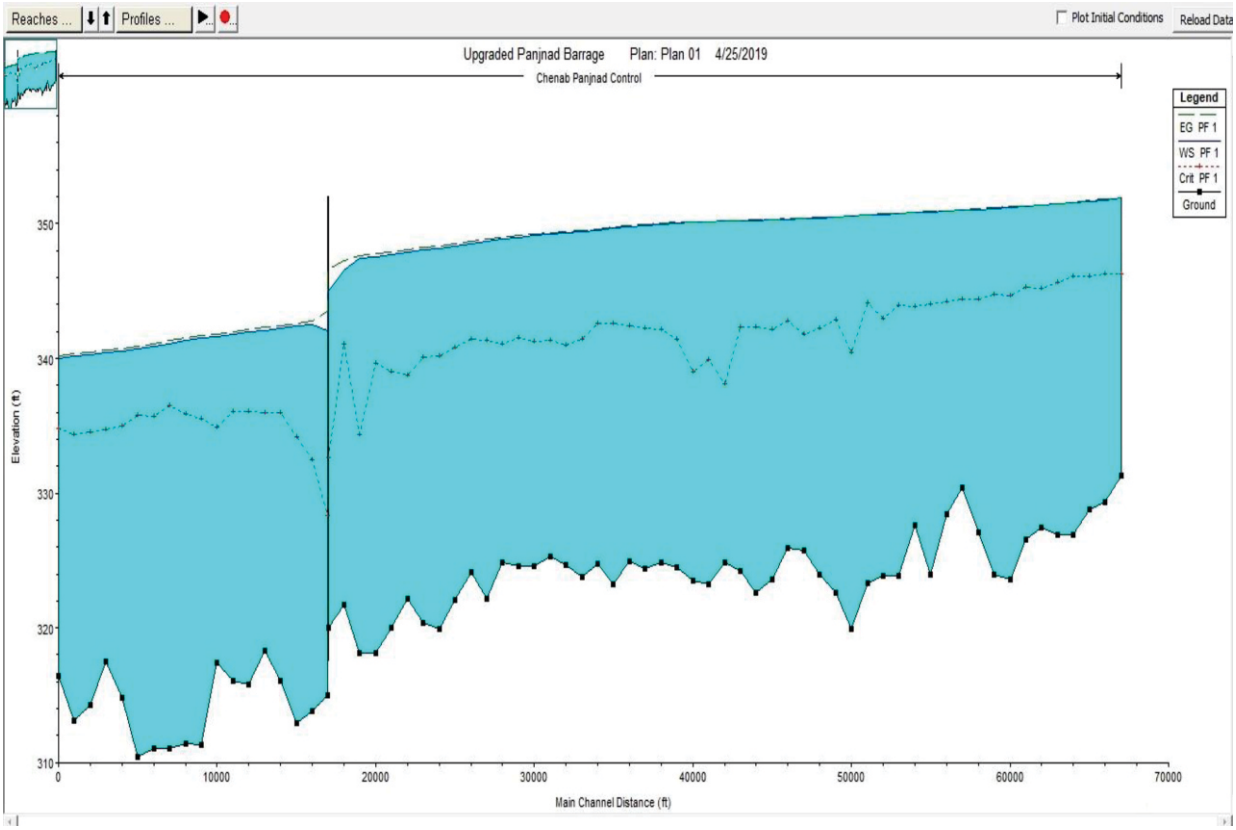


Figure 4.2: Water Surface Profile (M2 Profile) of Panjnad Barrage

Table 4.1: Hydraulic Analysis of Panjnad Barrage (HEC-RAS Model)

Discharge	US Water Level (ft)	Downstream Water Level (ft)	Water Level along LMB						
			RD 5+000	RD 10+00	RD 15+000	RD 20+000	RD 25+000	RD 35+000	RD 45+000
865,000	345.00	342.02	346.50	347.90	348.32	348.96	349.42	350.09	350.48

5.0 BREACHING SECTION

The allocated breaching section of Panjnad Barrage exists over the stretch from RD 28+000 to RD 30+000 of RMB and from RD 19+000 to RD 21+000 of Right Retired Embankment (RRE). The critical gauge is located at RD 15+000 of LMB with its existing critical value of 345.00 ft. The physical Comprehensive Model of the Upgraded Panjnad Barrage was operated for a deign flood of 865,000 Cusec at Irrigation Research Institute Nandipur. The Highest Flood Level (HFL) observed at RD 15+000 of LMB was 349.70 ft whereas the observed HFL at RD 15+000 of RMB is 347.00 ft. as mentioned in **Table 3.2**. Thus, the average HFL at a distance 8,000 ft upstream of the Barrage axis is 348.35 ft. observed at the physical comprehensive model.

As per HEC-RAS steady flow analysis of Upgraded Panjnad Barrage for design flood discharge of 865,000 Cusec, the calculated HFL at RD 15+000 of LMB is 348.32 ft. which is almost identical to the average HFL observed at the Physical Comprehensive Model (348.35 ft.). Thus, keeping in view of the results of the Physical and Numerical Hydraulic Model Study of Upgraded Panjnad Barrage, it was recommended that both above mentioned breaching sections should be operated simultaneously when Flood water Level at RD 15+000 of LMB touches the level of 348.50 ft. However, the top level of Embankments LMB and RMB should be fixed at prescribed standard Freeboard of 7ft. above HFL observed at respective RD's of LMB and RMB at the Physical Comprehensive Model of Panjnad Barrage.

6.0 SECTIONAL MODEL STUDY

Sectional Model of Main Weir and Depressed Bays were built at Irrigation Research Institute Nandipur on a Geometric Scale. The upstream discharge was measured/controlled through a Vertical Notch Weir built at a considerable distance upstream of the barrage as shown in **Figure 6.1**. The upstream approach velocity head was considered while measuring the discharge at the upstream control structure. For this purpose, upstream approach velocity at the control structure was first assumed and then net head above the crest was evaluated through back calculation using Weir Flow equation, accordingly the gauge (for measuring head above the crest at upstream of the control structure) was fixed. Once the required upstream water level was achieved, the velocity upstream of the control structure was measured with the Current Meter and it was assured that it matches with assumed value for the accurate measurement of the discharge.

The Tail Water Level downstream of the barrage was controlled through a Tail Gate built at a considerable distance downstream of the barrage. In this model study two bays of Main weir/Depressed bays were built in such a way that one full bay of 60 ft. has been kept in the center enclosed by half bay on either side separated by a pier in between, as shown in **Figure 6.2.**.The various Conversion Factors being employed for the sectional model study of Panjnad Barrage is given in **Table 6.1** as shown below.

Table 6.1: Conversion Factors for Sectional Model Study

Sr. No.	Features	Symbol	Conversion Factor	Scale Ratio
1	Length	$\mathrm{L_r}$	$\mathrm{L_r}$	1/16
2	Flow Area	$\mathrm{A_r}$	$L_r{}^2$	1/256
3	Time	$\mathrm{T_r}$	$L_r{}^{\frac{1}{2}}$	1/4
4	Flow Velocity	V_r	$L_{\mathrm{r}}{}^{\frac{1}{2}}$	1/4
5	Discharge	Q_r	$L_r{}^{\frac{5}{2}}$	1/1024

6.1 Coefficient of Discharge for Weir Flow

The sectional model of Main Weir and Depressed Bays was tested for various flood discharges ranging from100,000 Cusec to 865,000 Cusec under the three Tail Water Levels i.e. Average, Retrogressed and Accreted. Upstream and downstream gauges were installed to observe the floodwater levels. Weir Formula for the calculation of Discharge Coefficient "C_d" and Submergence formula is shown below.

$$Q = C_d B H_e{}^{1.5}$$

Where,

Q = Discharge, Cusec

B = Throat width, ft.

$\mathrm{H_e} = \text{Upstream Velocity Head} = \mathrm{H} + \dfrac{\mathrm{V}^2}{2\mathrm{g}}$

H = Upstream Head above the crest, ft.

V = Upstream flow Velocity, ft/sec.

g = Acceleration due to gravity = 32.20 $\frac{\mathrm{ft}^2}{\mathrm{sec}}$.

Submergence, $\mathrm{S} = \dfrac{\mathrm{H_d}}{\mathrm{H_e}}$

$\mathrm{H_d} = \text{Downstream Head above the crest, ft.}$

The Hydraulic Results pertaining to the Evaluation of Coefficient of Discharge for Flood Discharge ranging from 100,000 Cusec to 865,000 Cusec under the Average, Retrogressed and Accreted tail Water levels is shown in **Table 6.2 to 6.5.**



Figure 6.1: Upstream Rectangular Notch Weir for discharge measurement



Figure 6.2: Longitudinal Profile of Main Weir along with the Tail gate at the downstream end.



Figure 6.3: Hydraulic Test Pertaining to Design Flood Discharge of 865,000 Cusec

Table 6.2: Cd Versus Submergence Main Weir (Part-1)

Crest Level = 325.00 ft. US Floor Level = 320.50 ft. DS Floor Level = 316.50 ft.

Sr. No.	Q_p (Cusec)	q_p (Cusec/ ft)	US Water Level (ft)	DS Water Level (ft)	Approaching Intensity, q_a (Cusec/ft)	Approach Velocity, V_a (ft/sec)	Approach Velocity Head, H_v (ft)	US Head Above the Crest, H (ft)	DS Head Above the Crest H_d (ft)	Energy Head above the Crest, (ft) $H_e = H + H_d$	Submerg-ence, $S = \frac{H_d}{H_e}$	$C_d = \frac{q_p}{H_e^{1.5}}$
1	100,000	33.02	333.55	333.40	29.57	2.27	0.080	8.55	8.40	8.63	0.97	1.30
2		33.02	331.20	331.00	29.57	2.76	0.119	6.20	6.00	6.32	0.95	2.08
3		33.02	335.70	335.60	29.57	1.95	0.059	10.70	10.60	10.76	0.99	0.94
4	200,000	66.18	336.10	335.90	59.27	3.80	0.224	11.10	10.90	11.32	0.96	1.74
5		66.18	334.50	334.10	59.27	4.23	0.278	9.50	9.10	9.78	0.93	2.16
6		66.18	337.85	337.70	59.27	3.42	0.181	12.85	12.70	13.03	0.97	1.41
7	300,000	98.52	337.65	337.40	88.22	5.14	0.411	12.65	12.40	13.06	0.95	2.09
8		98.52	336.40	335.90	88.22	5.55	0.478	11.40	10.90	11.88	0.92	2.41
9		98.52	339.20	339.00	88.22	4.72	0.346	14.20	14.00	14.55	0.96	1.78
10	400,000	131.68	338.80	338.40	117.93	6.44	0.645	13.80	13.40	14.44	0.93	2.40
11		131.68	337.70	337.20	117.93	6.86	0.730	12.70	12.20	13.43	0.91	2.68
12		131.68	340.00	339.70	117.93	6.05	0.568	15.00	14.70	15.57	0.94	2.14

Table 6.3: Cd Versus Submergence Main Weir (Part-2)

Crest Level = 325.00 ft. US Floor Level = 320.50 ft. DS Floor Level = 316.50 ft.

Sr. No.	Q_p (Cusec)	q_p (Cusec/ ft)	US Water Level (ft)	DS Water Level (ft)	Approaching Intensity, q_a (Cusec/ft)	Approach Velocity, V_a (ft/sec)	Approach Velocity Head, H_v (ft)	US Head Above the Crest, H (ft)	DS Head Above the Crest H_d (ft)	Energy Head above the Crest, (ft) $H_e = H + H_d$	Submerg-ence, $S = \frac{H_d}{H_e}$	$C_d = \frac{q_p}{H_e^{1.5}}$
1	500,000	164.55	339.60	339.20	147.36	7.72	0.924	14.60	14.20	15.52	0.91	2.69
2		164.55	339.00	338.40	147.36	7.97	0.985	14.00	13.40	14.99	0.89	2.84
3		164.55	340.70	340.40	147.36	7.29	0.826	15.70	15.40	16.53	0.93	2.45
4	600,000	197.65	340.10	339.90	177.00	9.03	1.266	15.10	14.90	16.37	0.91	2.99
5		197.65	339.60	339.00	177.00	9.27	1.334	14.60	14.00	15.93	0.88	3.11
6		197.65	341.20	341.00	177.00	8.55	1.135	16.20	16.00	17.34	0.92	2.74
7	700,000	230.67	340.95	340.40	206.57	10.10	1.584	15.95	15.40	17.53	0.88	3.14
8		230.67	340.80	339.80	206.57	10.18	1.608	15.80	14.80	17.41	0.85	3.18
9		230.67	341.90	341.40	206.57	9.65	1.447	16.90	16.40	18.35	0.89	2.94
10	800,000	263.78	342.00	340.90	236.22	10.99	1.874	17.00	15.90	18.87	0.84	3.22
11		263.78	341.90	340.40	236.22	11.04	1.892	16.90	15.40	18.79	0.82	3.24
12		263.78	342.30	341.80	236.22	10.84	1.823	17.30	16.80	19.12	0.88	3.15
13	865,000	285.28	342.70	341.20	255.48	11.51	2.056	17.70	16.20	19.76	0.82	3.25
14		285.28	342.75	340.50	255.48	11.48	2.047	17.75	15.50	19.80	0.78	3.24
15		285.28	343.00	342.00	255.48	11.35	2.002	18.00	17.00	20.00	0.85	3.19

Table 6.4: Cd Versus Submergence Depressed Bays (Part-1)

Sr. No.	Q_p (Cusec)	q_p (Cusec/ ft)	US Water Level (ft)	DS Water Level (ft)	Approaching Intensity, q_a (Cusec/ft)	Approach Velocity, V_a (ft/sec)	Approach Velocity Head, H_v (ft)	US Head Above the Crest, H (ft)	DS Head Above the Crest H_d (ft)	Energy Head above the Crest, (ft) $H_e = H + H_d$	Submerg-ence, $S = \frac{H_d}{H_e}$	$C_d = \frac{q_p}{H_e^{1.5}}$
1	100,000	38.27	333.20	333.40	34.27	2.70	0.113	11.20	11.40	11.31	1.01	1.01
2		38.27	331.00	331.00	34.27	3.26	0.165	9.00	9.00	9.17	0.98	1.38
3		38.27	335.50	335.70	34.27	2.28	0.081	13.50	13.70	13.58	1.01	0.76
4	200,000	74.28	335.65	335.90	66.52	4.39	0.299	13.65	13.90	13.95	1.00	1.43
5		74.28	334.00	334.10	66.52	4.93	0.377	12.00	12.10	12.38	0.98	1.71
6		74.28	337.50	337.75	66.52	3.91	0.238	15.50	15.75	15.74	1.00	1.19
7	300,000	123.15	337.20	337.40	110.28	6.60	0.677	15.20	15.40	15.88	0.97	1.95
8		123.15	335.70	335.90	110.28	7.26	0.817	13.70	13.90	14.52	0.96	2.23
9		123.15	338.70	338.95	110.28	6.06	0.570	16.70	16.95	17.27	0.98	1.72
10	400,000	159.08	338.00	338.40	142.46	8.14	1.029	16.00	16.40	17.03	0.96	2.26
11		159.08	336.80	337.20	142.46	8.74	1.186	14.80	15.20	15.99	0.95	2.49
12		159.08	339.40	339.80	142.46	7.54	0.882	17.40	17.80	18.28	0.97	2.04

Crest Level = 322.00 ft. US Floor Level = 320.50 ft. DS Floor Level = 311.00 ft.

Table 6.5: Cd Versus Submergence Depressed Bays (Part-2)

Sr. No.	Q_p (Cusec)	q_p (Cusec/ ft)	US Water Level (ft)	DS Water Level (ft)	Approaching Intensity, q_a (Cusec/ft)	Approach Velocity, V_a (ft/sec)	Approach Velocity Head, H_v (ft)	US Head Above the Crest, H (ft)	DS Head Above the Crest H_d (ft)	Energy Head above the Crest, (ft) $H_e = H + H_d$	Submerg-ence, $S = \frac{H_d}{H_e}$	$C_d = \frac{q_p}{H_e^{1.5}}$
1	500,000	199.80	338.70	339.20	178.93	9.83	1.501	16.70	17.20	18.20	0.95	2.57
2		199.80	337.80	338.20	178.93	10.34	1.661	15.80	16.20	17.46	0.93	2.74
3		199.80	339.90	340.40	178.93	9.22	1.321	17.90	18.40	19.22	0.96	2.37
4	600,000	236.73	339.45	339.90	212.00	11.19	1.943	17.45	17.90	19.39	0.92	2.77
5		236.73	338.50	339.00	212.00	11.78	2.154	16.50	17.00	18.65	0.91	2.94
6		236.73	340.65	341.00	212.00	10.52	1.719	18.65	19.00	20.37	0.93	2.58
7	700,000	275.17	339.90	340.30	246.42	12.70	2.505	17.90	18.30	20.41	0.90	2.99
8		275.17	339.50	339.75	246.42	12.97	2.612	17.50	17.75	20.11	0.88	3.05
9		275.17	341.10	341.50	246.42	11.96	2.222	19.10	19.50	21.32	0.91	2.79
10	800,000	311.95	340.50	341.00	279.36	13.97	3.030	18.50	19.00	21.53	0.88	3.12
11		311.95	340.20	340.50	279.36	14.18	3.123	18.20	18.50	21.32	0.87	3.17
12		311.95	341.20	341.80	279.36	13.50	2.828	19.20	19.80	22.03	0.90	3.02
13	865,000	336.15	340.80	341.20	301.03	14.83	3.415	18.80	19.20	22.21	0.86	3.21
14		336.15	340.70	340.80	301.03	14.90	3.449	18.70	18.80	22.15	0.85	3.22
15		336.15	341.40	342.00	301.03	14.40	3.221	19.40	20.00	22.62	0.88	3.12

Crest Level = 322.00 ft. US Floor Level = 320.50 ft. DS Floor Level = 311.00 ft.

The number of tests carried out for the determination of coefficient of discharge under various Discharges and Tail Water Levels for Main weir and Depressed Bays were 62. The Coefficient Discharge so obtained along with the values of submergence were plotted on simple graph paper, taking coefficient of discharge on y-axis and Submergence on x-axis. Then the best fit line for the scattered data was evaluated as shown in Figure 6.4, therefore Cd Versus Submergence curve for Panjnad Barrage was evaluated. From the curve it is evident that submergence effect on Panjnad weir starts taking place at submergence 0.80, below which there is no submergence effect. The Cd versus Submergence obtained from the best fit line has been tabulated in Table 6.6.

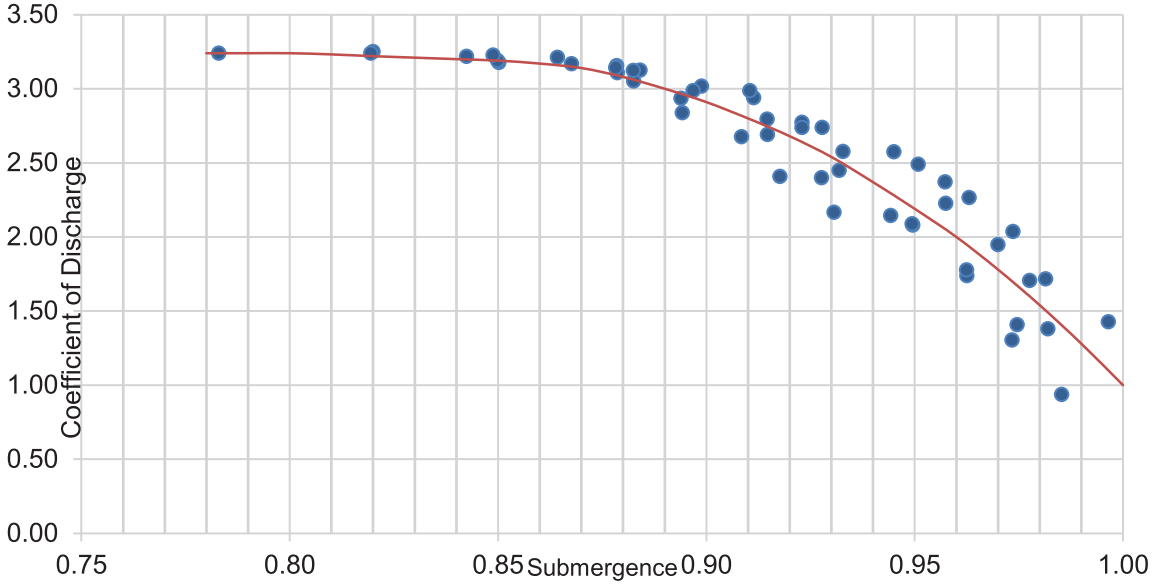


Figure 6.4: Cd Versus Submergence (Graphical Form)

Table 6.6: Cd Versus Submergence (Tabular Form)

Sr. No.	Sub-mergence	Cd	Sr. No.	Sub-mergence	Cd	Sr. No.	Sub-mergence	Cd
1	1.00	1.00	9	0.92	2.68	17	0.84	3.20
2	0.99	1.28	10	0.91	2.80	18	0.83	3.21
3	0.98	1.54	11	0.90	2.91	19	0.82	3.22
4	0.97	1.78	12	0.89	3.00	20	0.81	3.23
5	0.96	2	13	0.88	3.08	21	0.80	3.24
6	0.95	2.19	14	0.87	3.14	22	0.79	3.24
7	0.94	2.37	15	0.86	3.17	23	0.78	3.24
8	0.93	2.54	16	0.85	3.19	-		

7.0 SURFACE ANALYSIS OF PANJNAD BARRAGE

Hydraulic Analysis has been performed through Uniform Total Energy Level (TEL) Concept. The underlying concept for the precedent is that at any instant only one value of TEL prevails for all bays of the barrage. With reference to this energy level, total energy head over the crest has been computed for each bay, which pushes the discharge through the bay according to its hydraulic condition.

7.1 Safe Capacity of Existing Barrage

Initially the analysis was carried out for existing barrage to assess for a safe discharge capacity during a flood event of 100-year return period (865,000 Cusecs) under Average and Retrogressed Tail Water levels, and the hydraulic results are tabulated in **Table 7.1.** The basis to assess the safe discharge capacity of existing barrage are as follows:

- Using average and retrogressed Tail Water Levels corresponding to 865,000 Cusecs (developed using data set of 1991-2015).
- The Highest Flood Level (HFL) at left abutment should not exceed El. 341.50 ft.
- Satisfactoriness of hydraulic jump at 20% flow concentration (q' = 1.2q).
- Assuring formation of hydraulic jump on the downstream toe or on the glacis.
- Assuring the length of hydraulic jump remains within stilling basin.

Table 7.1: Safe Capacity of Existing Barrage

Sr. No.	Condition	Cd	US HFL	DS TWL	Safe Capacity of the Barrage (Cusec)			
					Left Pocket	Main Weir	Annexe Weir	Total
1	Average TWL	Sectional Model Study	341.50	341.20	58507	424175	204774	687455
2	Retrogressed TWL	Sectional Model Study	341.50	340.65	59083	428352	206791	694226

The resulting safe capacity worked out with new Tailwater levels are 687,455 Cusec and 694,226 Cusec for average and retrogressed Tailwater conditions respectively, while using the discharge coefficient obtained from Sectional Model Study.

7.2 Discharging Capacity of the Upgraded Barrage

The capacity of the existing barrage is under capacity to pass design flood of 865,000 Cusec. Thus, additional structural interventions are required to pass the discharge in excess of the barrage capacity to cater for the 100-year flood. The recommended flood by-pass arrangement is to add 3 No. Depressed Bays in place of Junction Groyne and increase in Flux by 1.36 ft.

The Capacity of Upgraded Barrage has been evaluated under Average, Retrogressed and Accreted Tail Water Levels using Coefficient of Discharge value from sectional Model Study and Hydraulic Results are Tabulated in **Table 7.2**.

Table 7.2: Surface Flow Analysis of Upgraded Barrage

Sr. No.	Condition	Cd	US HFL	DS TWL	Safe Capacity of the Barrage (Cusec)				
					Left Pocket	Main Weir	Depres-sed Bays	Annexe Weir	Total
1	Average TWL	Sectional Model Study	342.86	341.20	68261	494903	62917	238918	865000
2	Retrogre-ssed TWL	Sectional Model Study	342.82	340.65	68254	494850	63004	238892	865000
3	Accreted TWL	Sectional Model Study	342.95	342.02	68260	494910	62910	238920	865000

8.0 CONCLUSIONS

1. The upgraded Panjnad Barrage is capable to pass out 100-year Return period flood of 865,000 Cusec as Tested by Physical Comprehensive Model Study.
2. The revised Upstream Flood Water level at Critical gauge for the operation of breaching section is proposed at Elevation 348.50 ft keeping in view of the Physical and Numerical Hydraulic studies of Panjnad Barrage.
3. The Top Level of Left and Right Guide banks and Marginal Bunds are fixed keeping in view of maintaining 7 ft. Freeboard above the HFL recorded along the respective banks in Physical Comprehensive Model Study of Panjnad Barrage.
4. The increase in Afflux with regard to the original HFL of 341.50 ft as obtained through sectional Model Study is 1.36 ft. and 1.45 ft. under the Average and Accreted Tail Water Level.

Paper No. 801

REVIEW ON AEROBIC WASTEWATER TREATMENT AND ROLE OF BIOTECHNOLOGY

N. Maqbool, Sher jamal Khan

REVIEW ON AEROBIC WASTEWATER TREATMENT AND ROLE OF BIOTECHNOLOGY

By:

N. Maqbool[1] and Sher Jamal Khan[2]

Abstract:

Wastewater coming out of domestic, commercial and industrial sources has organic content, nutrients and metals in it. Its safe disposal into environment needs proper treatment. This treatment can be achieved by physical, chemical and biological processes or combination of them. Biological process is the natural process having provision of treatment of wastewater with minimum energy and chemical input requirements. However, selection of appropriate wastewater treatment technology varies from community to community and industry to industry. Environmental biotechnology helps in identification, selection, and extension of the services provided by these microbes. In this paper, initially conventional biological wastewater treatment processes are discussed. Advanced processes to overcome the cons of the older technologies are identified based on biotechnological support. Finally, discussion on role and importance of biotechnology is emphasized.

Introduction:

Wastewater discharged out of our home consists of 99% water and just 1% solids. This water, when discharged untreated releases multiple harmful compounds in the receiving water bodies. Thus making it a direct concern from an environmental point of view especially for the aquatic environment. Due to certain issues in wastewater collection system e.g. loose sewer pipes joint, the amount of wastewater that is collected at the end is often greater than what is consumed initially. Per capita water consumption and generation also varies from nation to nation and is highly dependent upon lifestyle and access to the water. A typical composition of municipal wastewater is as below (Cheremisinoff 1997):

Biological Oxygen Demand 54g/cap/day, Total Solids 600 mg/L

Total Suspended Solids 200 mg/L, Total Settable Solids 120 mg/L

Total Colloidal Solids 80 mg/L

There are two objectives of treating wastewater. The first one is the sanitation of the communities and secondly the safe disposal of the collected wastewater to the water bodies. The discharged water must comply with the available limits of set rules and regulations related to the environment. (Salgot and Folch 2018)

Currently, a lot of wastewater treatment technologies are available from conventional to advanced ones. These include physical, chemical, biological and combinations of technologies. All of them have some trade-off from capital, operation and maintenance point of view. The selection of technique for wastewater treatment depends upon plenty of factors. They include wastewater characteristics, quantity of wastewater to be treated, legislation and their regulation, expertise available in technology, economy, acceptance in society, location of the plant, quality

[1] Corresponding Author nidamaqbool@iese.nust.edu.pk +92-5190854361

[2] Institute of Environmental Sciences and Technology (IESE), School of Civil and Environmental Engineering (SCEE), National University of Sciences and Technology (NUST), H-12, Islamabad, Pakistan

of output, utilization at the end of process, available land size and by products (Metcalf, Eddy et al. 2003).

The decomposition of organic and inorganic matter has been occurring for million of years. The management of waste using biological means is not new. Almost all of the microbes are extracted from the soil or water. However their specific applications, with the aid of biotechnological advances are looked into in detail to use them as a potential source. No natural waste treatment is possible without these tiny natural worker (microbes). These microbes, however, require certain set of conditions to live and work. These conditions include pH, nutrient requirement, optimum temperature and terminal electron acceptor (O_2 in case of aerobic microbes, other in case of anaerobes).

Biotechnology serves as a tool to diagnose and get the help of potential living organisms for providing services to humanity. Mankind has been using this technology for thousands of years in agriculture and medicine.

This review covers the traditional and advanced biological treatment systems for wastewater treatment and how biotechnology aids in identifying potential workers (Microbes) for suitable processes. Main emphasis is delivered on advanced biotechnological approaches to find an optimal solution. In the end, future directions are also discussed to look into.

Conventional Biotechnological Approaches for Wastewater Treatment:

Wastewater treatment using biological means has been an attractive option because it's a natural process and economically feasible. This method has been used by nature since evaluation of bacterial and human population. It not only helps in oxidation of organic matter but also needed almost no chemical and energy input. A brief review of the most commonly used traditional technologies is given below:

Conventional Activated Sludge Process (CASP):

Wastewater containing organic matter is introduced into the reactor. Bacteria are held in suspension within the reactor using diffused or mechanical aerators. Bacteria consume the organic matter and start to form flocs. These flocs settle down in the next settling chamber. After settling of the flocs, clear water is extracted from upside and some proportion of the settled sludge is taken back in the reactor (containing bacteria) (Metcalf, Eddy et al. 2003). The process flow is shown in figure 01.

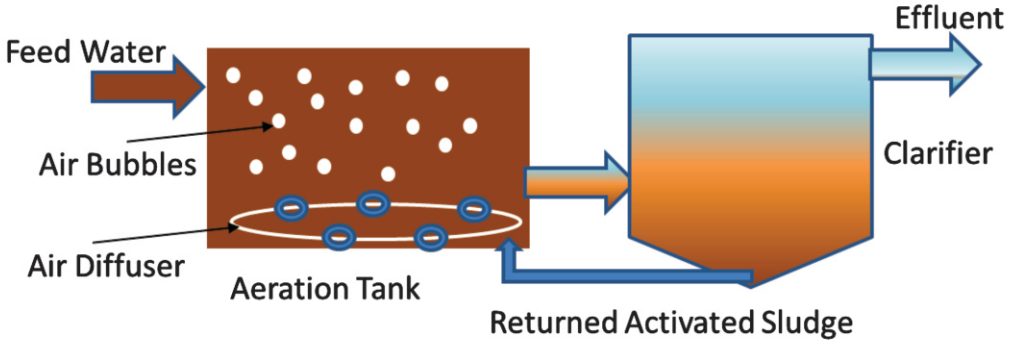


Figure 01: Conventional activated sludge process

Bacteria consume the organic matter by oxidation and hydrolysis. The reactions are as below:

$$CHONS(Organic\ Matter)+O_2(Electorn\ Acceptor)+Bacterial\ Cells \longrightarrow CO_2+H_2O+Inorganic\ Nutrients+New\ Biomass$$

The activated sludge process was discovered in 1913 in UK. Many modifications are introduced in the process but the basics remains the same. (Cheremisinoff 1997) These include:

1. Aerating activated sludge while returning to the reactor for complete decomposition of organic matter – contact stabilization
2. Introducing air at multiple points along the process – step aeration
3. Long aeration periods for maximum organic matter decomposition and minimum sludge production – Extended aeration
4. Providing pure oxygen instead of an air for complete decomposition of incoming organic content
5. Addition of Powdered activated carbon to extend removal efficiency of the process.

Mixed Liquor Suspended Solids (MLSS) are low in activated sludge (upto 3000 mg/L). The low value indicates that the Hydraulic Retention Time (HRT) is high (upto 14 hours) for activated sludge. The range of food to micro-organisms ratio is 0.2 – 0.5. Activated sludge process has removal ranges of Biological Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) up-to 95%, 60% for Total Suspended solids (TSS), 88% phosphorus and < 13% nitrogen (Kraume, Bracklow et al. 2005).

The floc formation is the critical step in the activated sludge process. Poor settlabaility of the sludge is a frequent issue with activated sludge process. Thus Conventional Activated Sludge Process (CASP) required large surface area for wastewater treatment. The sludge settling is measured by sludge volume index (SVI). It includes careful investigation of organic loading rate, sludge retention time, hydraulic loading rate, food to microorganism ratio, aeration frequency and designing of settling tank. (Adav, Lee et al. 2008, Hamza, Iorhemen et al. 2016).

Waste Stabilization Ponds:

Ponds are man made basins that provide aerobic, anoxic and anaerobic treatment to the wastewater in different basins. The variation in depth and contact with atmosphere results in varying treatments (Mara 1997). Depth plays a major role in developing the conditions for aerobic/anaerobic conditions. The depth of ponds for aerobic is usually < 1.5m while for anaerobic depth is upto 5m (Tilley 2008). The dimensions of ponds are shown in figure 02.

The removal of BOD is done by combined activities of microorganisms present in the ponds. BOD of effluent is lower than influent as biomass and algae consumes the available organic matter as food sources. New cell mass is being produced by the nutrients. Heterotrophic and autotrophic, both types of life exists in these ponds. Autotrophs provide oxygen to the heterotrophic microbes, hence a symbiotic relationship helps in depleting organic matter. However, their treatment efficiency is low as compared to other available techniques (< 60% BOD removal in 2.5 days retention time) (Ramadan and Ponce 2003).

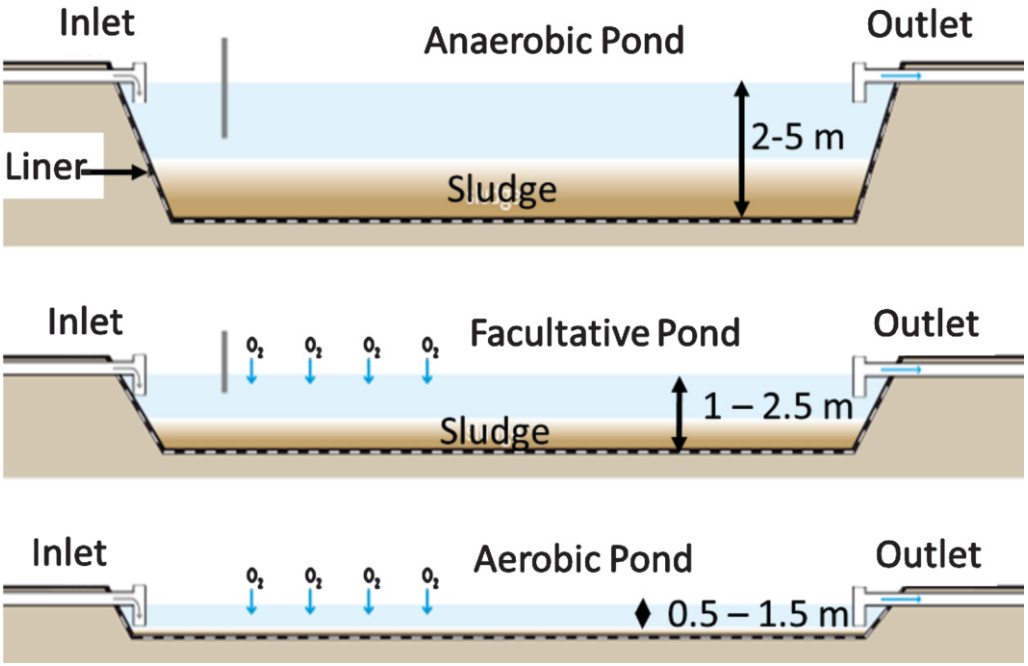


Figure 02: Schematic Representation of Ponds (Tilley 2008)

There are many infrastructures that are compared with these ponds including aerated lagoons, constructed wetlands, retention, infiltration and settling basins. Modifications in the traditional pond treatment include coupling of various other techniques termed as enhanced pond treatment. The solids are settled under gravity and are treated anaerobically. The nutrients available are then up-taken by algae which is then harvested. These include anaerobic ponds with covers, algae production and harvesting ponds and finally filtration using rock media. (Sutherland, Heubeck et al. 2018)

Trickling Filters:

In trickling filters, water trickle down from air into the immobilized filter media. The media has microbes present on it, which help in decomposition of the organic waste coming in the water. The schematic presentation of trickling filters is shown in figure 03. To maintain the aerobic condition within the filter, air is diffused naturally or forcefully with the help of aerators (Hamza, Iorhemen et al. 2016). Filter may consist of different media including natural and synthetic materials. The pollutants are removed by absorption and adsorption by the biofilm. The biofilm is usually thick with bacteria, protozoa, worms and annelids on them. Hence this biofilm is different from other biofilm based processes. Biofilm has aerobic and anaerobic zone thus providing oxidative and reductive reactions (Witt 1982). The hydraulic loading rate in trickling filter is much less as compared to previously mentioned techniques. However their efficiency is also low. These filters are usually combined with activated sludge process to accommodate variations in the system (Metcalf, Eddy et al. 2003).

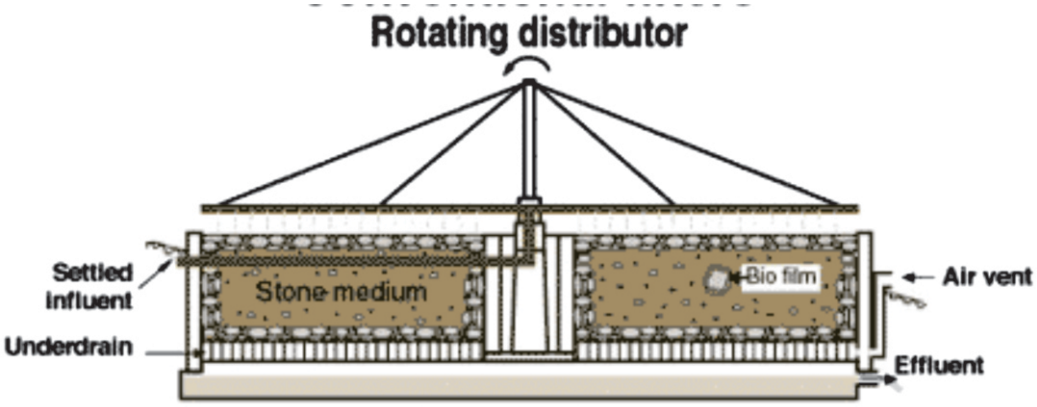


Figure 03: Trickling filters

Advanced Biological Systems

Membrane Bioreactors:

Membranes are semipermeable layers that allow only specific material to pass through. When combined with activated sludge, it allows only water to pass through while retaining microbes and solids. This combination is termed as Membrane Bioreactor (MBR). The use of membranes quicken the separation with application of pressure on the feed side avoiding the wait for flocs to be formed and settled. The schematic presentation is shown in figure 04.

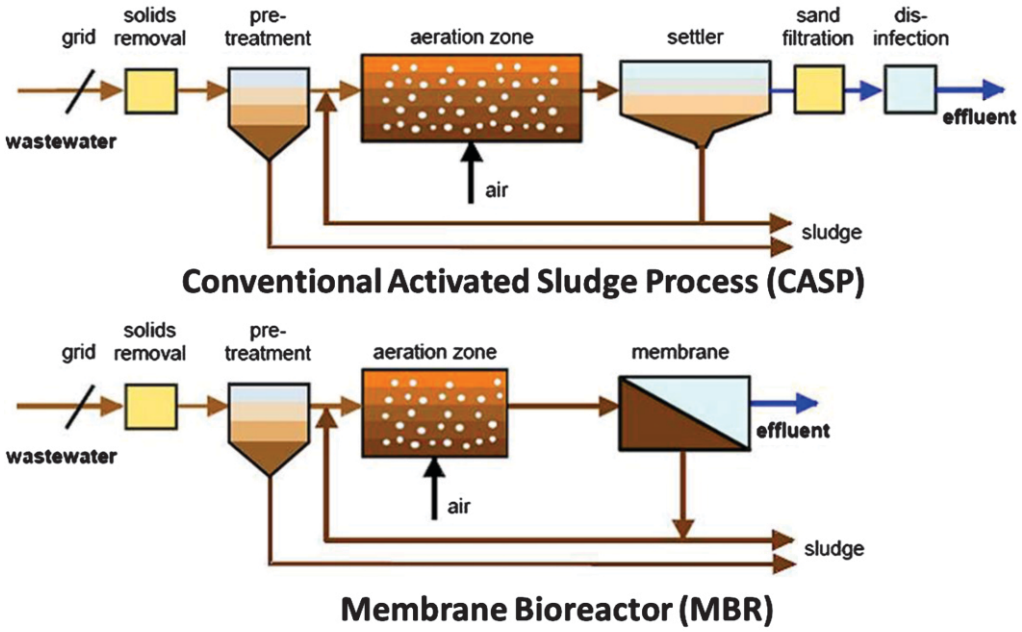


Figure 04: CASP vs MBR

The nutrients removal efficiency of MBRs is exceptional. MBRs have high Sludge Retention Time (SRT) (> 30days) which results in high presence of the biomass and hence, high percentage removal, while reducing the wastage of sludge. They have > 99% removal for BOD, COD, TSS, nitrogen and phosphorus (Kraume, Bracklow et al. 2005). They offer complete removal of the pollutants for any kind of waste water with combined COD, BOD, Total Suspended Solids (TSS) and nutrients removal in a single reactor.

MBR were initially used in 1970s in North America and 1980s in Japan. Gaining popularity from there, MBR are becoming a choice of operation because of less space requirements, much lesser hydraulic retention time needed and more control over the process. The footprint is also very low as compared to other available technologies. (Stephenson, Brindle et al. 2000). Table 1 shows the world's largest MBR installed country wise.

Table 01: Data of world's largest MBR Plants (The MBR Site)

Location	Technology Provider	date of commissioning	Peak Daily Flow (MLD)	Average Daily Flow (MLD)
USA	GE Water & Process Technologies	2018	250	83
Belgium	GE Water & Process Technologies	2017	190	86
China	Origin Water (Beijing)	2017	150	
China	Origin Water (Beijing)	2017	100	
France	GE Water & Process Technologies	2016	357	224
China	GE Water & Process Technologies	2016	234	180
China	Origin Water (Beijing)	2016	200	
China	Origin Water (Beijing)	2016	200	
China	Origin Water (Beijing)	2016	140	
Italy	GE Water & Process Technologies	2016	125	55
China	Origin Water (Beijing)	2016	120	
China	Origin Water (Beijing)	2016	100	
USA	Ovivo USA/Kubota	2015	333	159
China	Origin Water (Beijing)	2015	200	
China	Origin Water (Beijing)	2015	200	
France	Koch Membrane Systems	2015	144	42
China	Origin Water (Beijing)	2015	120	
USA	GE Water & Process Technologies	2015	116	58
USA	GE Water & Process Technologies	2014	186	124
USA	GE Water & Process Technologies	2014	171	85
China	Origin Water (Beijing)	2014	150	
China	Origin Water (Beijing)	2014	150	
China	Origin Water (Beijing)	2014	140	
China	Origin Water (Beijing)	2014	105	
China	Origin Water (Beijing)	2014	100	
China	Origin Water (Beijing)	2013	250	
USA	GE Water & Process Technologies	2013	135	58
France	GE Water & Process Technologies	2013	108	60
China	Origin Water (Beijing)	2012	120	

Korea	GE Water & Process Technologies	2012	102	102
USA	GE Water & Process Technologies	2011	175	122
China	Origin Water (Beijing)	2011	150	
China	Origin Water (Beijing)	2011	150	150
USA	GE Water & Process Technologies	2011	136	97
USA	GE Water & Process Technologies	2011	114	71
China	Mitsubishi Rayon Corporation	2010	100	
China	Memstar	2010	100	
China	Mitsubishi Rayon Corporation	2009	110	110
China	Origin Water (Beijing)	2007	100	100
South Korea	Hyundai	Jun-05	122	122

Although their exceptional efficiency makes them very feasible for use in wastewater treatment, however, they have some areas to work on. The most common issue is fouling of the membranes resulting in reduced life of membranes. Thus, they need replacement which is huge investment in capital cost. Membrane need proper physical and chemical cleaning as a process requirement. Moreover, they require aeration with the help of diffused or surface aerators and pumps either to pressurize or suck water out of the membranes (Judd 2008).

Fouling in membrane bio-reactors is done by the soluble microbial products (SMPs) and Extracellular Polymeric Substances (EPS) released by microorganisms. These material along with organic matter settles on the surface of membranes resulting lower permeate flux. The major operational bottleneck in MBR is fouling. It is mandatory to apply certain cleaning techniques to remove these fouling films. This includes (Singh and Hankins 2016):

1. Backwashing / back flushing (after 8-14 minutes)
2. Maintenance cleaning (every week)
3. Recovery cleaning (Twice in a year)

This fouling is inevitable. However, with new biotechnological options, more insight into the reasons of forming and control over the fouling is possible.

Quorum Quenching Membrane Bioreactors:

Biofouling is the unwanted outcome of using membrane in a bioreactor. 60% of the research done in membrane bioreactors is basically on the fouling and its mitigations. The fouled layer is usually removed with the help of physical and chemical cleaning agents. Membrane surface modifications are also in practice. Moreover, coagulants, chemical agents and optimization of conditions. However, full control over biofouling was not found yet. In 2009 a positive correlation between quorum sensing and biofouling was observed (Yeon, Cheong et al. 2008).

Biofouling can be controlled by control over intercellular communication (also known as Quorum Sensing (QS)) among bacteria. The communication is in the form of sending and receiving signals from other bacteria. This communication can be inter species and trans-species. For each type of communication the autoinducers (signals) are different (Singh and Hankins 2016). Bacteria exhibit different behaviors under the effect of this communication. These include virulence, antibiotic production, bio luminance, spores formulation and biofilm development (Oh and Lee 2018). These signals when interrupted cannot result in these behaviors. The control is termed as quorum quenching (QQ) (Ham, Kim et al. 2018). An isolated strain of Rhodococcus

sp. found a significant reduction in the development of communities responsible for QS mechanism (Kim, Oh et al. 2013). A lot of studies are available for the isolated bacterial strains producing QS and QQ (Gül and Koyuncu 2017, Oh and Lee 2018). The graph in figure xyz shows the effect on transmembrane pressure of signaling molecules (AHLs). The transmembrane pressure increases rapidly due to biofilm development (Oh and Lee 2018). QQ immobilized beaded bioreactors show 90% reduction in Soluble Microbile Products (SMPs) production and 700% more filtration period due to less fouled membranes (Maqbool, Khan et al. 2015).

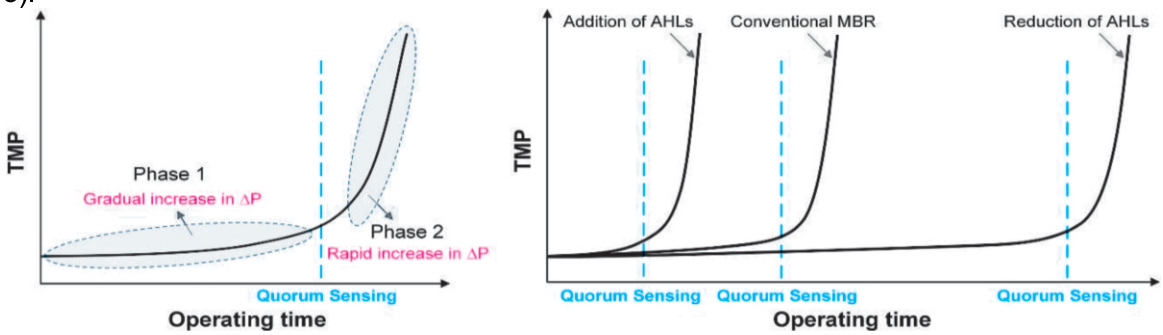


Figure 5: Effect of quorum sensing and increase in pressure requirement.

Aerobic Granular Sludge and Membrane Bioreactors:

Aerobic granules are innovative type of sludge that can self-immobilize flocs and microorganisms into compact round shaped particles. This microbial community can remove organic carbon, nitrogen, phosphorus and other pollutants in a single reactor. The salient features of these granules is as discussed. These granules have large sizes resulting in rapid settling in case of non-mixing conditions. They have high specific gravity (1.017), high settling velocity (>10m/hr), and high SVI. They have distinct layers of aerobic, anaerobic and anoxic environments which allow all redox reactions to take place within the flocs. Aerobic granules can bear toxic contaminants and can perform with shocking loads too (Nancharaiah and Reddy 2017, Winkler, Meunier et al. 2017, Xia, Ye et al. 2018). Aerobic granules have also shoed greater potential toward removal of heavy metals from wastewater (Wei, Ngo et al. 2018). The pictorial representation of the aerobic granule is shown in figure 06.

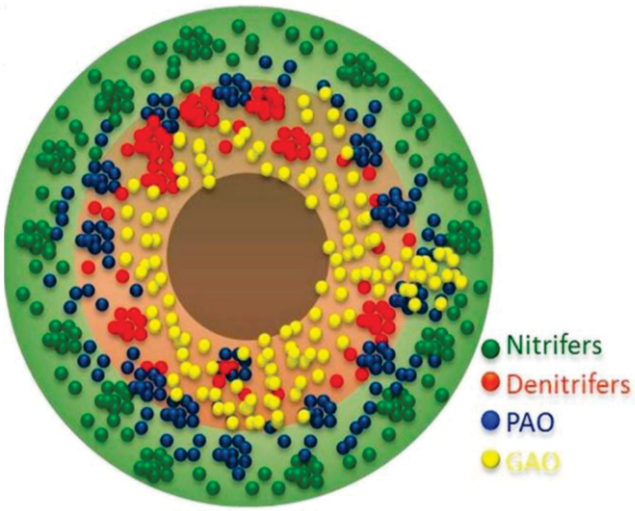


Figure 06: A Single Aerobic Granule

These granules are formed in a sequencing batch reactor without requirement of any media to grow. For the formation and growth of these granules, firstly wellfed and starved situations are created for microorganisms. During feeding, the microorganisms store the organic matter to be further used in famine period. High aeration and high hydrodynamic conditions result in round and compact particles. Their formation and growth are shown in figure 07. The role of cellular interactions in granule formation has been mainly explored by detecting autoinducer molecule producing bacteria (*Aeromonas* sp., *Pseudomonas* sp., and *Acinetobacter*sp.,), quorum sensing (QS) molecules (N-acyl-homoserine lactones (AHL) and Autoinducer-2) and quorum quenching (QQ) enzymes in aerobic granules (Nancharaiah and Reddy 2017). Molecular diagnostic techniques like DGGE and t-RFLP has been used to identify the microbial community present in these granules (Winkler, Meunier et al. 2017).

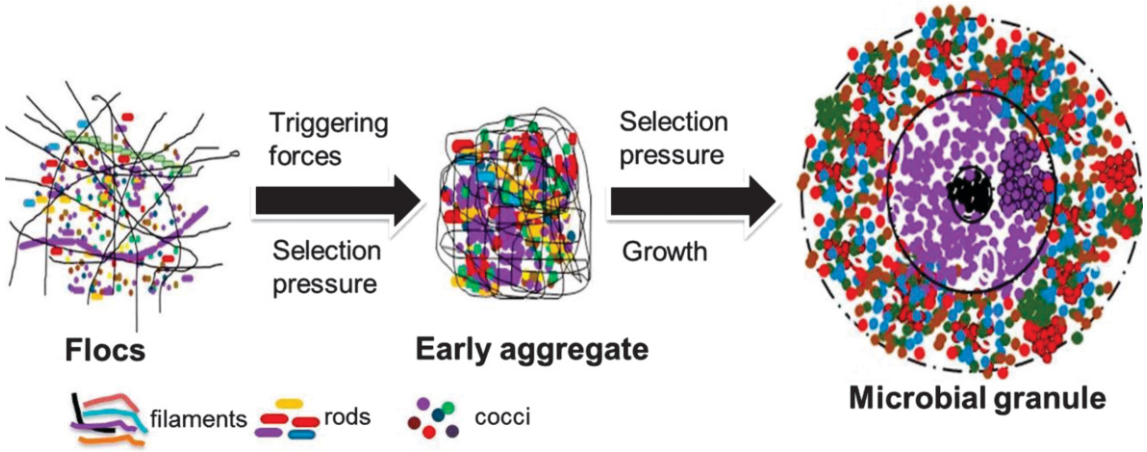


Figure 07: depicting formation and growth of Aerobic Granule

Despite having good settling potential, the effluent coming out of aerobic granular sludge reactor needs post-treatment to meet effluent criteria (< 80% BOD and TP removal). This can be done by integrating aerobic granular sludge with membrane bioreactor. Aerobic granules coupled with membrane bioreactors (AGCMBR) have shown excellent outcome. The reason to use membranes along with aerobic granules is to remove the suspended solids out of the effluent completely (Tay, Yang et al. 2007). High COD removal rate of greater than 96% was observed in coupled Membrane Bio-Reactors (MBRs) (Thanh, Visvanathan et al. 2008, Liébana, Modin et al. 2018).

The soluble microbial particles are the major foulants (material causing membrane fouling) in AGCMBR. The larges granules resulted in cake film developments on the membrane while the soluble microbial products result in adoption of these particles on the internal side of the membrane resulting in pore narrowing. The pictorial representation of the fouling is shown in figure 08.

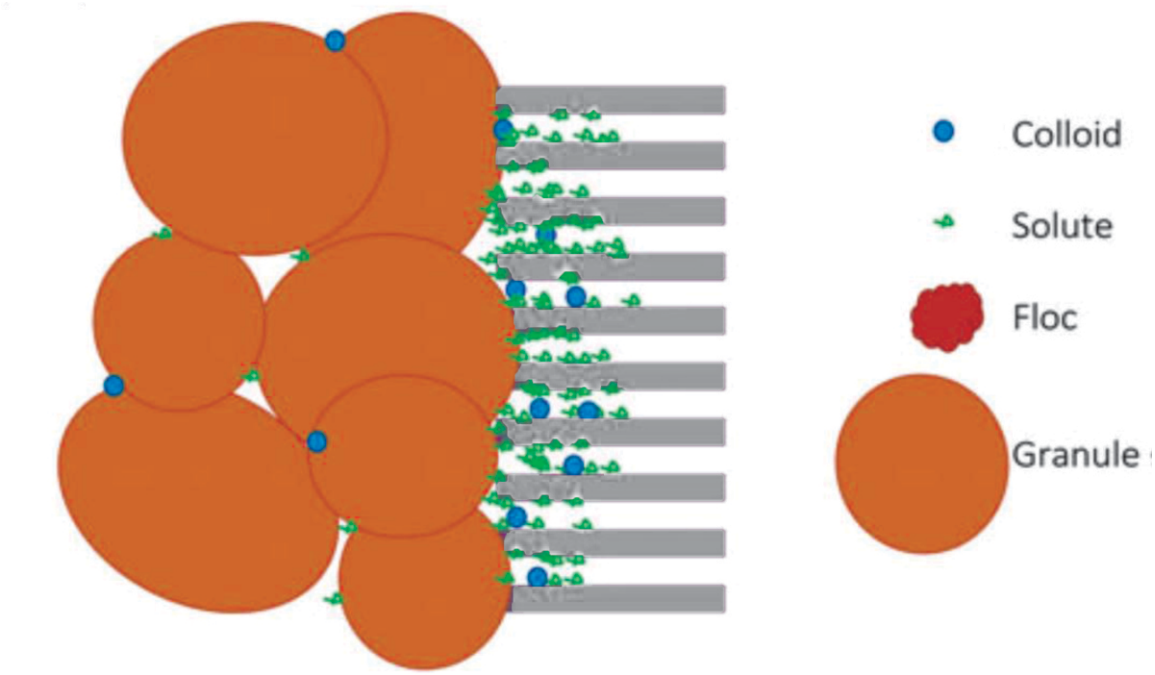


Figure 08: showing fouling in AGCMBR (Liébana, Modin et al. 2018)

Role of Biotechnology in Wastewater treatment:

The basis of wastewater treatment are oxidation and reduction reactions. Although all living organisms are performing these reactions but microorganisms have unparalleled capability to perform these reactions. Without microorganisms, wastewater treatment is not possible. The designing of these reactors were initially based on physical and chemical parameters without knowledge of the potentials of these microorganisms (Gilbride, Lee et al. 2006). As an applied research, MBRs are performing an outclass job but one need to see into the insight to look for answers for the following questions (Rittmann 2009):

1. What type of microbial consortium is present in the wastewater?
2. What are metabolic reactions occurring?
3. How do the microorganisms interact with each other?
4. How the efficiency of the microorganisms can be enhanced?

The answers to these questions are given by biotechnological advancements. During the 1980s, genomic tools directed to identify the microorganisms present based on their 16S rRNA. These 16S rRNA is present in all prokaryotes and is amplified naturally. This conserved and variable region helps in detection of the individual microorganism. Microorganisms can be detected visually with integration of this Ribonucleic Acid (RNA) with Fluorescent in situ hybridization (FISH) techniques (Rittmann 2009). These molecular methods have reduced the reliability of conventional techniques in which isolation and culturing of those microbes was mandatory. The advanced methods can be applied to natural and engineered systems as well. They can be used to study vast variety and the interrelationships of microbes among each other.

Table 02 summarizes different biotechnological approaches to study wastewater microorganisms along with their pros and cons (Gilbride, Lee et al. 2006).

Table 02: Techniques to identify microorganisms in wastewater

Technique	Benefits	Limitations
Microscopy	Fast and Direct observation of microbial cells	Majority of bacterial population cannot be identified
Media-based methods	Easy to perform and individual microorganisms are identified	< 1% of the microorganisms can be cultivated
Indicator microorganism-based pathogen estimation	Easy to perform	Labor intensive and time consuming
	Current standard for coliforms	Indirect estimation of pathogens rather than direct detection
Amplified ribosomal DNA restriction analysis (ARDRA)	Culture-independent	DNA extraction and PCR biases
	Suitable for analysis of a wide range of microorganisms	Not quantitative
Ribosomal RNA intergenic spacer analysis (RISA)	Culture-independent	DNA extraction and PCR biases
	Suitable for analysis of a wide range of microorganisms	
	Significant heterogeneity in length and sequence among bacteria	Not quantitative
		Significant heterogeneity in length and sequence among bacteria
Denaturing gradient gel electrophoresis (DGGE)	Culture-independent	DNA extraction and PCR biases
	Suitable for analysis of a wide range of microorganisms	
	Use of rRNA gene sequence heterogeneity	Not quantitative
		Specificity can be an issue because of short target sequences
Terminal-restriction fragment length polymorphism (t-RFLP)	Culture-independent	DNA extraction and PCR biases
	Suitable for analysis of a wide range of microorganisms	
	Fast and semi-quantitative	
Fluorescent In Situ Hybridization (FISH)	Quantitative	Inactive cells may not be detected
	Direct visual resolution of microbial cells including non-culturable	
Fluorescent in situ hybridization (FISH) and confocal scanning laser microscopy (CSLM)	Quantitative	Expensive instrumentation
	Direct visual resolution of microbial cells including slow growing and non-culturables	
Multiplex PCR	Rapid and simultaneous detection of several target microorganisms	Combinations of primer pairs must function in a single PCR reaction
Nucleic acid microarrays	High throughput design	Low sensitivity for environmental samples
	Various applications	Sample processing complexities
On-chip technology	Combination of PCR with nucleic acid hybridization on a single chip	Integration and packaging
	Less interference between parallel reactions	

Recommendations and Way Forward

- The key to successful treatment of wastewater lies in understanding biological community.
- With the newer techniques developed to identify microbial species, better technologies are coming up which require lesser space, serve more to the mankind.
- Membrane based solutions provide a promising futuristic techniques to deal with the issues of wastewater treatment.
- Anaerobic based solutions are also giving required treatment efficiencies with minimum energy and operational requirements.
- Hence a combination of mentioned aerobic and anaerobic studies can lead to find further optimal solution toward reducing this global burden of wastewater.

Conflict of Interest:

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

References

www.thembrsite.com/interactive-map-history-of-the-largest-municipal-mbr-installations/

USEPA, Wastewater Technology Fact Sheet Anaerobic Lagoons, 2016[06.01.06] Available at: http://www3.epa.gov/npdes/pubs/alagoons.pdf.

Adav, S. S., et al. (2008). "Aerobic granular sludge: recent advances." Biotechnology advances **26**(5): 411-423.

Cheremisinoff, N. P. (1997). Biotechnology for waste and wastewater treatment, Elsevier.

Gilbride, K. A., et al. (2006). "Molecular techniques in wastewater: understanding microbial communities, detecting pathogens, and real-time process control." Journal of microbiological methods **66**(1): 1-20.

Gül, B. Y. and I. Koyuncu (2017). "Assessment of new environmental quorum quenching bacteria as a solution for membrane biofouling." Process Biochemistry **61**: 137-146.

Ham, S.-Y., et al. (2018). "Mitigation of membrane biofouling by a quorum quenching bacterium for membrane bioreactors." Bioresource technology **258**: 220-226.

Hamza, R. A., et al. (2016). "Advances in biological systems for the treatment of high-strength wastewater." Journal of Water Process Engineering **10**: 128-142.

Judd, S. (2008). "The status of membrane bioreactor technology." Trends in biotechnology **26**(2): 109-116.

Kim, H.-W., et al. (2013). "Microbial population dynamics and proteomics in membrane bioreactors with enzymatic quorum quenching." Applied microbiology and biotechnology **97**(10): 4665-4675.

Kraume, M., et al. (2005). "Nutrients removal in MBRs for municipal wastewater treatment." Water Science and Technology **51**(6-7): 391-402.

Liébana, R., et al. (2018). "Integration of aerobic granular sludge and membrane bioreactors for wastewater treatment." Critical reviews in biotechnology: 1-16.

Maqbool, T., et al. (2015). "Membrane biofouling retardation and improved sludge characteristics using quorum quenching bacteria in submerged membrane bioreactor." Journal of Membrane Science **483**: 75-83.

Mara, D. (1997). "Design manual for waste stabilization ponds in India, Lagoon Technology International Ltd." University of Leeds, Leeds, UK.

Metcalf, et al. (2003). Wastewater engineering: treatment and reuse, McGraw Hill.

Nancharaiah, Y. and G. K. K. Reddy (2017). "Aerobic granular sludge technology: mechanisms of granulation and biotechnological applications." Bioresource technology.

Oh, H.-S. and C.-H. Lee (2018). "Origin and evolution of quorum quenching technology for biofouling control in MBRs for wastewater treatment." Journal of Membrane Science.

Ramadan, H. and V. M. Ponce (2003). "Design and performance of waste stabilization ponds." Carlsbad: Virgin GLOBE, Storm Water and Surface Water Management Service.

Rittmann, B. E. (2009). "Environmental biotechnology in water and wastewater treatment." Journal of Environmental Engineering **136**(4): 348-353.

Salgot, M. and M. Folch (2018). "Wastewater treatment and water reuse." Current Opinion in Environmental Science & Health.

Singh, R. and N. Hankins (2016). Emerging membrane technology for sustainable water treatment, Elsevier.

Stephenson, T., et al. (2000). Membrane bioreactors for wastewater treatment, IWA publishing.

Sutherland, D. L., et al. (2018). "Seasonal performance of a full-scale wastewater treatment enhanced pond system." Water research **136**: 150-159.

Tay, J., et al. (2007). "Reactor performance and membrane filtration in aerobic granular sludge membrane bioreactor." Journal of Membrane Science **304**(1-2): 24-32.

Thanh, B. X., et al. (2008). "Fouling characterization in aerobic granulation coupled baffled membrane separation unit." Journal of Membrane Science **318**(1-2): 334-339.

Tilley, E. (2008). Compendium of sanitation systems and technologies, Eawag.

Wei, D., et al. (2018). "Biosorption performance evaluation of heavy metal onto aerobic granular sludge-derived biochar in the presence of effluent organic matter via batch and fluorescence approaches." Bioresource technology **249**: 410-416.

Winkler, M.-K. H., et al. (2017). "An integrative review of granular sludge for the biological removal of nutrients and recalcitrant organic matter from wastewater." Chemical engineering journal.

Witt, E. R. (1982). Biological filter and process, Google Patents.

Xia, J., et al. (2018). "Microbial community structure and function in aerobic granular sludge." Applied microbiology and biotechnology **102**(9): 3967-3979.

Yeon, K.-M., et al. (2008). "Quorum sensing: a new biofouling control paradigm in a membrane bioreactor for advanced wastewater treatment." Environmental science & technology **43**(2): 380-385.

Paper No. 802

MODELLING OF FUTURE DISCHARGE PROJECTION AND ESTIMATION OF SNOW/ICE MELT CONTRIBUTIONS FROM THE GLACIERIZED HUNZA RIVER BASIN, PAKISTAN

Syed Hammad Ali, Muhammad Arshad Pervez,
Mujahid Tanveer Ahmad, Rijan Bhakta Kayastha, Richard Armstrong

MODELING OF FUTURE DISCHARGE PROJECTION AND ESTIMATION OF SNOW/ICE MELT CONTRIBUTIONS FROM THE GLACIERIZED HUNZA RIVER BASIN, PAKISTAN

By:

Syed Hammad Ali[1], Muhammad Arshad Pervez[1], Mujahid Tanveer Ahmad[1], Rijan Bhakta Kayastha[2], Richard Armstrong[3]

Abstract

This study presents the results of a semi-distributed modified positive degree-day model (MPDDM) for estimating snow-ice melt contributions to discharge and future discharge projection from the glacierized Hunza River basin, tributary of Indus river Pakistan. The model is calibrated for the period 1995-2001 and validated for 2002-2013. Furthermore, the Weather Research and Forecasting model projected temperature and precipitation data from 2016-2050 are used for representative concentration pathways RCP 4.5 and RCP 8.5, and bias correction was done using a statistical approach for future discharge estimation. No drastic changes in future discharge are predicted for the emissions scenarios except some high discharges in few years that may cause floods. Peak discharge are found to be in July and August in 2020, 2025, 2031, 2040 and 2045, with values of 2258m^3/s, 1978 m^3/s, 1773 m^3/s, 2184 m^3/s, and 1872 m^3/s, respectively which may cause floods in these years as observe the similar higher discharge in 2010 which leads to flooding where the highest discharge was 1928 m^3/s. This may be due to increases in temperature causing more snow and glacier melt. The aggregate snow-ice melt contribution is 39% of total discharge in the period 1993-2013. Snow-ice melt contribution ranges from 35% to 63% during the high flow period (May to October), which constitutes 89% of annual discharge; in the low flow period (November to April) it ranges from 0.02% to 17%, which constitutes 11 % of the annual discharge. The aggregate snow-ice melt contribution to total discharge will increase gradually in the future and reach up to 45% in 2041-2050. From a sensitivity analysis it is found that the combination of a 2°C temperature rise and 20% increase in precipitation shows a 10% increase in discharge. The study allows us to evaluate the impact of climate change in such basins and is also useful for the future prediction of discharge to define hydro-power potential, inform other water resource management in the area, to understand future changes in snow-ice melt contribution to discharge, and offer a possible evaluation of future water quantity and availability.

Keywords: Positive degree day, regional climate model, water resource management, future discharge projection, Hunza River basin.

INTRODUCTION

Pakistan is an agriculture-based country and highly reliant on the Indus irrigation system (United Nations, 2010). The Indus River is the key source of water in Pakistan. The Upper Indus basin is comprised of the Gilgit, Hunza, Shigar, Shyok, Zanskar, Shingo, Astor, and Upper Indus sub-basins. A major share of flow in the Indus River is contributed by its snow and glacier-fed river sub-basins situated in the Karakoram Range (Bajracharya and Shrestha, 2011). It is therefore

1 Glacier Monitoring & Research Center, Water & Power Development Authority, Pakistan

2 Himalayan Cryosphere, Climate and Disaster Research Center, Department of Environmental Science and Engineering, School of Science, Kathmandu University, Dhulikhel, Nepal

3 National Snow and Ice Data Center, The University of Colorado, Boulder, USA. Corresponding Email syedhammadali2001@yahoo.com. Corresponding author. Tel.: +92-3004300685.

essential to estimate the discharge from these catchments for water resource management in the region. The hydrology of mountainous areas is mainly reliant on the climatic conditions of the territory, as mountains generally receive large amounts of precipitation, which may be deposited in the form of snow and can be stored as glacier ice.

Climatic regimes vary considerably across the different mountain ranges in the Hindu-Kush Karakoram Himalaya (HKKH). The climate in the eastern Himalaya is dominated by monsoon dynamics, with the bulk of the annual precipitation occurring during summer. In the Hindu-Kush Karakoram (HKK) in the west, where the greater part of the Upper Indus Basin (UIB) is located, precipitation also occurs during winter, having dominant influence on the cryospheric regime (Hewitt, 2011a). High altitude precipitation does not contribute significantly to the pluvial source of river flows but to the nourishment of perennial snow cover and glaciers (Khan et al., 2014). Runoff will primarily increase as glaciers melt and will then decline as deglaciation progresses (Solomon et al., 2007). Rivers are fed by groundwater from November to February. Snowmelt begins in the lower parts of the basin in March, and groundwater discharge increases to a maximum in July – August. By September Rivers are fed by groundwater, ice melt, snowmelt and precipitation. Snowmelt will finish by October in the high mountains and rivers are again fed primarily by groundwater (Dreyer et al., 1982).

The sustainability of Pakistan's economy and food security is reliant on these water resources (snow and glaciers) of the Hindu Kush Himalaya (HKH) and Karakorum ranges and their management. Any change in the availability of these water resources through climate variability, socio-economic factors or international policies will have a serious impact on food security and the environment in Pakistan. Therefore, it is very important to study the status of snow and glaciers and their impacts on the hydrologic regime of this Upper Indus region under climate variability in order to manage the available water resources. For this purpose, using of reliable hydrological tools to simulate runoff resulting from snow and glacier melt under future climate change scenarios in the high-altitude catchments is very important to assess the water supply available for fulfilment of future requirements (Tahir et al., 2011). Specifically, gacio-hydrological models are primarily used for hydrologic predictions in glacierzed river basins.

Hydrological models are often poorly calibrated with respect to glaciers due to a shortage of available information. Inaccuracies in precipitation approximation, for example, are often compensated by increased glacier melt (Schaefli et al., 2005), which produces the correct model result but for the wrong reason. It is expected that future climate change will impact future water availability in the UIB (Immerzeel et al., 2010b, 2013; Lutz et al., 2014b), as temperature increases and changes in the timing, magnitude, and phase of precipitation will alter the timing and contribution of snow and ice melt (Shrestha and Aryal, 2010). General Circulation Models need to be downscaled to provide appropriate input fields for estimating future water yields, and be used to generate hydrological forecasts for the UIB.

This study estimates daily discharge, snow-ice melt contribution from debris-free areas, and ice melt under debris layers based (which was not done by other researchers) on the positive degree-days calculated from daily mean temperature and precipitation in the glacierized Hunza River basin for the time period 1995 - 2013 using a Modified Positive Degree Day Model (MPDDM).The MPDDM requires limited data so it is appropriate to use in the Hunza River basin due to the scarcity of data. The main objective of this study is to estimate snow and ice melt contribution to discharge in the glacierized Hunza River basin, Pakistan by applying the concept of a degree-day factor using the MPDDM. The model is first calibrated by using various parameters, after which it is validated to check the model performance. Projected temperature and precipitation derived from the Weather Research and Forecasting (WRF) model are then used to generate the future discharge and snow-ice melt contribution to discharge in the basin.

STUDY AREA

The present study is conducted in the Hunza River basin with a drainage area of 13,713 km2 (Fig. 1).Geographically, the basin extends from 36.05 °N, 74.04 °E to 37.08 °N, 75.77 °E and is situated in the high-altitude central Karakoram region with elevation ranges from 1432 - 7849 m a.s.l. Shuttle Radar Topography Mission Digital Elevation Model (SRTM DEM 2000) of resolution 90m from the U.S. National Aeronautics and Space Administration (NASA) is used to delineate the catchment boundary of the study area. The total glaciated area is 4152 km^2, out of which the clean glacier area is 3,673 km2 and the debris covered area is 479 km^2.

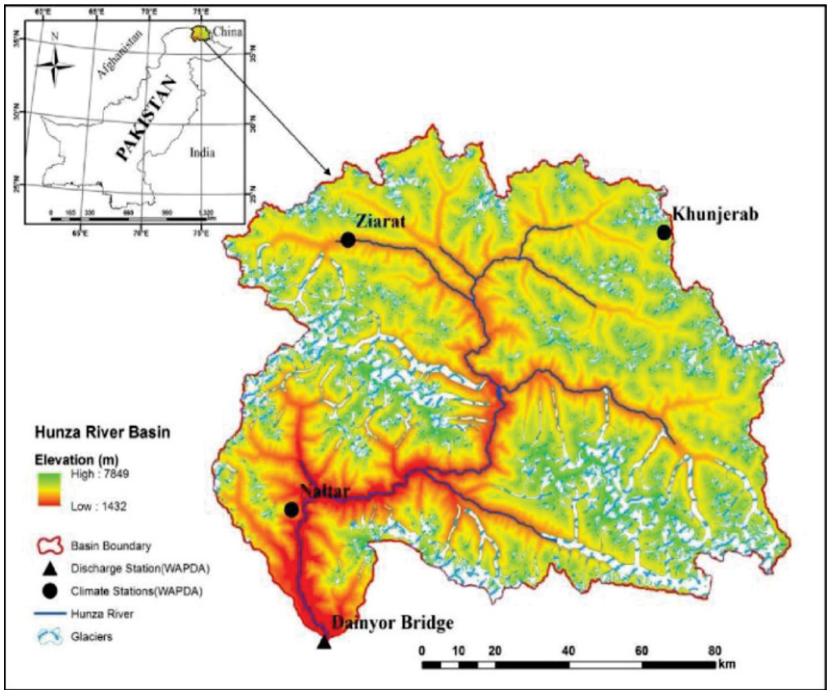


Fig.-1: Location map Hunza River basin in Pakistan.

The remaining area is covered by rock and vegetation as shown in the hypsograph of the basin (Fig.2).

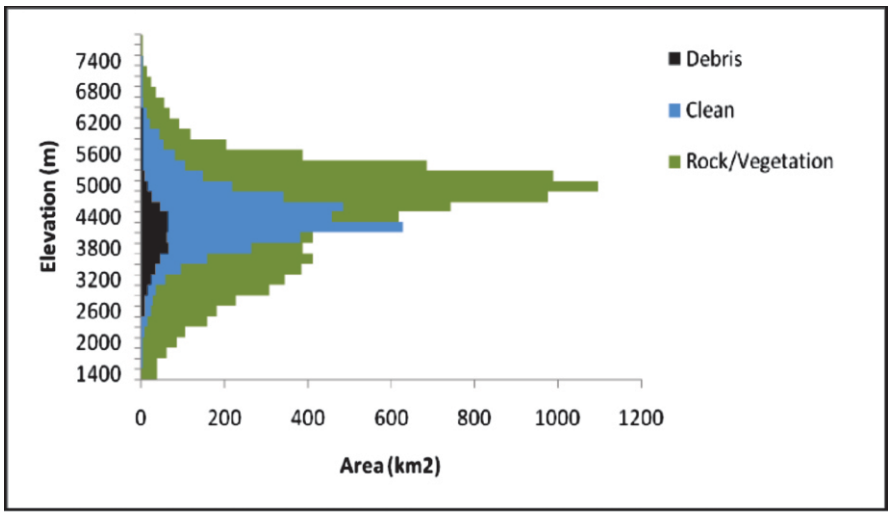


Fig.-2: Hypsograph Hunza River basin.

The snow covered area in the Hunza River basin varies from approximately 80% in winter to 30% in summer (Tahir et al., 2011). Hydro-meteorological data of Naltar and Daniyour Bridge stations were obtained from the Water and Power Development Authority for the period 1995-2013. Annual mean temperature over the basin is 6.38 °C (mean over the period from 1995 to 2013) while the annual mean precipitation is 669 mm (mean over the period from 1995 to 2013).The discharge regime can be classified as glacial when the high flow period with maximum discharge occurs from May to October, and non-glacial during the low flow period from November to April when minimum discharge occurs.

METHODOLOGY

The Modified Positive Degree Day Model (MPDDM) version 1.0 developed by the Himalayan Cryosphere, Climate and Disaster Research Centre (HiCCDRC) at Kathmandu University, Nepal in 2014 is used in this study. The MPDDM is based on the proportional relationship between the melting of snow or ice during any particular period and the number of positive degree-days. The positive degree day factor involves a simplification of complex processes that are more properly described by the energy balance of the glacier surface and the overlaying atmospheric boundary layer (Braithwaite and Olesen, 1989). This approach is appropriate in regions with scarce data as it requires less input data and uses simple equations to estimate melt. Daily temperature and precipitation data from the climate stations of Water and Power Development Authority (WAPDA) Pakistan are used in the model as input.

In this model, the entire study basin is divided into 33 elevation zones using 200m bands (Fig. 2). Temperature and precipitation in each elevation zone is obtained by using the temperature lapse rate and precipitation gradients applied to the temperature and precipitation values at the Naltar automatic weather station(AWS) (2889 ma.s.l), Ziarat AWS (3669 ma.s.l) & Khunjerab AWS (4730 ma.s.l). In each zone, daily snow and ice melt from the glacierized and glacier free areas is calculated using Equation 1:

$$M=\begin{cases} k_{b/s/d}\times T & if\ T>0°C \\ 0 & if\ T\leq 0\ °C \end{cases} \qquad (1)$$

Where M is the snow or ice melt (mm/d), T is the air temperature (°C) and kb, ks and kd is the degree day factor for snow, ice and debris (mm/d/°C).

The following transition scheme outlined by Lutz et al.(2014) is used to separate snow and rain in this study:

$$\begin{cases} Precipitation = Snow if T \leq 0°C \quad (AllSnow) \\ Precipitation = Snow + Rain if\ 0°C \leq T \leq 2°C\ (Snowandrain) \\ Precipitation = Rain if T > 2°C\ (\ AllRain) \end{cases}$$

The snow and ice melt and the precipitation that contribute to both runoff and base flow in each elevation zone are calculated as given in Equation 2. The discharge from all zones is summed to get the discharge from the entire basin (Q) as given in Equation 3. The flow chart of the MPDDM is shown in Figure 3.

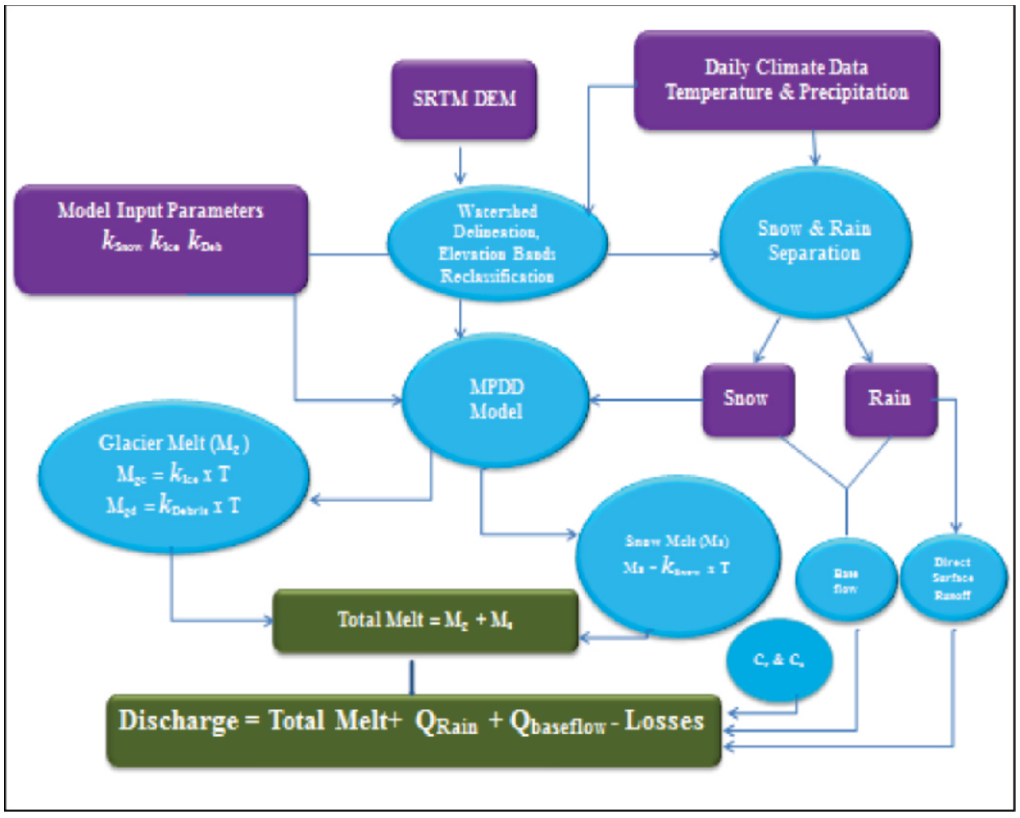


Fig.-3: Flow Chart of Modified Positive Degree Day Model (MPDDM).

$$Q_z = Q_r * C_r + Q_s * C_s + Q_b \qquad (2)$$

$$Q = \sum_{z=1}^{z=n} Q_z \qquad (3)$$

where, Q_z is the discharge (m^3/s) from zone Z;Q_r and Q_s are the discharge (m^3/s) from direct precipitation and snow and ice melt, respectively; C is the runoff coefficient with C_r referring to rain and C_s to snow-ice melt (Martinec, 1975); and Q_b is the base flow (m^3/s). The discharge, Q is then routed to the basin outlet as per the recession equation, Equation4 (Martinec, 1975):

$$Q_n = Q*(1-k) + Q_{n-1}*k \qquad (4)$$

where, Q_n is the river discharge (m^3/s) at the basin outlet on the nth day and k is the recession coefficient.

The base flow is estimated by plotting the hydrograph from observed monthly discharge data (1995-2013) and applying the base flow separation Method III. This method of base-flow separation is realistic in situations where the groundwater contributions are significant (Subramanya, 2008).

A list of fine-tuned parameters used in this study is presented in Table 1.These parameters are adjusted within ranges based on previously published values to minimize the difference between simulated and observed daily runoff for the period 1995–2013.

Parameters	Description	Values
k_s	Degree day factor for snow ablation	5.0-6.0 mm/°C/day (Jan – Apr)
	(Bocchiola, et. al. 2011)	6.0-8.0 mm/°C/day (May – Sep)
		6.5-7.0 mm/°C/day (Oct – Dec)
k_i	Degree day factor for ice ablation	6.0-8.0 mm/°C/day (Jan – Apr)
	(Bocchiola, et. al. 2011)	6.0-9.0 mm/°C/day (May – Sep)
		7.5-8.5 mm/°C/day (Oct – Dec)
k_d	Degree day factor for debris covered ice melt(Mihalcea, et . al. 2006)	4 - 6 mm/°C/day
Γ	Temperature Lapse Rate	0.48 -0.76 °C/100m
PG	Precipitation Gradient	0.25 -1
Cr	Coefficient of Rain	0.08-0.5
Cs	Coefficient of Snow.	0.1-0.40
	(Tahir, et al. 2011)	
X	Constant for Recession Coefficient	0.97
Y		0.04

Table-1: List of calibrated parameters used in MPDDM.

Future Dataset

For future climate projections, Regional Climate Model (RCM) data are used. Daily precipitation and temperature data derived from the Weather Research and Forecasting (WRF) model were acquired from the Bjerkens Centre for Climate Research (BCCR), University of Bergen, Norway for the Hunza River basin. Two different emissions scenarios, RCP4.5 and RCP8.5, are used in this study. The RCP4.5 and RCP8.5 are the Representative Concentration Pathways (RCP) of greenhouse gas concentration trajectories that results in +4.5 and +8.5 W/m^2, respectively. These are radiative forcing values in the year 2100 relative to pre-industrial values. Temperature and precipitation data generated for Naltar Climate station are bias-corrected using a statistical approach because of its computational efficiency and the bias-corrected data are downscaled to the desired spatial resolution. There are several methods to bias correct the WRF data, but in this study the method proposed by Weiland et al. (2010) (Equations 5 and 6) for temperature and precipitation issued.

$$T_{corrected_MOD} = T'_{MOD} + (T_{OBS} - T_{MOD}) \quad (5)$$

where Tcorrected_MOD is the value obtained after calibration; TOBS and TMOD are the observed and modelled daily temperature, respectively; and T'MOD is the mean daily value of modelled temperature.

$$P_{corrected_MOD} = P_{MOD} \frac{\square_{OBS}}{\square_{MOD}} \quad (6)$$

where P_{MOD} is the daily modelled precipitation, and P_{OBS} and P_{MOD} are the average observed and modelled precipitation for 1996-2005, used for bias correction.

Hydro-meteorological Input Data Analysis

In the present study, a Mann Kendall trend analysis has been done to determine the temporal trends in the hydro-climatic series and shows no statistically significant trend in either temperature or precipitation data (p-value> 0.01). From this data analysis, it is observed that temperature is slightly decreasing by -0.0097 °C per year. The annual temperature trend is shown in Figure 4a.Precipitation data shows an escalation by 0.3 mm annually, as shown in Figure 4b.

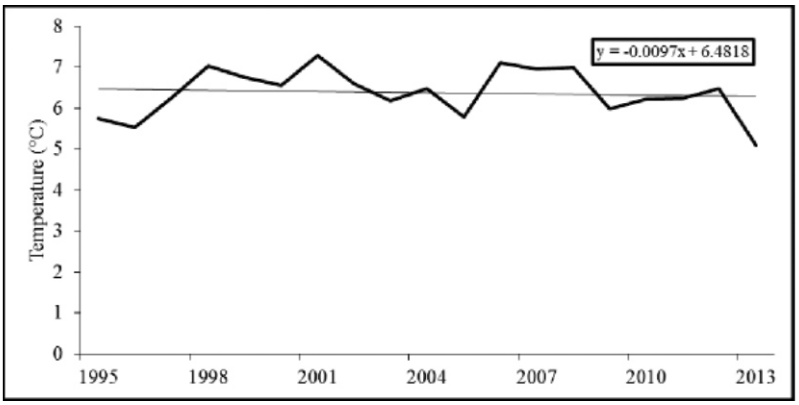


Fig.-4a: Annual temperature trend from 1995 to 2013 at Naltar station, Hunza valley. The thin straight line is a trend line.

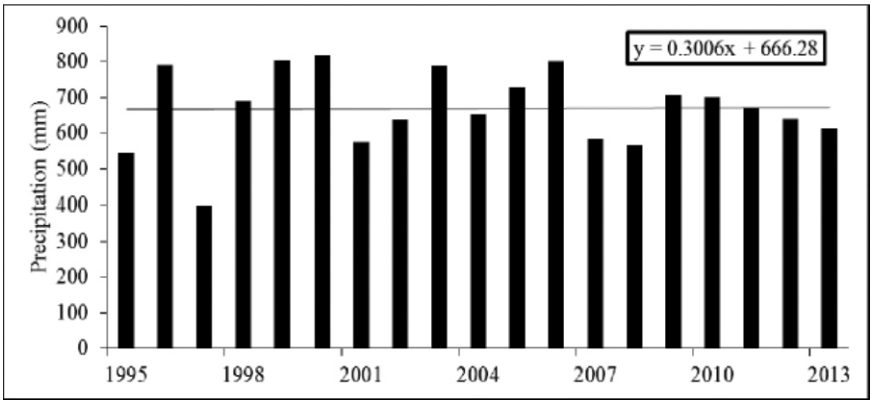


Fig.-4b: Annual precipitation trend from 1995 to 2013 at Naltar station, Hunza valley. The thin straight line is a trend line.

The mean annual precipitation in the Hunza River basin is 209 mm at Khunjerab (4730 m), 285 mm at Ziarat (3669 m) and 672 mm at Naltar (2858 m), according to the 19-year record (1995–2013) of the three climatic stations in the catchment. The decrease in precipitation at higher altitude is partly due to wind-induced error, especially in the case of snowfall where losses can be on average 10–50%, regardless of the many gauges furnished with wind shields (Sevruk, 1985; Sevruk, 1989); Forland et al., 1996). Naltar is located in the south of the basin and has the highest precipitation and the strongest influence of the monsoon (June, July, August [JJA]). The JJA variability is also the highest in Naltar, underlining the strong variability in monsoon strength. Precipitation in higher parts of the basin is more evenly distributed over the seasons, with less variability, which confirms reliable precipitation which results from westerly disturbances. These patterns are confirmed by the observed average monthly precipitation from 1995 to 2013 at the 3-meteorological stations (Fig.-5).

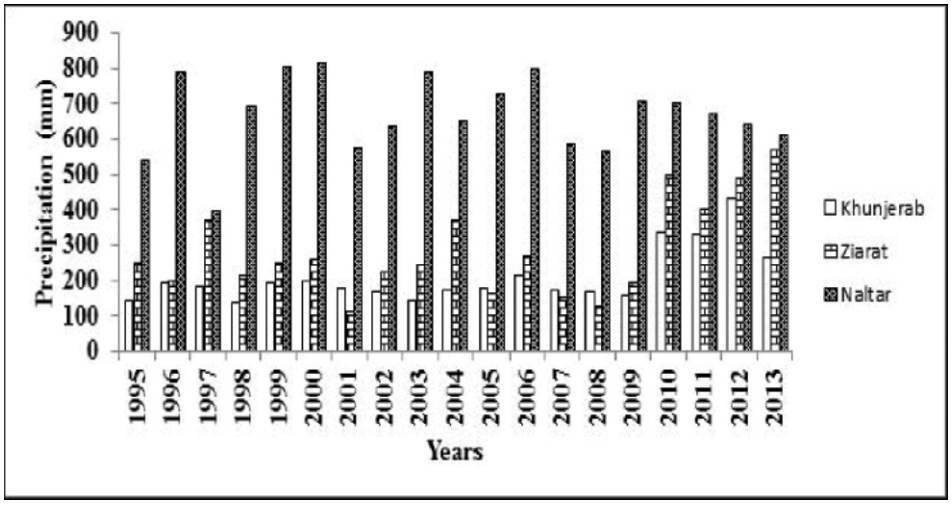


Fig.-5: Variation of precipitation in the Hunza River basin at different climate stations.

Discharge starts to increase in March at the lower stations as snowmelt commences, but not until May and June in and Upper Indus. Between 40-70% of total runoff is in July and August, when discharges are between 15 to 40 times those in March. Rivers are fed by groundwater from November to February (WAPDA, 1979). Snowmelt begins in the lower parts of the Upper Indus basin (UIB) in March, and groundwater discharge increases to a maximum in July – August. Snowmelt ceases by October in high mountains and rivers are then fed primarily by groundwater.

ASSESSMENT OF MODEL ACCURACY

To test whether the simulation matches the measured discharge, accuracy tests are used, namely the non-dimensional Nash-Sutcliffe coefficient (NSE).The Nash-Sutcliffe coefficient is computed using Equation 7:

$$NSE = 1 - \frac{\sum_{i=1}^{n}(Q_i - Q_i')^2)}{\sum_{i=1}^{n}(Q_i - Q_i'')^2)} \qquad (7)$$

where Q_i is measured daily discharge; Q'_i is computed daily discharge; Q''_i is average daily discharge for the simulation period; and n is number of daily discharge values. The volume difference, VD, is computed using Equation 8:

Where VR is measured runoff volume and VR~ is simulated runoff volume. The NSE values vary from 0 to 1, with 1 indicating a perfect fit. VD can take any value, however the smaller the value is the better the model results are:

FUTURE DATA ANALYSIS

The projected period of future climate data analysis is from 2016 to 2050 in this study. Mann Kendall trend analysis is performed for both temperature and precipitation downscaled data for RCP4.5 (RCP = Refer to the write-up under References) and RCP8.5 emissions scenarios, which shows a statistically significant positive trend in the temperature data with $p < 0.01$ values. For RCP4.5 and RCP8.5 scenarios, temperature shows an increasing trend of 0.034 °C and 0.033 °C per year, respectively. Likewise, the projected precipitation for the same period (2016-2050) for both emissions scenarios shows insignificant trends, with increasing values of 1.67mm and 1.00mm per year, respectively, as shown in Figures-6 and 7. Neither emissions scenario shows a drastic increase or decrease in temperature and precipitation data over the years. However, the occurrence of a number of extreme events, such as extremely hot or cold days

and higher precipitation is slightly more frequent in the RCP8.5 as compared to RCP4.5 emission scenario (Figure 7). For example, in the years 2022, 2033, 2040 and 2050, the precipitation values are 720, 724, 716 and 688 mm per year in RCP8.5 while on the other end in the same years in RCP4.5 RCP = Refer to the Write-up at the end of References precipitation values are 661, 353, 639 and 622 mm per year respectively. Many studies have suggested that the reaction of glacier runoff to climate warming is abrupt in the early phase (Braun et al., 2000; Jansson et al., 2003). With rapid warming, additional water is released from glacier storage due to increased melting, resulting in a significant increase in glacier runoff. The future trend analysis shows that in both emissions scenarios the climate responds very similarly to what is predicted by the 5th Assessment Report (IPCC, 2014), i.e, increases in temperature by 1.4 °C and 2.0 °C in the mid 21st century (2046-2065) for RCP4.5 and RCP8.5, respectively.

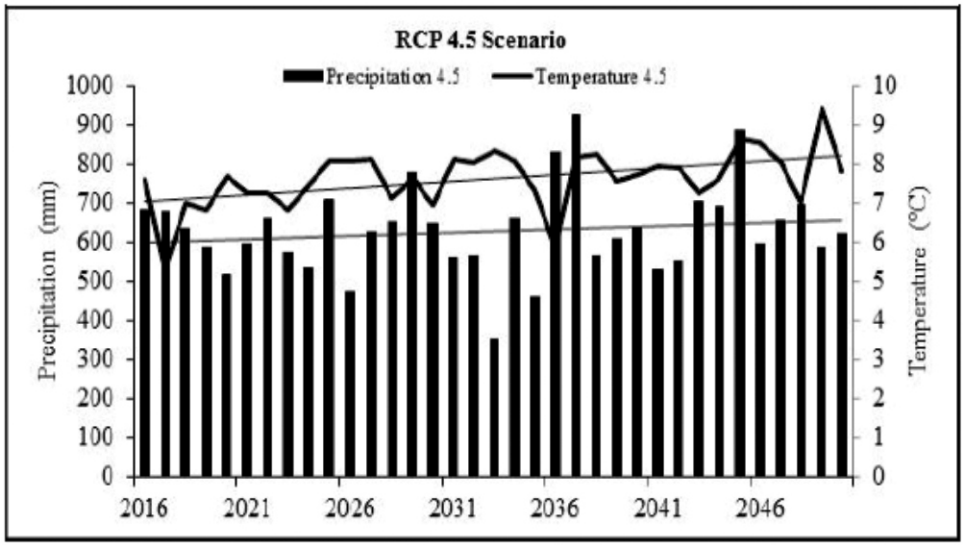


Fig.-6: Distribution of projected annual temperature and precipitation under RCP 4.5 scenario for the Hunza River basin (2016–50).

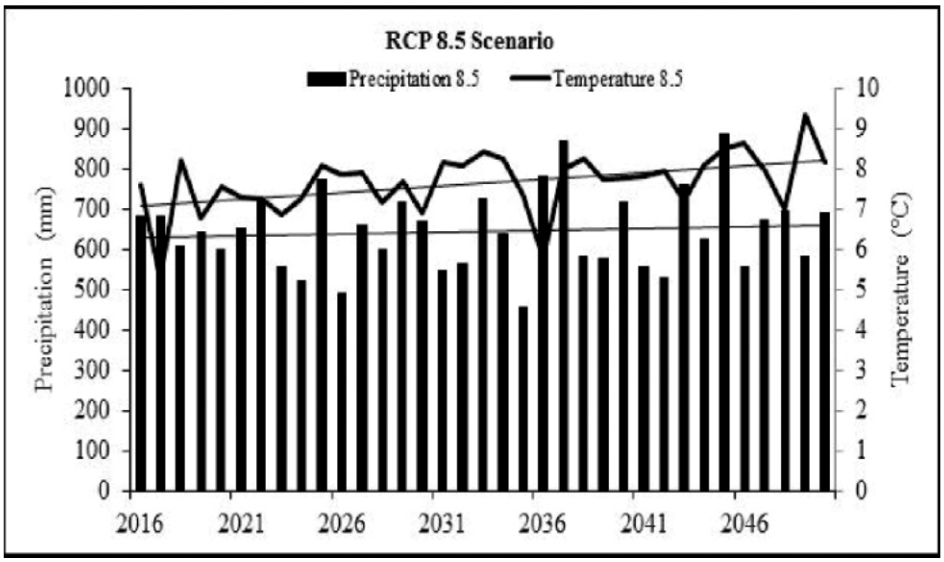


Fig.-7: Distribution of projected annual temperature and precipitation under RCP 8.5 scenario for the Hunza River basin (2016–50).

RESULTS & DISCUSSION

Model Calibration & Validation

The MPDD model has been calibrated for 1995 – 2001 and the model results are in good agreement between observed and simulated discharge. The Nash-Sutcliffe Efficiency and volume difference are 0.90 and 3.67%, respectively, for calibration. As suggested by Moriasi et al. (2007) the modelling performance can be classified as 'very good' (0.75< NSE~1.0), 'good' (0.65 < NSE~0.75), 'satisfactory' (0.50 < NSE~0.65), or 'unsatisfactory' (NSE~0.50).It has efficiently captured both low flow and high flow, except some sudden peak flows(Fig. 8).This implies that the model imitates the main glacio-hydrological processes in the catchment using the ideal parameter sets (Table 1) with a rating of 'very good' on the scale of Moriasi et et al. (2007).After calibration, validation was carried out for 2002 – 2013. In the validation period three years (2005-2007) of discharge data are missing, therefore, we have not used these years for validation. For the validation period, the Nash-Sutcliffe Efficiency and volume difference are 0.88 and 11.59%, respectively. Figure 9 shows the validation of the MPDDM.

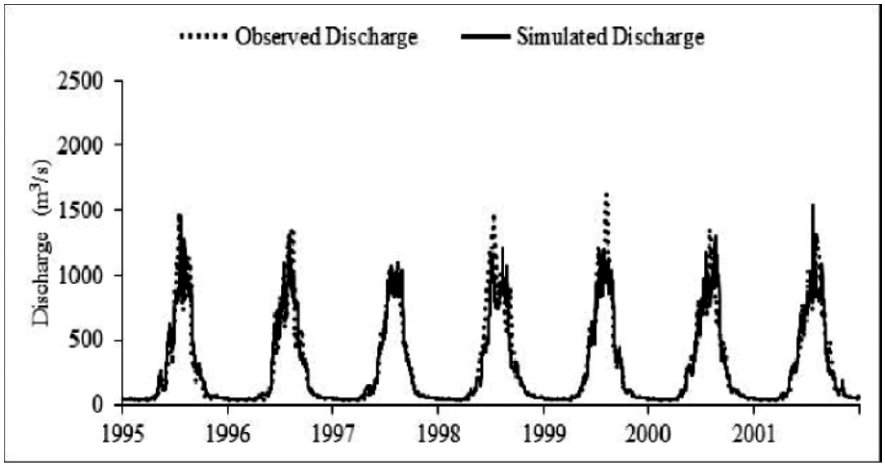


Fig.-8: Distribution of discharge in Hunza River basin in calibration period.

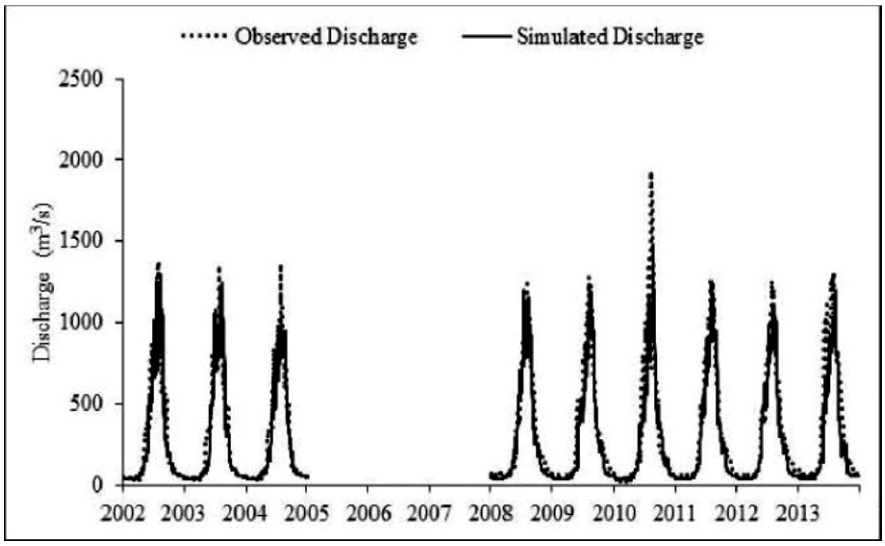


Fig.-9: Distribution of discharge in Hunza River basin in validation period.

The glacial ponds used to store water downstream from the terminus of the glacier and would produce a surge either by accelerated melting of snow/ice or by intense rainfall (Rasul et al.,

2011). Booni Gole Glacier located near Chitral in the Hindu Kush mountain range generated an outburst flood in July 2010 which was triggered by a monsoon downpour and caused huge erosive damage to agricultural land and human settlements along the flow channel. Due to the steep slope downstream, the outflow river carried loads of mud and rubble, including large boulders, which caused immense losses to land, settlements and infrastructure. However those events do not affect the overall pattern of long term averages of monthly flows in any substantial way. Occasional outbursts due to heavy thunderstorms may contribute to a sudden rise in flows. Passu Lake outburst in Hunza basin also followed a similar mechanism in the past with the incidence of flash floods at an irregular interval of 2 to 5 years (Zaidi, et. al. 2013).According to Din et al. (2014) study for the period from 1994 to 2012 in the Hunza, the occurrences of flash flood events there were linked to the melting of glacier ice. Higher temperatures and rainfall accelerate the melting of ice, causing a rise of the water level in the lakes. Generally flash floods events have occurred during the months of March to August, which indicates that flash floods are related to seasonal rises in temperature and the subsequent increase in ice melt. These meteorological events can cause mass movement in the form of avalanches, rock falls, and slumping of ice into the glacial lakes, thus an outburst from the lakes can be triggered and this abruptly raises the water levels in the river downstream as observed in 1999, 2004 and 2010 (Fig. 8).

FUTURE DISCHARGE PROJECTION

After the model calibration and validation, future discharge is estimated for 201 6–50 by using projected temperature and precipitation data from the WRF model. Figures 10 and 11 show the projected discharge and projected precipitation for both RCP4.5 and RCP8.5 in the Hunza River basin. Projected discharge shows no significant trend. No drastic changes in the future discharge in the Hunza River basin are predicted for either scenario. Peak discharge in 2020, 2025, 2031, 2040 and 2045 are found to be in July and August, with values of 2258m^3/s,1978 m^3/s, 1773 m^3/s, 2184 m^3/s, and 1872 m^3/s, respectively which may cause flood in these years because as we observe the high discharges in calibration and validation years which leads to flooding in that years like in 2010 where the highest discharge was 1928 m^3/s. Decadal hydrographs for the period 2016-2020, 2021-2030, 2031-2040 and 2041-2050 (Fig. 12) show that discharge in the monsoon period will be higher than current in both scenarios. This may be due to increases in temperature causing more snow and glacier melt. There is no trend in the shifting of the hydrograph.

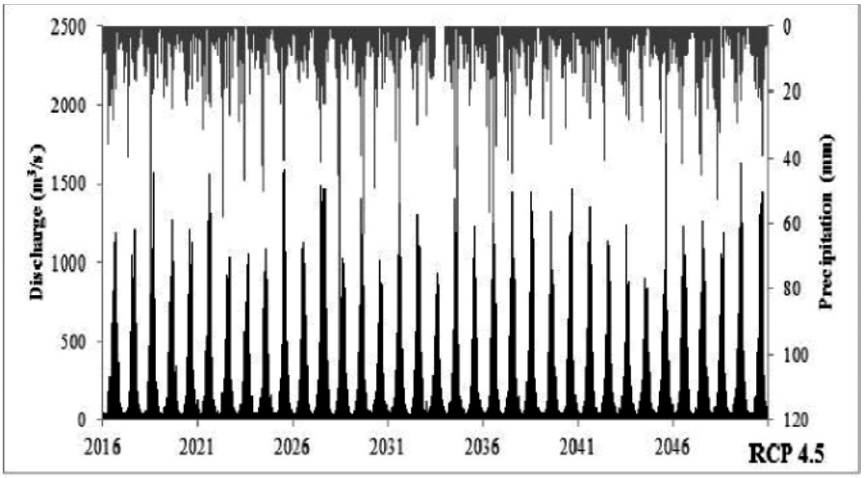


Fig.-10: Distribution of the projected discharge simulated from the MPDDM and projected precipitation for RCP 4.5 scenario.

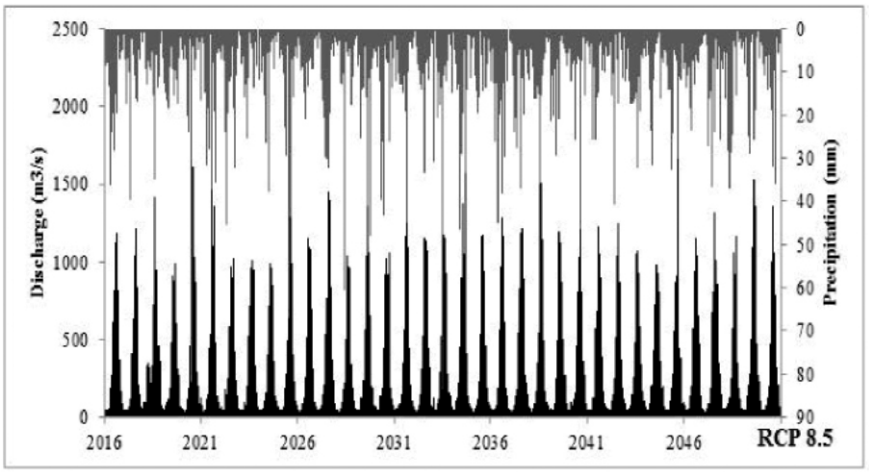


Fig.-11: Distribution of the projected discharge simulated from the MPDDM and projected precipitation for RCP8.5 scenario.

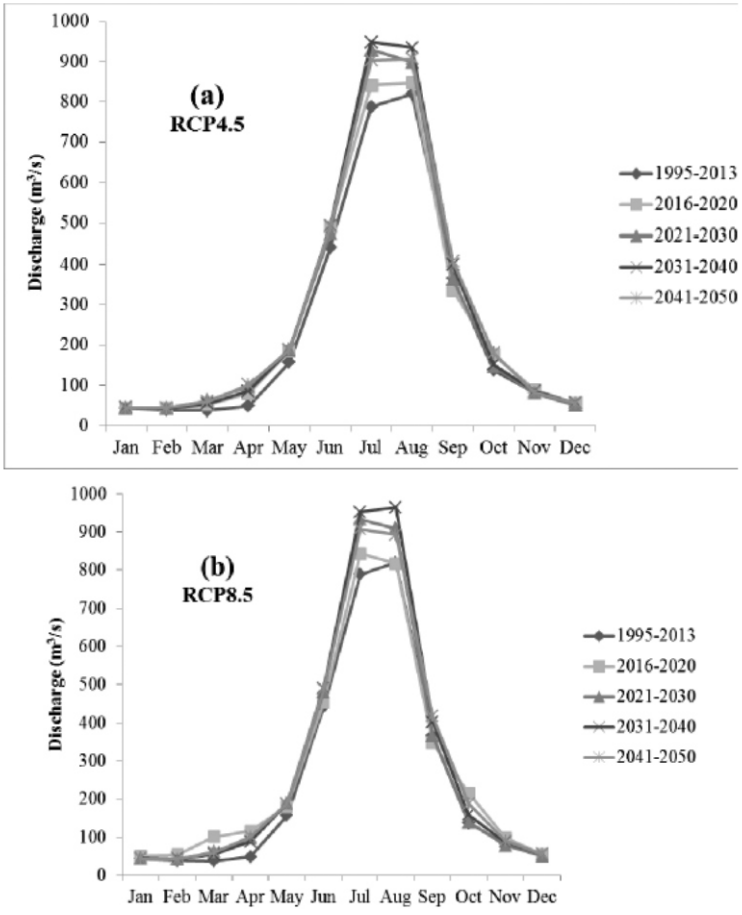


Fig.-12: Comparison of projected decadal hydrographs with the observed hydrograph for RCP4.5 (a) and RCP8.5(b)

SNOW/ICE MELT CONTRIBUTION

From the model output, the relative contribution of snow-ice melt and rain-base flow to total discharge is analyzed. The aggregate snow-ice melt contribution is 39% of the total discharge in

the period 1993-2013. The snow-ice melt contribution ranges from 35% to 63% during the high flow period (May to October), which constitutes 89% of annual discharge, and in the low flow period (November to April) it ranges from 0.02% to 17%, which constitutes 11 % of the annual discharge. Savoskul et al. (201 3) assessed various data sets to approximate glacial melt water and seasonal snowmelt contributions in six major river basins of the HKH-Tibetan Plateau region. According to their estimates, in the entire Indus Basin melt water contributes around 35–40% of the total flow, with seasonal snowmelt and glacier runoff shares being approximately equal. Similarly, other hydrological modeling studies have used ice melt rates for the entire snow-glacier areas during summer months (e.g. Immerzeel et al., 2009, 2010, 2013; Bookhagen and Burbank 201 0;Lutz et al., 2014a &b), and thus overestimated snow-glacier melt relative to Savoskul et al. (2013). The snow-ice melt contribution will increase gradually in the future in both scenarios and reaches a maximum of 45.4% in 2041–50 due to increased temperatures and more glacier runoff. Overall contribution of snow and ice melt is estimated to increase by 6 %. Figures-13 and -14 show the contributions of snow-ice melt and rain/base flow to the total discharge in the periods 1995–2013, 2016–20, 2021–30, 2031–40 and 2041–50.Contradiction among results from various studies (e.g. Mukhopadhyay and Khan 2014; Yu et al., 2013; Lutz et al., 2014 a,b; Tahir et al., 2011; Naz 2011) can be due to differences in study time periods, use of an different drainage basin area, use of different snow-glacier areas and use of different methods.

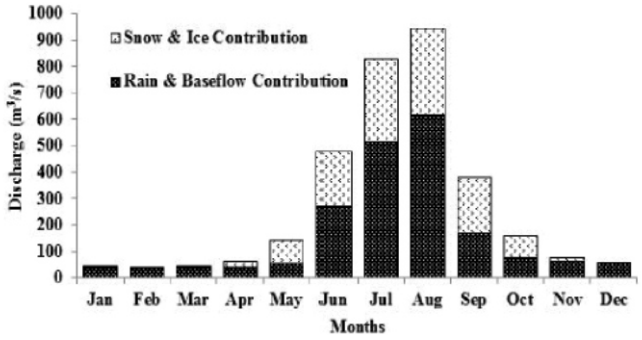
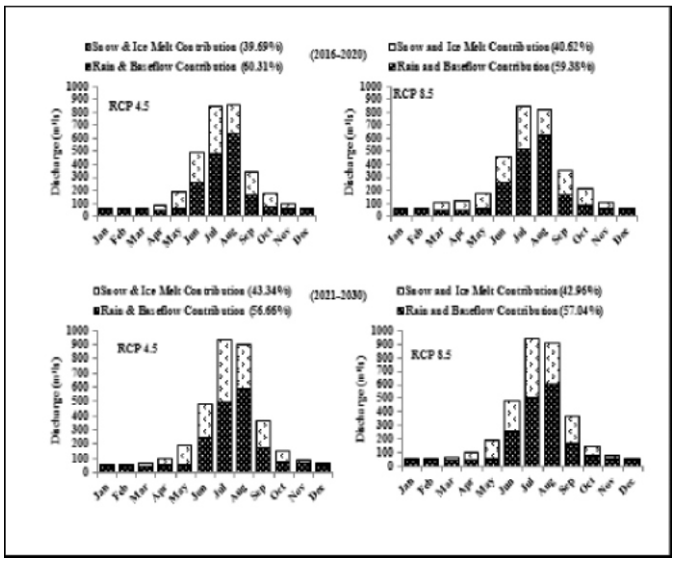


Fig.-13: Snow-ice & rain-base flow contributions averaged for 1995 – 2013.



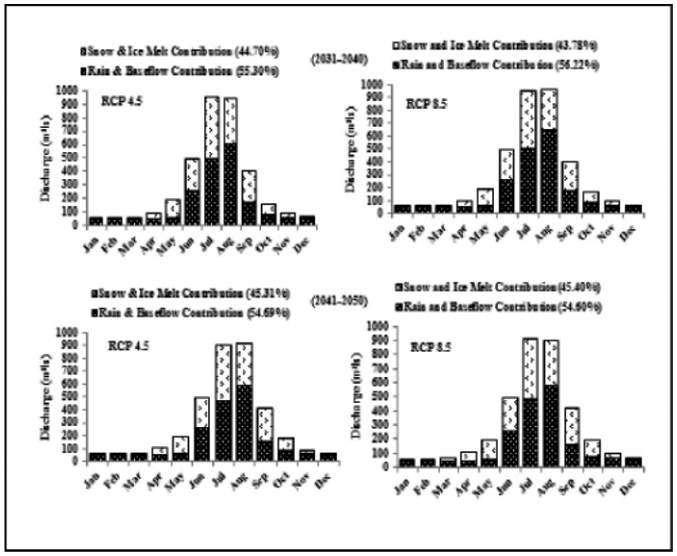
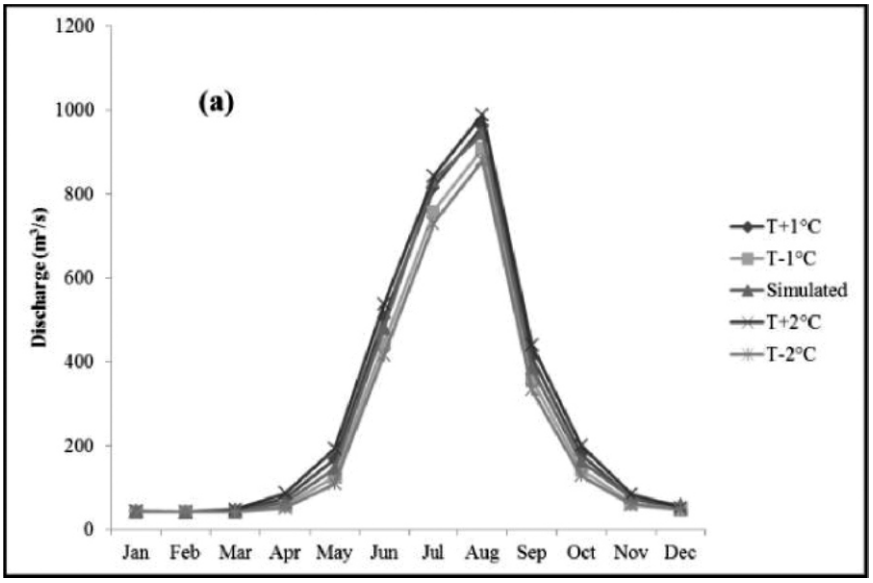


Fig.-14: Snow-ice & rain-base flow contributions in different time periods for the two emissions scenarios. Contribution percentages are annual averages

SENSITIVITY ANALYSIS

Two parameters (temperature and precipitation) are chosen to test the sensitivity of the model temperature with 1°C & 2 °C increases and decreases, precipitation with 10 % & 20 % increases and decreases (Fig.-15 a & b), and different combinations of temperature and precipitation (Fig.-16 a & b).



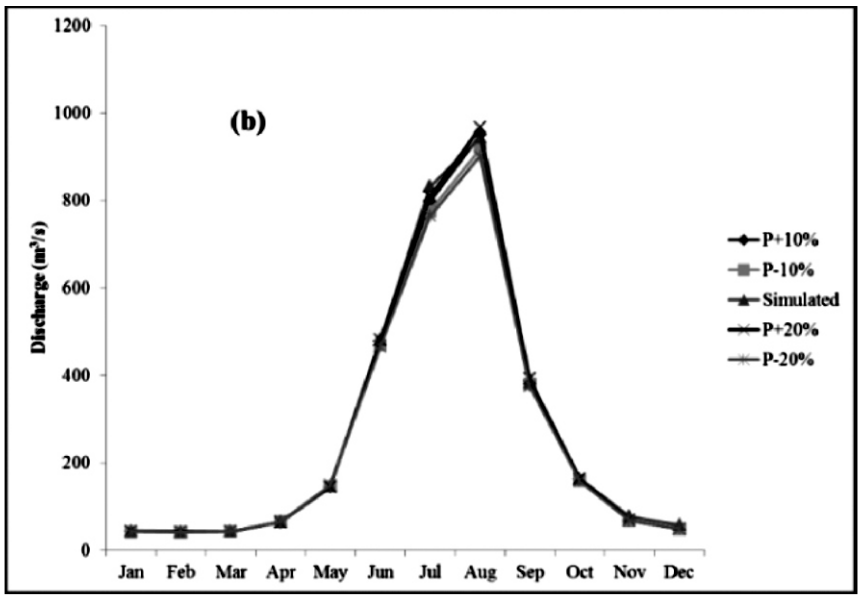
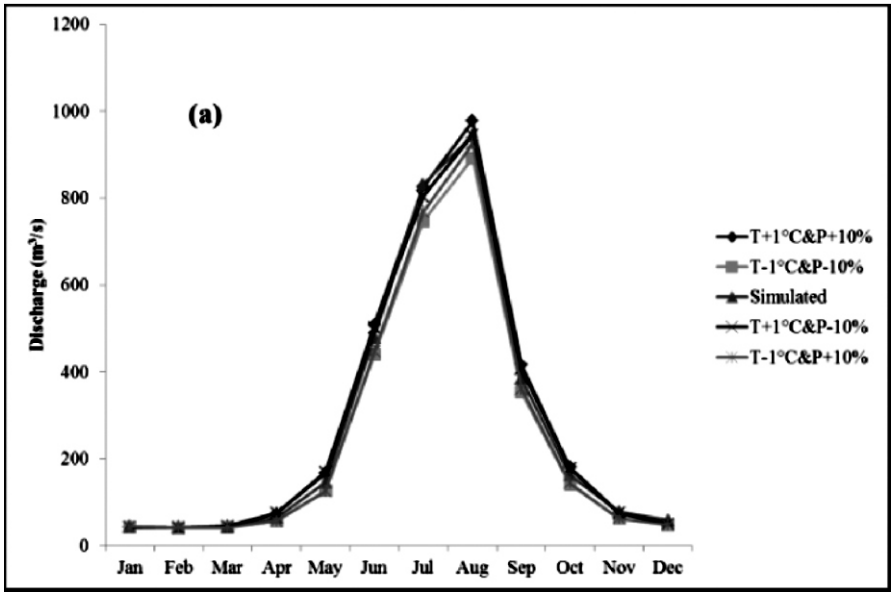


Fig.-15: Change in hydrograph with + 1&2 °C change in temperature (a) and + 10% & 20% change in precipitation (b).

From this analysis, it is found that temperature is more sensitive than precipitation. The combination of a 2 °C increase in temperature and a 20% increase in precipitation shows the largest increase in discharge of + 28.92 m^3/s.



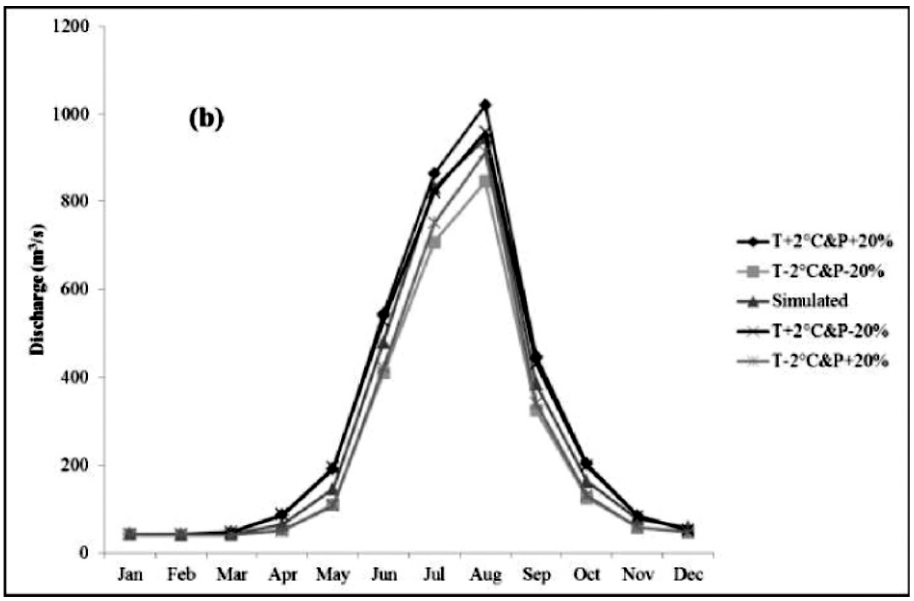


Fig.-16: Change in hydrograph with four different combinations of +1°C (a) & 2°C (b) changes in temperature using +10% & 20% changes in precipitation.

The combination of a 2 °C decrease in temperature and a 20% decrease in precipitation shows the highest decrease in discharge of -39.29 m^3/s (Table-2).

Table-2: Change in discharge (m^3/s) from different sensitivity analyses.

Parameters	Test	Change in Discharge (m^3/s)
Temperature	T+1 °C	+7.41
	T-1°C	-20.72
	T+2 °C	+23.12
	T-2 °C	-33.30
Precipitation	P+10 %	-4.29
	P-10 %	-10.27
	P+20 %	-1.25
	P-20 %	-13.20
Combination of Temperature and Precipitation	T+1 °C& P+10 %	+10.38
	T-1 °C& P-10 %	-23.69
	T+1°C&P-10 %	+4.47
	T-1°C& P+10 %	-17.71
	T+2 °C& P+20 %	+28.92
	T-2°C& P-20 %	-39.29
	T+2°C & P-20 %	+17.42
	T-2°C& P+20 %	-27.35

CONCLUSIONS

The MPDDM was used to estimate discharge from the Hunza River basin. As the model provides information on snow-ice melt, rain and base flow, it gives insights into the hydrological system dynamics of the basin. Although the model is simple, it was able to simulate the discharge in the calibration as well as the validation period. For the calibration and validation

periods, Nash–Sutcliffe values were found to be 0.90 and 0.88, respectively. Projected annual average temperature from 2016 to 2050 for both RCP 4.5 and RCP 8.5 scenarios shows an increasing trend of 0.034 °C and 0.033°C per year, while precipitation shows an increasing trend of 1.67mm per year and 1.00mm per year, respectively. Future water scenarios from this model suggest that the discharge will be higher in the monsoon period relative to other seasons and the peak discharge will be in July and August in both RCP 4.5 & 8.5 scenarios. The contribution of snow-ice to the total discharge is increasing gradually and reaches 45.40% in 2041–50. The sensitivity analysis results show that the MPDDM is more sensitive to temperature than to precipitation. However, a combination of increases in both temperature and precipitation shows the highest increase in discharge. The obtained results enable us to conclude that the MPDDM can be used to estimate the discharge of snow and glacier fed mountainous catchments like the Hunza River basin. It can also be used to study the impact of climate change in such basins and be useful for the future prediction of discharge in order to define hydro-power potential and inform other water resource management in the area. It also helps to understand future changes in snow-ice melt contribution to discharge and offer a possible evaluation of future water quantity and availability. From the present study we can conclude that there will be no drastic change in discharge or shift of discharge pattern till 2050 in the Hunza River basin except some sudden peak discharges in few years which may be designated as flooding years. Similar studies should be carried out in other parts of the Karakoram region to increase understanding of the hydrological system dynamics and potential impacts of climate change.

ACKNOWLEDGEMENTS

We acknowledge support from the Contribution to High Asia Runoff from Ice and Snow **(CHARIS)** Project, University of Colorado, Boulder, USA funded by the United States Agency for International Development **(USAID).** We thank the project partners for their help in carrying out this study, including: the Himalayan Cryosphere, Climate and Disaster Research Centre **(HiCCDRC),** the Department of Environmental Science and Engineering, School of Science, Kathmandu University, Glacier Monitoring Research Center **(GMRC);** Water & Power Development Authority **(WAPDA)** Government of Pakistan.

REFERENCES

Arjumand, Z. Z., Zeenat, Y., Danish, M. S., 2013. Glacial Lake Outburst Flood (GLOF) risk mapping in Hunza River Basin (Pakistan) using geospatial techniques. Conference paper January 2013 DOI: 10.1 109/RAST.2013.6581 198

Bajracharya, S. R., Shrestha, B., 2011. The status of Glaciers in Hindu Kush-Himalayan region. Kathmandu: ICIMOD.

Bocchiola, D., Diolaiuti, G., Soncini, A., Mihalcea, C., Ageta, C.D., Mayer,C., Lambrecht, A., Rosso,R., Smiraglia,C., 2011. Prediction of future hydrological regimes in poorly gauged high altitude basins: the case study of the upper Indus, Pakistan. Hydrology and Earth System Sciences.

Bookhagen, B., Burbank, D.W., 2010. Toward a complete Himalayan hydrological budget: spatiotemporal distribution of snowmelt and rainfall and their impact on river discharge. J. Geophys. Res. 115, F03019.

Braun, L.N., Weber, M., Schulz, M., 2000. Consequences of climate change for runoff from Alpine regions. Annals of Glaciology, 31: 19–25.

Din, K., Tariq, S., Mahmood, A., Rasul, G., 2014. Temperature and Precipitation: GLOF Triggering Indicators in Gilgit-Baltistan, Pakistan. Vol. 10, Issue 20: Jan, 2014. Pakistan Journalof Meteorology.

Dreyer, N. N., Nikolayeva,G.M., Tsigelnaya, I. D.,1982. Maps of streamflow resources of some high mountain areas in Asia and North America Hydrological Aspects of Alpine and High Mountain Areas (Proceedings of the Exeter Symposium, July 1982). IAHS Publ. no. 138.

Forland, E.J., 1996. Manual for operational correction of Nordic precipitation data.24/96, DNMI, P.O. Box 43, Blindern, Oslo, Norway.

Hewitt, K., 2011a. Glacier Change, Concentration, and Elevation Effects in the Karakoram Himalaya, Upper Indus Basin, Mt. Res. Dev., 31(3), 188–200, doi: 10.1 659/MRD-JOURNAL-D-1 1-00020.1.

Immerzeel, W.W., Droogers, P.D.E., Jong, S.M.,Bierkens, M.F.P., 2009. Largescale monitoring of snow cover and runoff simulation in Himalayan river basins using remote sensing. Remote Sens. Environ, 113, 40-49.

Immerzeel, W.W., Pellicciotti, F.,Bierkens, M.F.P., 2013. Rising river flows throughout the twenty-first century in two Himalayan glacierized watersheds. Nature Geosci, 6, 742-745.

Immerzeel, W.W., Van, B., Bierkens, M.F.P., 2010a. Climate change will affect the Asian water towers. Science, 328, 1382-1385.

Immerzeel, W.W., Van, B., Bierkens, M.F.P., 2010b. Climate change will affect the Asian water towers, Science (80-.)., 328(5984), 1382–5, doi:10.1 126/science.1 183188.

IPCC. 2014. Climate change 2014, Impacts, Adaptation, and Vulnerability, Part A: Global and Sectoral Aspects, working group II contribution to the fifth assessment report of the intergovernmental panel on climate change. Cambridge University Press.

Jansson, P., Hock, R., Schneider, T., 2003. The concept of glacier storage: a review, Journal of Hydrology, 282(1): 116-129.

Kayastha, R.B.,Ageta, Y.,Nakawo, M., 2000. Positive Degree-day factors for ablation on glaciers in the Napalese Himalayas: case study on Glacier AX010 in Shorong Himal Nepal. Bulletin of glaciological research, 17.1-10.

Khan, A., Bibi, S.N., Laura, C.B., 2014. Separating snow, clean and debris covered ice in the Upper Indus Basin, Hindukush-Karakoram-Himalayas, using Landsat images between 1998 and 2002. Journal of Hydrology 521 46–64.

Lutz, A.F., Immerzeel, W.W., Shrestha, A.B.,Bierkens, M.F.P., 2014a. Consistent increase in High Asia's runoff due to increasing glacier melt and precipitation. Nature Clim. Change, advance online publication. DOI: 10.1 038/NCLIMATE2237

Lutz, A.F., Immerzeel, W.W.,Kraaijenbrink, P.D.A., 2014b. Gridded Meteorological Datasets and Hydrological Modelling in the Upper Indus Basin. Wageningen,The Netherlands: Future Water, Costerweg 1V, 6702 AA Wageningen, The Netherlands, for International Centre for Integrated Mountain Development (ICIMOD).

Martinec, J., 1975. Snowmelt-runoff model for stream flow forecasts. Nordic Hydrology, 6(3), 145-1 54. Doi:10.2166/nh. 1975.010.

Martinec, J. Rango, A., 1986. Parameter values for snowmelt runoff modelling, Journal of Hydrology, 84, 197- 219.

Mihalcea, C., Mayer, C., Diolaiuti, G., Lambrecht, A., Smiraglia, C., and Tartari, G., 2006. Ice ablation and meteorological conditions on the debris-covered area of Baltoro glacier, Karakoram, Pakistan. Annals of Glaciology 43.

Moriasi D.N., Arnold, J., Liew, M.W., Bingner, R.L., Harmel, R.D.,Veith, T.L., 2007. Model evaluation guidelines for systematic quantification of accuracy in watershed simulations. Trans. Am. Soc. Agric. Biol. Eng., 50(3), 885–900

Naz, B. S., 2011. The Hydrological sensitivity of the Upper Indus River to glacier changes in the western Karkakoram Himalayas. PhD, Purdue University, USA.

Rasul, G., Chaudhry, Q.Z.A., Mahmood, K., Hyder, W., Dahe, Q., 2011.Glaciers and Glacial Lakes under Changing Climate in Pakistan. Pakistan Journal of Meteorology. Vol. 8, Issue 15.

Savoskul, O.S., Smakhtin, V., 2013. Glacier Systems and Seasonal Snow Cover in Six Major Asian River Basins: Hydrological Role Under Changing Climate. International Water Management Institute, Colombo, Sri Lanka, Report 150. doi: 10.5337/2013.204.

Schaefli, B., Hingray, B., Niggli, M., Musy, A., 2005, A conceptual glacio-hydrological model for high mountainous catchments, Hydrol. Earth Syst. Sci., 2(1), 73–117, doi:10.5194/hessd-2-73-2005.

Sevruk, B., 1985. Correction of precipitation measurements, Workshop on the Correction of Precipitation Measurements. WMO/IAHS/ETH, Zurich, Switzerland, pp. 13–23.

Sevruk, B., 1989. Reliability of precipitation measurement, International Workshop on Precipitation Measurement. WMO Tech. Document, pp. 13–1 9.

Shrestha, A. B., and Aryal, R., 2010. Climate change in Nepal and its impact on Himalayan glaciers, Reg. Environ. Chang.,1 1(S1), 65–77, doi:10.1007/s10113-010-0174-9.

Solomon, S., 2007.Climate change 2007: the physical science basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge

Subramanya, K., 2008.Engineering hydrology, 4th edn. Tata McGraw-Hill Education, New Delhi

Tahir, A.A., Chevallier, P., Arnaud, Y., Ahmad, B., 2011 .Snow cover dynamics and hydrological regime of the Hunza River basin, Karakoram Range, Northern Pakistan. Hydrology and Earth System Sciences 15(7):2275–2290. www.hydrolearth- syst-sci.net/15/2275/201 1/; accessed 4 August 2011 .http://dx.doi.org/1 0.5194/hess-15-2275-2011.

United Nations, 2010.Population division of the department of economic and social affairs, World population prospects. http://esa. un.org/unpd/wpp/Sorting-Tables/tab-sorting-population. htm.

WAPDA, 1979. Tarbela dam project: Sedimentation Base Surveys. Water and Power Development Authority, Lahore.

Weiland, F.C.S., VanBeek, L.P.H., Kwadijk, J.C.J.,Bierkens, M.F.P., 2010. The ability of a GCM-forced hydrological model to reproduce global discharge variability. Hydrological Earth System Science, 14: 1595-1621. doi: 10.51 94/hess-14-1595-2010.

Yu, W., Yang, Y. C., Savitsky, A., Alford, D., Brown, C., Wescoat, J., Debowicz,D. Robinson, S., 2013. The Indus Basin of Pakistan: The Impacts of Climate Risks on Water and Agriculture. Pakistan: The World Bank, South Asia Region.

Representative Concentration Pathways (RCPs)

Scenarios that include time series of emissions and concentrations of the full suite of greenhouse gases (GHGs) and aerosols and chemically active gases, as well as land use/land cover (Moss et al., 2008). The word representative signifies that each RCP provides only one of many possible scenarios that would lead to the specific radiative forcing characteristics. The term pathway emphasises that not only the long-term concentration levels are of interest, but also the trajectory taken over time to reach that outcome (Moss et al., 2010). **WGIII**

RCPs usually refer to the portion of the concentration pathway extending up to 2100, for which Integrated Assessment Models produced corresponding emission scenarios. Extended Concentration Pathways (ECPs) describe extensions of the RCPs from 2100 to 2500 that were calculated using simple rules generated by stakeholder consultations, and do not represent fully consistent scenarios.

Four RCPs produced from Integrated Assessment Models were selected from the published literature and are used in the Fifth IPCC Assessment as a basis for the climate predictions and projections presented in WGI AR5 Chapters 11 to 14:

RCP2.6 One pathway where radiative forcing peaks at approximately 3 W m^{-2} before 2100 and then declines (the corresponding ECP assuming constant emissions after 2100);

RCP4.5 and **RCP6.0** Two intermediate stabilisation pathways in which radiative forcing is stabilised at approximately 4.5 W m^{-2} and 6.0 W m^{-2} after 2100 (the corresponding ECPs assuming constant concentrations after 2150);

RCP8.5 One high pathway for which radiative forcing reaches greater than 8.5 W m^{-2} by 2100 and continues to rise for some amount of time (the corresponding ECP assuming constant emissions after 2100 and constant concentrations after 2250).

Paper No. 803

GROUNDWATER PROSPECTUS, CHALLENGES AND MANAGEMENT STRATEGIES IN INDUS BASIN

Ghulam Nabi, Noor Muhammad Khan, Muhammad Waseem,
Habib-ur-Rehman, Ijaz Ahmad

GROUNDWATER PROSPECTUS, CHALLENGES AND MANAGEMENT STRATEGIES IN INDUS BASIN

By:

Ghulam Nabi[1], Noor Muhammad Khan[1,2]., Muhammad Waseem[1], Habib-ur-Rehman[2], Ijaz Ahmad[1]

Abstract

In Pakistan, on-demand availability of groundwater has transformed the concept of low and uncertain crop yields into more assured crop production. Increased crop yields have resulted in food security and improved rural livelihoods. However, this growth has also led to problems of overdraft, falling water tables and degradation of groundwater quality, and yields generally remain well below potential levels. Over the last three decades, Pakistan has tried several direct and indirect management strategies for groundwater management. However the success has been limited. There is a need to develop frameworks and management tools that are best suited to Pakistani needs. Pakistan should follow both supply and demand management approaches. For demand management, adoption of water conservation technologies, revision of existing cropping patterns and exploration of alternate water resources should be encouraged.

Keywords: Groundwater, Water Quality, Regulation, Aquifer, Irrigation demand

Introduction

Groundwater has emerged as an exceedingly important water resource and its increasing demand in agriculture, domestic and industrial uses ranks it as a resource of strategic importance. Global estimates show that approximately 4,430 km^3 of fresh water resources are abstracted annually, of which 70% are used in agriculture, 25% in industry and 5% in household (Kinzelbach et al. 2003). On the whole, annual groundwater abstracted for the world can be placed at 750–800 km3, which is about one-sixth of the total freshwater abstraction (Shah 2000). The amount of groundwater contribution to agriculture is less as compared to surface water on the global scale, yet its unique advantages like reliability, accessibility, on-demand availability, less capital investment and high productivity outweigh the volumetric access of surface water.

Indus Basin Irrigation System (IBIS) of Pakistan was designed about a century along with an objective to expand settlement opportunities, prevent crop failure and avoid famine (Jurriens and Mollinga 1996). IBIS is a gravity run system with minimum management and operational requirements, which is an advantage with an inherited disadvantage of inflexibility. The operation of IBIS is based on a continuous water supply and is not related to actual crop water requirements. Irrigation canals are usually not allocated more than their design capacity, of which a typical value is about 2mm/day. Despite significant increases in storage capacities, it is essentially a supply-based system. This cannot accommodate changing water demands during the crop season. The total surface water availability in the Indus Basin is 137 × 109 m^3 with a total served area of 16.7 million ha (Bhutta and Smedema 2007)

1 Centre of Excellence in Water Resources Engineering, University of Engineering and Technology, Lahore 54890, Pakistan

2 Civil Engineering Department, University of Engineering and Technology, Lahore 54890, Pakistan

Large amounts of ground water are present under unconfined conditions in the Indus Plain and other parts of Pakistan. The aquifer in the Indus Plains mainly consists of sandy alluvium to a considerable depth and form a highly transmissive aquifer system. The thickness of the sandy deposits vary from more than 300 m (1000 ft) in Punjab and upper Sindh to around 60 m (200 ft) in lower Sindh. The aquifer hydraulic conductivity varies from 50 to 200 m/d in Punjab and KPK and from 25 to 50 m/d in Sindh as finer alluvial deposits were carried by river water to lower parts of Indus Plains.

The ground water reserve is constantly being replenished by recharge from different sources as seepage from irrigation canals, watercourses and fields, seepage from link canals, seepage from rivers, and recharge from precipitation. All of the recharge to the ground water body cannot be usefully recovered e.g. recharge in the areas having saline ground water, areas which are shallow or have have low transmissivity. The extent of recharge estimate differs widely. In 1988 WAPDA estimated total recharge as 56 BCM (Billion Cubic Meter) and useable recharge as 36 BCM. The annual recharge was estimated by Chandio and Aftab (1997) as 62 BCM. ACE- Halcrow (2001) estimated the total ground water balance as 82 BCM. FPC (1990) estimated useable recharge as 45 BCM (Billion Cubic Meter). Thus the sustenance of ground water reserve depends upon the recharge from the surface water system in the region. The total useable recharge per annum which can be recovered is estimated as 28.9 BCM with salt content less than 1500 mg/l and additional 6.7 BCM with salt content varying from 1500 to 3000 mg/l.

Although the ground water is available in large quantities, yet its exploitation is quite costly. The surface water supplies cost only Rs. 30 to 50 per acre-feet (AF) to farmers. On the contrary the ground water costs Rs. 1200 to 1500 per AF in shallow water table areas (DWT < 10 m) and Rs. 2600 to 4500 per AF in deep water table areas (DWT > 20 m). Nevertheless the ground water serves useful purpose of supplying water extremely needed for domestic, industrial and irrigation use especially in the event of droughts.

Groundwater Fluctuations

Pakistan has been endowed with vast quantities of ground water. The ground water resources of the country exist in the form of vast unconsolidated aquifers in the Indus Plain which have been recharged in the geologic times from natural precipitation and river flows, and more recently, by the seepage from canal system and agricultural fields (PANCID, 2005). A total of 35 million hectares mostly located in the Indus Plains (in Punjab and Sindh) are underlain with groundwater of various qualities. Smaller quantities of ground water are also available in arid zones, intermountain valleys and areas with recharge sites. The piedmont plains for various rivers in Baluchistan also contain small amounts of groundwater.

The ground water reservoir is constantly being recharged by irrigation systems, rivers and precipitation and, thus, represents renewable resources. The groundwater reservoir underlying the Indus Plains is an inherent offshoot of the canal system in the area. The total groundwater recharge is estimated as 82 billion cubic meters - BCM (66 MAF) out of which useable recharge is as 45 BCM (36 MAF) per annum. The groundwater is being exploited by installing public and private tubewells, mostly for irrigation, municipal and industrial purposes. The groundwater now supplies about 45% of the crop water requirements in the country (Bhatti, 2005). It is considered that further ground water development potential of the irrigated Indus Plains is of the order of 10 BCM (8.1 MAF) per annum.

Data on groundwater use are scarce; however, Figure-1 presents a back-cast of the probable trajectories of growth in groundwater use in selected countries (Shah, 2009). In the USA, Spain, Mexico, and North African countries, like Morocco and Tunisia, total groundwater use peaked during the 1980s. In South Asia and the North China plains, the upward trend began during the

1970s and is just plateauing now in 2014. A third wave of growth in groundwater irrigation is now taking place in many parts of sub-Saharan Africa and in some south and south-east Asian countries, such as Cambodia, Indonesia, Viet Nam, Laos, Myanmar, and Sri Lanka (Barker and Molle, 2002; Giordano, 2006; Shah, 2009).

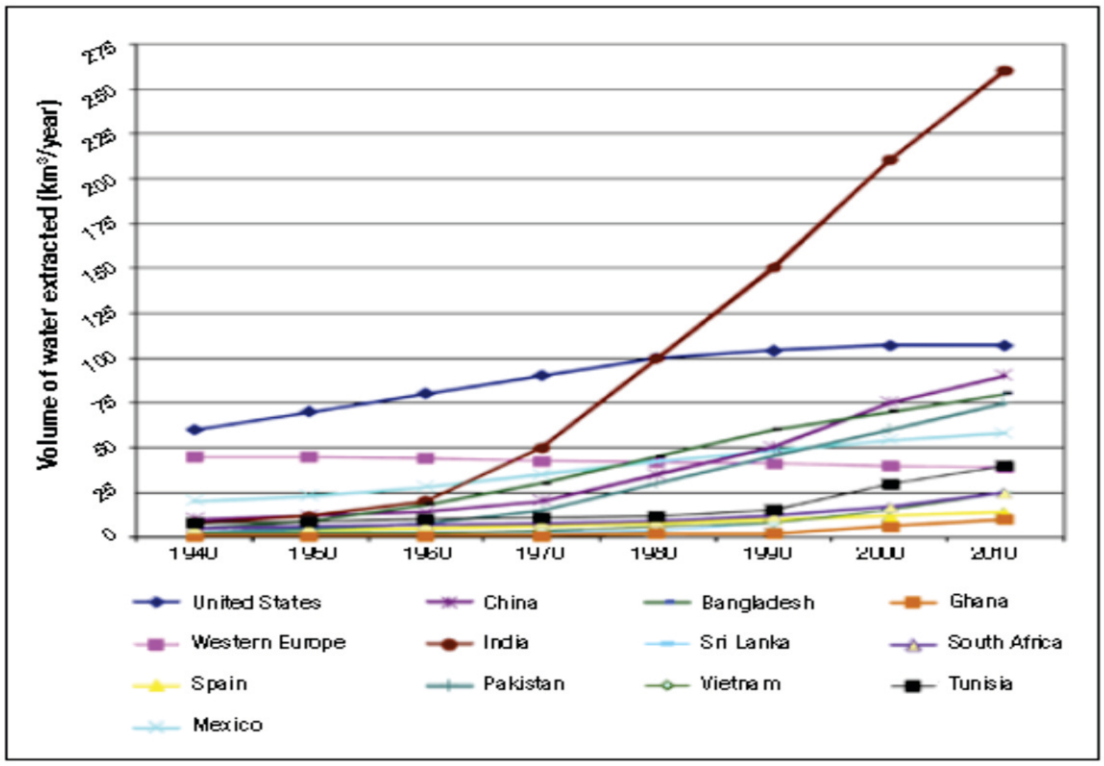


Figure-1: Growth trends in global groundwater use

Groundwater Use for Irrigation at International Level

There are three distinct groups. First, are the many low-income developing countries (such as India) where the marginal value product of groundwater is modest, but it is the basis of livelihoods for large sections of the population. Second, includes regions (like California, Morocco, and Spain), where groundwater-value productivity is high and groundwater irrigation continues because it has a large impact on commercial farming incomes and on agricultural exports. The third includes regions (like Jordan) where groundwater is often the only source of irrigation. This economic dynamic is critical to success in eliciting farmer participation in the sustainable management of aquifers. Technical interventions that fail to factor in this dynamic will have little chance of success. Figure-2 provides a broad 'picture' of prominent groundwater-irrigation economies based on estimates of the proportion of the population dependent on groundwater irrigation for their livelihoods, the annual volume of groundwater used, and the value of groundwater-irrigated agricultural output (in US$) produced per cubic meter of water.

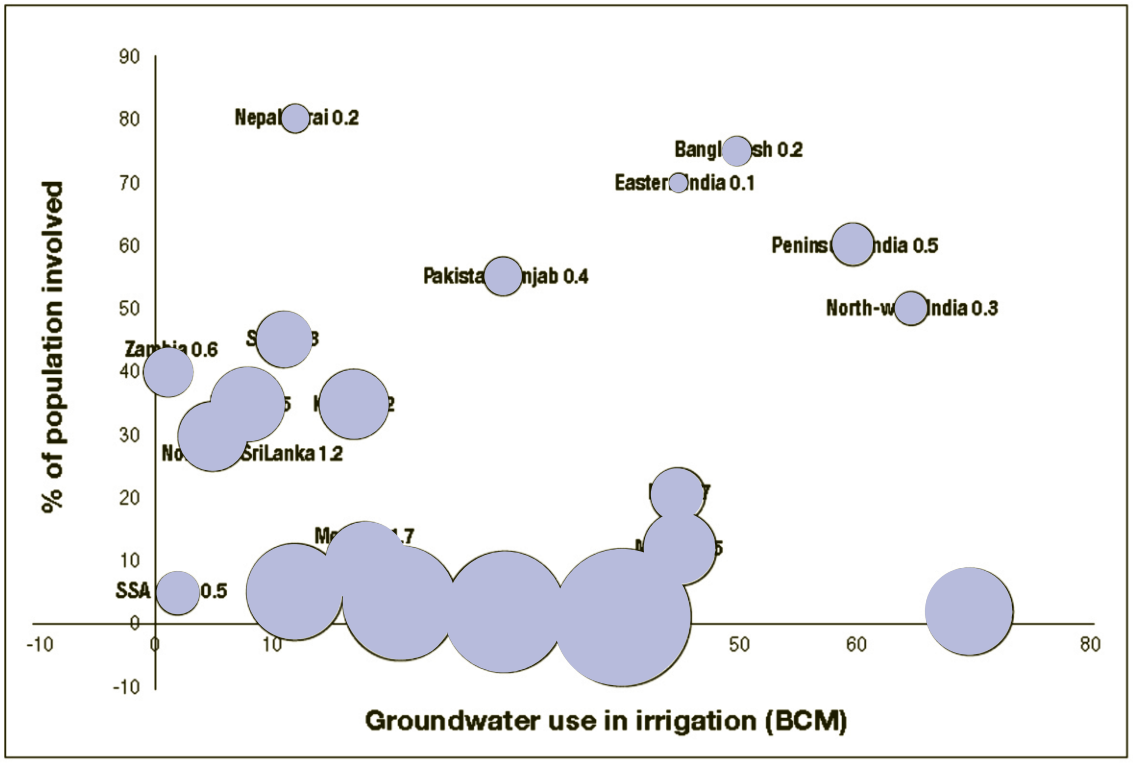


Figure 2: Prominent groundwater-irrigation economies: Volume of groundwater use (billion m^3/ year), proportion of the population dependent on groundwater-irrigation (%); and value of groundwater-irrigated farm output (US$/$m^3$)

Groundwater Quality

The groundwater reservoir in Pakistan is much greater than all present and potential surface water storage reservoirs in the country. However, the quality of the ground water varies from completely fresh to extremely saline. In total some 8.13 million ha is underlain by fresh water (salt content less than 1500 mg/l), 1.94 million ha by marginal water (salt content 1500 to 3000 mg/l) and 6.4 million ha by saline water (salt content more than 3000 mg/l). The major areas of fresh water lie adjacent to the rivers whereas the interior parts of Doabs and areas farther away from rivers generally have saline ground water. The sustenance of ground water reserve depends upon the recharge from the surface water system in the region. The total useable recharge per annum which can be recovered is estimated as 28.9 BCM with salt content less than 1500 mg/l and additional 6.7 BCM with salt content varying from 1500 to 3000 mg/l.

Fresh ground water also occurs in areas outside the Indus Plains in small isolated basins close to presently active areas of water recharge such as torrent beds, old river beds such as Hakra River and intermountain valleys such as Bannu, Mardan, Peshawar areas in NWFP and Quetta, Mastung, Lorali valleys and Makran coast in Baluchistan. Some of these aquifers are sufficiently deep and transmissive whereas other areas may be shallow or have low transmissivity. Such water is usually in small amounts and is generally exploited for human consumption and small-scale orchards production. The recharge to various aquifers outside the Indus Plains is 1.2 BCM. Areas outside the canal commands have generally deep saline ground water. The saline areas may have a thin layer of fresh water overlying the lower saline water. Such freshwater can also be skimmed to some extent for beneficial uses.

Groundwater Use

Indus Basin Irrigation System was designed for an annual cropping intensity of about 75 percent with the intention to spread the irrigation water over as large an area as possible to expand the settlement opportunities (Jurriens and Mollinga, 1996). Now, the increasing demand for food to cope with the ever-increasing population has caused the annual cropping intensities to rise to 150 to 180 percent in different canal commands. This has been possible only with increasing contribution of groundwater for meeting additional water requirements but has resulted in both mining and quality deterioration of the aquifers. Large-scale groundwater irrigation demonstrated under Salinity Control and Reclamation Projects (SCARPs) in 1960s led to a proliferation of private tubewells with a capacity of about one cusec (cfs) and less by farmers in the 1970s, 1980s and onward. The cropping intensity was 102.8, 110.5 and 121.7% during 1960, 1972 and 1980 respectively (Ahmad, 1995), and now operating at about 150% and even higher in different areas. As a result, groundwater mining due to higher abstraction rates as compared to the corresponding recharge is well reported in the literature (Shakir et al. 2011; NESPAK/SGI. 1991; Steenbergen and Olienmans, 1997; Halcrow 2006; Basharat and Tariq 2012).

Ground water is generally exploited for human consumption and irrigation and agricultural production by installing tubewells in public or private sector. In areas with shallow water tables, the ground water is pumped out under SCARP program to provide drainage of the areas. Water is pumped by installing either public or private tubewells in the country. Under different SCARPs more than 16,500 tubewells of different capacities were installed in both fresh and saline ground water areas during the period 1960 to 1995. These wells have average annual pumpage of 5.93 and 5.23 BCM in Kharif and Rabi periods, respectively. The number of public/SCARP tubewells is now decreasing due to reasons as mechanical life of the wells and SCARP Transition Program where public tubewells are being disinvested and sold/transferred to private sector in various parts of the country.

The challenges associated with tubewell development are overdraft, high energy cost, pollution, soil salinity. In the Punjab 12% 67% and 21% are driven by electricity, diesel engines (high speed peter engine as well as slow speed) and tractors, respectively. The percentage of electric tubewells has decreased from more than 30% in 1991 to around 11% in 2002 due to an upward change in electricity tariff. The tubewell utilization is 17.75% for electric tubewells, 6.54% for peter diesel engines and 7.79% for tractor driven tubewells with overall average as 8.76% (11.36% in Kharif and 6.15% in Rabi). The annual pumping is determined as 13.2, 20.9 and 9.32 BCM for electric, diesel and tractor driven tubewells respectively and total pumping as 43.4 BCM.

Skimming well technology with multiple strainers is used in areas having a thin layer of fresh water atop lower saline aquifer. Some 2 to 26 strainers spaced 1.5 to 4/5 m with depth ranging from 9 to 27 m have been used as most used. Such wells with 3-6 strainers spaced uniformly on periphery of 1.5 m diameter circle with strainer depth not exceeding 60% of the fresh layer thickness can produce 3-8 l/s discharge with 4-6 hrs. pumping per day; longer screens and/or longer pumping duration will result in irreversible upcoming beneath the well and consequent deterioration of water quality.

Ground Water Development Potential

The ground water resources in the country are not fully exploited by now. Analysis for 1985-86 (Wapda 1988) indicates that further ground water development potential of the irrigated Indus Plains (Table 1.11) is of the order of 10.25 BCM (8.3 MAF) per annum (Punjab = 6.79 BCM, Sind = 2.1 BCM, and NWFP = 1.36 BCM). The ground water development potential outside the Indus Plain is small and estimated as 2.0 BCM (1.62 MAF) per annum. PANCID (2005)

estimated the future potential as 7.4 BCM (useable potential = 66.6 BCM, present pumpage = 59.2 BCM). Bhatti (2005) noted that the sustainable groundwater potential in Pakistan is 48 MAF/annum (Punjab = 36, Sindh = 8, KPK = 2, Baluchistan = 2 MAF) with additional development potential of 6 MAF only. The ground water development potential is not uniformly distributed and in some areas the present abstraction exceeds the annual recharge in the area. Part of the water recharge in the marginal and saline areas may also be exploited by tapping and skimming the overlying lenses of fresh ground water by suitable technology including skimming and scavenger wells. Ground water exploitation in Pakistan had already resulted in various problems in some regions. These problems include excessive water table lowering due to ground water mining, saline water upconing, and lateral saline water intrusion. Presently ground water development in Pakistan is unrestricted, unregulated and without any proper plans. It is necessary that future ground water development in the country must be well guided and regulated with the intention to not accentuate the above mentioned problems at minimum or better to reverse and overcome the problems being faced due to earlier ground water developments.

Masood (2001) and Masood and Gohar (2000) estimated that Punjab province has annual pumping as 36 MAF and the recharge is estimated as 30.8 MAF resulting in decline of ground water table levels. For total command area of 24.62 MA, the area with depth to water table of less than 3m decreased from 39.2% in 1960 to 25.2% in 1999. The area with depth to water table greater than 3m increased from 60.8% in 1960 to 74.8% in 1999. This indicates ground water table falling trend in the region.

Water Conservation Strategy

To work out a sound and cogent water conservation strategy is the need of the time, as demand for water continues to rise because of increasing use of water in agriculture and industry for the purpose of economic development and due to rapid growth of population, whereas there is limited supply of water. Water management is the biggest challenge of 21st century confronted by the country, as irrigated agriculture is 24 percent of GDP, the livelihood for the majority of country and input of agro-based industry/exports. It has been made known that a considerable amount of water is lost during its conveyance for the seepage in the lengthy canals. Proper lining of the canal system could reduce these losses. According to a WAPDA Report more than 5 MAF of irrigation could be saved by lining of minor canals and additional 3.6 MAF could be saved by improvement of watercourses. It is heartening to note that Government of the Punjab has introduced modern telemetery system to check and control water theft by the farmers. In order to overcome the menacing of water shortage and its losses, it has become imperative to work on the lines of “Blue Revolution” which is a threshold of the strategy meant for making use of more effective techniques and obtaining optimum results for reduction in water losses. The definition of “Blue Revolution” has been coined as a system of drip irrigation that delivers water directly to the roots of crops by cutting use of water by 30 to 70 percent and raising crop yield on the average by 20 to 90 percent.

The Medium Term Development Framework (MTDF)

(i) adoption of integrated approach, rational resource use, and the introduction of water efficient techniques;

(ii) containment of environment degradation;

(iii) institutional strengthening, capacity building and human resource development (HRD);

(iv) improving performance and utilization of local systems through better planning, management and community participation;

(v) improving quality of life and easy access to water supply, especially for women,

(vi) improving sanitation through sewerage and drainage schemes;

(vii) promoting increased take up of household sanitation; and

(viii) improving the understanding of the linkages between hygiene and health through community education campaigns, especially among the women and children.

Apart from MTDF strategy following recommendations are proposed in the contest of water conservation and management; Crash program for cleaning of water channels including canals / watercourses and distributaries. Participatory water management at secondary tertiary level in collaboration with provincial irrigation departments.

The groundwater should be considered as Government property, there should be regulation and restrictions on groundwater pumping. Regulating ground water pumping by issuance of licenses to check overdraft of aquifer. Better water management for increasing cropping intensity with riverine area. Technical land leveling, surge irrigation, high irrigation efficiency technology including drip and sprinkler.

The high delta crops should be replaced with low delta crops. Strengthening of institutional capacity building by improving financial sustainability. Better and more efficient use of funds. To harness the uncultivated lands for irrigation purpose, storage of floodwater during Monsoon season by construction of a series of small dams/reservoirs on the barren lands and Barani areas of Northern Punjab, KPK and Balochistan. Attracting more foreign investment by making an environment lucrative to it. Launching of incentive based upon public campaign emphasizing conservation of water at all levels.

Conclusions and Recommendations

There should be integrated effort of research and implementing institutions to find the solutions to groundwater issues by comprehensive studies, the following.

i. Trends in groundwater pollution; trends in loss of groundwater quality and related aquifers services.

ii. Conjunctive use and management of groundwater and surface water.

iii. Urban-rural tensions; opportunities for co-management.

iv. Management of recharge/discharge processes and aquifer equilibrium states

v. Groundwater policy and governance.

vi. Legal framework for sustainable groundwater governance.

vii. Trends in local groundwater management institutions / user partnerships.

viii. Social adoption of groundwater pumping technology and the development of groundwater cultures: governance at the point of abstraction.

ix. Macro-economic trends that influence demand for groundwater and related aquifer services.

x. Governance of the subsurface and groundwater frontier.

xi. Political economy of groundwater governance.

xii. Groundwater and climate change adaptation.

References

Ahmad N., 1995. Groundwater Resources of Pakistan (Revised), 16B/2 Gulberg-III, Lahore.

Basharat M. and Tariq A. R, 2012. Spatial climatic variability and its impact on irrigated hydrology in a canal command. Arabian Journal for Science and Engineering, issue No. 37-8.

Bhatti, S. A. 2005. Water Resources of Pakistan. Daily Dawn 12-May-2005. Karachi.

Halcrow, 2006. Punjab irrigated agriculture development sector project, Final report Annex 5 – Groundwater management. Asian Development Bank TA-4642-PAK.

Jurriens R, Mollinga PP (1996) Scarcity by design: protective irrigation in India and Pakistan. Irrig Drain 45(2):31–53 Google Scholar

Jurriens R., Mollinga PP. 1996. Scarcity by design: protective irrigation in India and Pakistan, ICID Journal 45(2): 31-53.

Kinzelbach W, Bauer P, Siegfried T, Brunner P (2003) Sustainable groundwater management—problems and scientific tools, vol 26, no 4. Institute for Hydromechanics and Water Resources Management, ETH, Zurich, Switzerland, pp 279–283 Google Scholar

Masood, S. and S. Gohar. 2000. Participatory drainage and ground water management under Punjab Private Sector Groundwater Development Project. Proceedings of National Seminar on Drainage in Pakistan Aug 16-18, 2000. Institute of Irrigation and Drainage Engineering, Mehran University of Engineering & Tech., Jamshoro, Sindh, Pakistan. pp:29-44

NESPAK/SGI (1991) Contribution of private tubewells in the development of water potential. Final report. NESPAK in association with Specialist Group Inc (Pvt) LtdGoogle Scholar

NESPAK/SGI. 1991. Contribution of Private Tubewells in the Development of Water Potential. National Engineering Services of Pakistan and Special Group Inc., Lahore.

PANCID 2005. (@www.icid/org/cp_pakistan.html)

Shah T (2000) Groundwater markets and agricultural development: a South Asian overview. In: Proceedings of regional groundwater management seminar, Pakistan Water Partnership, 9–11 October 2000 Google Scholar

Shah T, Debroy A, Qureshi AS, Wang J (2003) Sustaining Asia's groundwater boom: an overview of issues and evidence. Nat Resour Forum 27:130–141. doi: 10.1111/1477-8947.00048 Cross Ref Google Scholar

Shakir, AS., Rehman H., Khan N M., and Qazi AU. 2011. Impact of Canal Water Shortages on Groundwater in the Lower Bari Doab Canal System in Pakistan. Pakistan Journal of Engineering & Applied Sciences. 9 (87-97).

Wapda 1988. Water Sector Investment Planning Study: Groundwater Development Potential (canal commanded area). Planning Division, WAPDA, Wapda House, Lahore. Nov. 1988.

WAPDA (2007) Waterlogging, salinity and drainage situation. SCARP Monitoring Organization, Water and Power Development Authority, Lahore Google Scholar

World Bank (2007) Punjab groundwater policy—mission report. WB-SA-PK-Punjab GW Mission report. http://www.worldbank.org/gwmate. Accessed June 2007

LIST OF PREVIOUS PAPERS

PRESENTED AT PROCEEDINGS

PAKISTAN ENGINEERING CONGRESS

LIST OF PAPERS PRESENTED AT ANNUAL PROCEEDINGS

*"**M**" Indicates that the Paper was awarded the **Congress Medal***
*"**Km**" Indicates that the Paper was awarded the **Kennedy Medal***

S. No. Title of Paper and Name of the Author

VOLUME - I - 1913 (1912-14)—(Out of Print)

1 Grain Elevators and their Application to the Punjab Wheat Transport Problem. - **Victor Bayley.**
2 The Formation of Land by Rivers and Torrents in the Punjab. - **A. J. Wadley.**
3 Auxiliary Reservoirs for Irrigation in the Punjab. - **C. E. Blaker**
4 Dams and Storage Reservoirs. - **F. W. Schonemann.**
5 Concrete Work in New Loco Shops, Lahore. - **J. A. Bell.**
6 Reinforced Concrete Pile Foundations in the West Beyne Bridge. - **E. A. C. Lister.**
7 The Mechanical Equipment of Irrigation Works. - **John Ashford.**

VOLUME - II - 1914 (1914-15)– (Out of Print)

8 The Hindustan - Thibet Road. - **A. R. Astbury**
9 The Development of Canal Falls for the Production of Artificial Fertilizers. – **Captain B. C. Battye.**
10 Tube Wells. - **T. A. Miller Brownlie.**
11 The Design of Canal Head works. - **F. W. Schonemann.**
12 Maintenance of Marala Weir. - **Cecil A. Colyer.**
13 Duty of Distributaries in Sandy Soils. - **F. Marshall Purves.**
14 Notes on Some Works on the Upper Swat Canal. - **A. J. Wadley.**
15 Some Notes on the Results of River Training in the Punjab. - **F. J. Harvey.**
16 Notes on the New Road Bridge over the River Ravi at Lahore. - **D. Macfarlane.**
17 Open Fireplaces in Bungalows. - **F. B. Martin.**

VOLUME - III - 1915 (1915-16)– (Out of Print)

18 The Construction of a Double Track Girder Bridge across the Jumna River on the North - Western Railway between Kalanour and Sarsawa. - **A. J. Sleigh.**
19 Reinforced Concrete Platforms for Carriage Washing at Lahore Station. - **Captain E. P. Anderson.**
20 A Research and Investigation Section for the Public Works Department. - **Cecil A. Colyer.**
21 Temperature Experiments at Lahore. - **W. S. Dorman.**
22 Water Proofing Operations on the Jhang Branch of the Lower Chenab Canal during 1913-14. - **T. A. Curry**
23 Some Practical Mathematics of Canal Works. - **A. J. Wadley.**
24 The Training Works on the Sutlej at Rupar. - **H. W. Nicholson.**

VOLUME - IV - 1916 (1916-17)– (Out of Print)

25 The Testing of Bridges. - **H. S. Sales.**
26 Notes on Efflorescence on Buildings and Structures together with the Means of Combating it. - **C. S. Waite.**
27 River Training Works and Diversion of the Sutlej near Bahawalpur. - **J. Harford.**
28 Distributary Heads and other Canal Diversion Works. - **A. S. Gibb.**
29 The Design of Head Regulators of Irrigation Distributaries. - **F. W. Schonemann.**
30 Distributary Off-takes in Relation to Silt Conditions. - **F. V. Elsden.**

VOLUME - V - 1917 (1917-18)

31 The Absorption Losses of Punjab Irrigation Canals. - **F. W. Schonemann.**
M32 Lining Irrigation Channels. - **J. A. Curry.**
33 The Namal Dam. - **Lahna Singh.**
34 Sialkot Water Supply. - **E. S. Heard.**
35 Surface Drainage Schemes in the Punjab. - **Amar Nath Nanda.**
36 Canal Outlets. - **B. P. Varma.**

VOLUME - VI - 1918 (1918 - 19) – (Out of Print)

37 The Extension of American Cotton Cultivation under Irrigation in the Western Punjab and Sindh. - **W. Roberts.**
38 The Subsoil Water Table under the Tracts Irrigated by the Lower Chenab Canal. - C. G. May
39 Water Supply from Tube Wells. - **T. A. Miller Brownlie.**
40 Note on Tube Wells. - **John Ashford.**
41 Exclusion of Heavy Silt from Channels by Vaned Pitching. - **H. W. King.**
42 Reinforced Concrete Siphons on the Lower Swat Canal. - **F. H. Burkitt.**
43 The Distribution of Canal Water with Special Reference to Outlets. - **J.O. Waterhouse.**
44 Alignment Charts. - **A. C. Padday.**

VOLUME - VII - 1919 (1919-20)

45 Highways in the Punjab, Past and Future. - **W. S. Dorman.**
46 Mechanical Filter Installations at Jammu. - **P. G. Dani.**
47 Remodelling Inundation Canals in the Muzaffargarh District. - **G. W. Duthy.**
48 Discharge Observations. - **W. B. Harvey.**
49 Regime Channels. - **E. S. Lindley.**
50 A Project for Providing the Punjab with a Cheap Supply of Electric Power. - **F. L. Milne.**
M51 Experiments on Broad Crested Weirs. - **F. H. Burkitt.**
52 Water-Logging. - **Iqbal Hussain.**
53 Reinforced Concrete Tanks. - **R. A. Wallace.**
54 An Investigation and Research Institute for the Public Works Department. - **F. A. Carne.**
55

VOLUME - VIII - 1920 (1920-21)

55 Liquid Fuel Installation at Kotri, North - Western Railway. - **N. Pearce.**
56 Railway - Water Supplies. - **C. B. Barrie.**

57 Tube Well in Borstal Central Jail Garden at Lahore. - **W. S. Dorman.**
58 Shortening the Alexandra Bridge over the Chenab River near Wazirabad. - **F. C. Pavry.**
59 Ferro - Concrete Well Curbs and Roadway Slabs used on the Chenab Bridge. - **A. R. B. Armstrong.**
60 Kharif Channels. - **T. M. Bostock.**
61 The Design of Regulators for Distributaries. - **W. P. Thompson.**
62 Silt Vanes. - **H. W. King.**
63 Wet Soils and their Behaviour under Loads. - **Iqbal Hussain.**
64 Grades and Curves on Hill Roads. - **A. R. B. Armstrong.**
M65 A Few Aspects of the Punjab Road Transport Problem. - **K. G. Mitchell.**

VOLUME - IX - 1921 (1921-22)

66 A Description of the Erection and Operation of Sliding Forms in Grain Elevator Construction. - **Major. J. K. Wyman**
67 Drains on the Lower Chenab Canal. - **W. P. Thompson**
M68 Water-Logging from Irrigation Canals in Alluvial Soil. - **F. V. Elsden.**

VOLUME - X - 1922 (1922-23)

M69 The Design and Construction of Light Suspension Bridges. - **A. St. G. Lyster.**
70 Aerial Ropeways. - **Major F.N. Budden**
71 Supply of Road Metal in the Punjab. - **G. T. Pound.**
72 Sub Soil Water in the Punjab Plains. - **J. H. T. Middleton.**
73 The Electrical Equipment of the North Western Railway Power Station and Workshops at Moghalpura. - **K. Preston.**
74 The Use of Mud in Building Construction. - **D. Macfarlane.**
75 Water Supply Improvements. - **W. Cathrow.**
76 Notes on Exhibit of Road Transport Vehicles and Other Plant. - **W. S. Dorman** and Note on Hollow Walls. - **Major W. Garforth**

VOLUME - XI - 1923 (1923-24)

77 Percolation and Absorption of Water in the Soil. - **B. H. Wilsdon.**
78 Notes on Cracks in Buildings in Dera Ghazi Khan. - **J. H. Johnston.**
79 Notes on the Rusting of Steel in Contact with Lime Mortar. - **A. R. Astbury.**
80 Note on the Locating of a Burst Main. - **W. E. Buchanan.**
M81 Application of Modules in Irrigation. - **E. S. Lindley.**
82 Some Problems of High Voltage Transmission in the Lower Himalayas. - **Lt. Col. B. C. Battye**
82(a) A Note as to why certain Buildings in the Civil Lines in Ambala have cracked. - **W. S Dorman**

VOLUME - XII - 1924 (1924-25)

83 Tests carried out on Sand from the Sutlej River and Punjab Portland Cement. - **A. N. M. Robertson** and **A. Weighall.**
84 Temporary Quarters: No. 1 Division, Khyber Railway. - **Major. E. P. Anderson**

85 Notes on the Design of Girder-Bridge Abutments for Broad - Gauge (5'-6") Track. - **N. G. Watson.**

M86 Economic Railway Construction. - **Major E. P. Anderson**

87 Some Aspects of Track Maintenance and Permanent Way on the North-Western Railway. - **E. Watson**

88 Low Fall Hydro - Electric Power Installations. - **Major John Ashford**

89 Discharge Curve and a Slide Rule. - **E. S. Lindley**

90 Note on Aerial Photographs of Canal Works exhibited at the 1924 Congress Session. - **E. S. Lindley**

VOLUME - XIII - 1925 (1925-26)

91 Draglines and the Development of the Single Bucket Excavator. - **R. Hockney.**

92 Some Experiences with a Dragline Excavator. - **R. P. Hadow**

93 The Construction of the Road Bridges over the Chenab and Palkhu at Wazirabad. - **W. S. Dorman**

M94 Analysis of Partly Stiffened Suspension Bridges, Type No. 2F. - **J. Halcro Johnston**

95 Transportation of Silt by Flowing Water. - **P. Claxton.**

96 Principles of Design for Proportionate Flumes at Heads of Channels. - **Prabh Singh.**

97 Canal Falls and their Uses as Meters. - **E. S. Lindley**

VOLUME-XIV-1926 (1926-27)

98 The Sub soil Water-Table and Methods for its Investigation. - **B. H. Wilsdon.**

99 A Descriptive Note on the North - Western Railway Creosoting Plant at Dhilwan by **Wazir Singh Aggarwal.**

100 The Relativity of Navigation and Engineering Science. - **P. Claxton.**

101 Design of Canals. - **Pir Mohamed Ibrahim**

M102 Concrete Lining of the Gang (Bikaner) Canal. - **C. E. Jefferis.**

103 Weirs and Headworks on the Sutlej Valley Project and some Connected Problems. - **E. R. Foy**

104 The Construction of the Rawalpindi City Water - Supply Extension Scheme. - **J. A. R. Bromage**

105 The Metering of Water Supplies. - **W. E. Buchanan.**

VOLUME - XV - 1927 (1927-28)

106 Modern Road Construction. - **G. T. Pound**

107 Note on Organization of the Government School of Engineering Punjab Rasul. - **C. E. Blaker.**

108 Interlocked Adjustable Module in Precast Reinforced Concrete Units. - **Ajudhia Nath Khosla.**

109 Note on Outlets and Adjustable Proportional Modules. - **J. D. H. Bedford.**

M110 Report on Flume Experiments on Sirhind Canal. - **A. G. C. Fane**

111 The Broad - Crested Weir - Meter. - **C. A. Colyer.**

112 The Principles of Design of a Dissipator below a Fall. - **C. A. Colyer.**

113 Portland Cement. - **Campbell Gray.**

114 Report on Tensile Tests of Various Mortars. - **C. E. Blaker.**

VOLUME - XVI - 1928 (1928-29)

115 Cheap Feeder Railways of 5 feet 6 inches Gauge and the Bahawalnagar - Cholistan Railway. - **T. N. Kunzru.**

116 Some Experiences with Diesel Dragline Excavators. - **J. D. H. Bedford.**

117 The Sudan Public Works Department. - **D. Macfarlane.**

118 Water Supplies to Towns in Canal Colonies. - **J. A. R. Bromage**

119 Inundation Canal Practice. - **P. Claxton.**

120 Reinforced Concrete Bridges on the Sirhind Canal. - **A. G. C. Fane**

121 Reinforced Concrete through Roofing. - **Ajudhia Nath Khosla** and **Kanwar Sain.**

122 The Future of Communications in the Punjab. - **Major H. L. Woodhouse.**

123 Bituminous Road Construction in the Punjab. - **William Stewart Dorman**

124 The Treatment of Waterlogged or Threatened Areas by Changes in Distribution and Supply of Irrigation Water. - **Bernard Howell Wilsdon.**

VOLUME - XVII - 1929 (1929-30)

M125 Headless Canal Meters. - **F. H. Burkitt**

126 Energy of Flowing Water, Critical Flow and Standing Waves. - **A. M. R. Montague.**

127 Extension of the Training Works at the Jumna Bridge near Kalanour (between Saharanpur and Jagadhri). – **Rai Sahib D. C. Varma.**

128 Scientific Distribution of Canal Water and the Use of Auto-adjusting Orifice Distributors. - **Radha Krishna Khanna.**

129 The Tube Well Practice of the Public Health Circle, P. W. D. Punjab. - **D. A. Howell.**

130 Punjab Building Timbers and Methods of Extraction. - **H. M. Glover.**

131 Locomotive and Drinking Water-Supply on the North Western Railway. - **J. Vardon.**

132 The Purchase of Cement for Government Works. - **A. R. Astbury.**

VOLUME - XVIII - 1930 (1930-31)

133 Construction Plant and Methods Used on the Uhl River Hydro Electric Project. - **Col. B. C. Battye**

134 Hydraulic Observations on the Shyok Flood of 1929. - **J. P. Gunn.**

135 Erosion in the Punjab Himalayas and its Probable Effect on Water Supplies. - **L. B. Holland** and **H.M. Glover**

136 The Survey and Construction of the Kangra Valley Railway. - **Major R. D. Waghorn.**

137 Earth Roads. - **S. G. Stubbs.**

M138 Hydraulic Gradients in Sub soil Water Flow in Relation to Stability of Structures Resting on Saturated Soils. - **Ajudhia Nath Khosla**

139 Some Interesting Tubewells on the North - Western Railway. - **J. Vardon.**

140 Exponential Law of Sub-soil Flow. - **Dr. N. K. Bose**

141 Energy Losses over Long Crested Weirs. - **J. D. H. Bedford** and **A. M. R. Montagu.**

142 Stability of Weirs and Canal Works. An Application of the New Theory of Hydraulic Gradients. - **Ajudhia Nath Khosla**

VOLUME-XIX-1931 (1931-32)

143 Materials and Construction of Trunk and Distribution Pipe-lines for Water Supply Using Metal Pipes. - **D. A. Howell.**

144 Recent Practice in Girder Erection on the North - Western Railway. - **Major C. F. Carson**

M145 Construction of a Railway Bridge over the River Indus at Kalabagh. - **W. D. McD. Cruickshank.**

146 Theoretical Design of a New Type of Outlet for Irrigation Channels - **K. R. Sharma.**

147 Damaged Falls on Khadir Branch of the Pakpattan Canal. - **E. L. Prothero.**

148 Underpinning Satghara Rest House. - **K. R. Sharma**

149 Methods of Calculation and Analysis of Structures Employed on the North Western Railway. – **Rai Bahadur P. L. Dhawan.**

VOLUME-XX 1932 (1932-33)

150 Some Examples of Control of Floods in Torrents in the Punjab. - **Rajbansi Lal.**

151 A Study of the Internal Economy of Water as Practised by Zemindars on an Outlet on the Upper Bari Doab Canal. - **J. D. H. Bedford.**

152 Tubewells on Zhob Valley Railway, Baluchistan. - **J. Vardon.**

M153 Tunnelling in Connection with the Uhl River Hydro-Electric Project. - **G. H. Hunt. R. D. Keane,** and **N. V. Dorofeeff.**

154 Remodelling of Mithalak Distributary. - **K. R. Sharma**

155 Repairs and Remodelling of Rasul Weir, 1929-31. - **T. A. Foy**

156 Girder Erection of the deMontmorency Bridge Across the Jhelum River at Khushab. - **Capt J. R. Simpson**

157 The Completion of Kalabagh Bridge. - **F. C. Judges**

158 Pressure Observations at Jaurian and Dugri Siphons. - **P. A. Turner.**

159 Influence Surfaces for Concentrated Loads on Slabs. - **J. Halcro Johnston**

VOLUME-XXI-1933 (1933-34)

160 Description of Several Unusual Structures Adopted in Bridge Construction. - **W. T. Everall.**

161 Protection of Upstream Foreshore Mangla Regulator. - **F. F. Haigh.**

M162 Pressure Pipe Observation at Panjnad Weir. - **Ajudhia Nath Khosla.**

163 Dissipation of Energy Below Canal Falls. - **F. F. Haigh.**

164 Pipes and Fittings Used in Water Service to Buildings. - **J. A. R. Bromage.**

165 Theory of Earthquake Resisting Design with a Note on Earthquake Resisting Construction in Baluchistan. - **S. L. Kumar.**

166 Uses of Bibliography in Engineering. - **A. M. R. Montagu.**

167 An Optical lever Siltometer. - **V. I. Vaidhainathan.**

168 Silt Conduction by Irrigation Outlets. - **K. R. Sharma**

M169 Silt Exclusion from Distributaries. - **H. W. King.**

170 Experiments with a Short Crested Weir Model. - **C. C. Inglis.**

VOLUME-XXII-1934 (1934-35)

171 The Chakki - Dalhousie Road. - **J. Halcro Johnston**

172 Remodelling of Channels on the Lower Bari Doab Canal, Illustrated by Dilwan (15 L) Distributary. - **S. L. Malhotra.**

173 A Study of the Flow of Water under Works on Sand Foundations by Means of Models. - **E. McKenzie Taylor** and **Harbans Lal Uppal.**

M174 Metallic Arc Welding as Applied to Bridges and Allied Structures with Special Reference to the North - Western Railway. - **W. T. Everall** and **P. S. A. Berridge.**

175 Two Notes on Grouting Applied to Bridge Work. - **J. D. Watson**

176 On the Design of an A. P. M. - **Pandit K. R. Sharma**

177 The Construction of a Reinforced Concrete Bridge on the Grand Trunk Road over the Bhimber Nallah in Gujrat District on Vibro - Pile Foundations. - **P. L. Varma.**

VOLUME - XXIII - 1935 (1935-36)

178 Sillanwali Drain. - **S.D. Khangar** and **N. D. Gulhati.**

179 Replacement of Gallery No. 826 on the Kalka-Simla Railway by a Steel Trestle Bridge. - **W. A. Anderson**

180 Super Elevation on Highway Curves. - **Murari Lal.**

181 Provision for Temperature and Shrinkage Movements in Cement Concrete Structures (Plain and Reinforced). - **Kanwar Sain.**

182 Design of Weir on Sand Foundations. - **F. F. Haigh.**

183 The Extension of the River Training Works at Gidarpindi Bridge. - **G. A. Plank.**

184 The Lacey Slope Formula. - **T. Blench.**

185 Pressures Under a Model of Panjnad Weir and under the Prototype. - **Harbans Lal Uppal.**

186 The Selection of Electric Motors and Control Gear for Industrial Use. - **M. F. Thomson.**

VOLUME-XXIV - 1936 (1936-37)

187 Scientific Irrigation Channel Design. - **T. Blench.**

188 Water Distribution and Assessment of Revenue at Volumetric Rates. - **Khushi Ram Erry.**

189 A Silt Selective Distributary Head Regulator. - **Khushi Ram Sharma**

190 Electrical Method for Determining Pressure Distribution under Hydraulic Works. – **Dr. V. I. Vaidhianathan** and **Gurdas Ram.**

191 Reconditioning of Kankar Roads. - **Brij Mohan Lal.**

192 Silt-Movement and Design of Channels. - **Dr. N. K. Bose.**

193 Concrete Trackway on Lahore - Multan Road (Arterial No. 4) Miles 2 and 3 in Lahore District. - **Bhikam Singh.**

194 Flooding of Rohtak Civil Station in September, 1933 and Measures Taken for Relief and for Future Safety. - **Kanwar Sain**

M195 Reconstruction of the Khanki Weir. - **Ajudhia Nath Khosla**

196 Pipe Line Penstock, Pipe Tunnels and Surge Shaft on the Mandi Hydro Electric Scheme, Punjab. - **Capt. N. Boddington.**

VOLUME - XXV - 1937 (1937-38)

M197 Water-Logging on the Upper Chenab Canal, its Causes and Cure. – **Rai Bahadur Bawa Natha Singh**

198 Agricultural Economics with Special Reference to Irrigation Problems in the Punjab. - **W. Roberts**
199 The Raising of Jhelum Bridge. - **T. McIntyre.**
200 The Roads to Kulu. - **J. Halcro Johnston.**
201 Turbulent Flow in Channels. - **T. Blench.**
202 A Note on the Building of Two Reinforced Concrete Box Culverts on the North Western Railway - **S. L. Kumar.**
203 Some Notes on Gunite and its Uses on Certain Works on the North Western Railway - **S. L. Kumar.**
204 The Deg Diversion and the Combined Head-Fall and Aqueduct. - **B. K. Kapur.**
205 A Regulation Gauge for Headless Canal Meters. - **A. N. Wilson**
206 Quetta Reconstruction Progress 1935-36. - **Captain N. Boddington**
207 Experiments of Premix Work in Mile 35 G. T. Road. - **Murari Lal.**

VOLUME -XXVI-1938 (1938-39)

208 Fundamentals of Rate Fixing for Electrical Undertakings. - **H. P. Thomas**
209 Some Experiments on Seepage Losses in Irrigation Channels. - **Nand Gopal** and **K. R. Sharma.**
210 Remodelling Upper Chenab Canal Head Regulator. - **C. L. Handa**
M211 Silt Excluders. - **F. F. Haigh.**
212 Energy Theory of Turbulent Flow in Liquids. - **T. Blench.**
213 Syphon Under Rakh Branch for the Marh - Chiniot Drain. - **S. L. Malhotra.**
214 Protection Against Scour Below River and Canal Works. - **H. L. Uppal**
M215 Reconditioning Marala Weir. - **E. O. Cox** and **R. B. Ganpat Rai**
216 Conservation of Punjab Water Supplies. - **Dr. R. M. Gorrie.**
217 Earthquake Reconstruction in North Bihar. - **A. St. G. Lyster.**

VOLUME - XXVII - 1939 (1939-40)

218 Diagrams for the Design of an Adjustable Proportional Module. - **N. D. Gulhati**
219 Rail and Road Competition. - **F. R. Hawkes.**
220 The Water Supply of the Sun Eclipse Fair at Thanesar. - **D. A. Howell.**
M221 Lining of the Haveli Main line Canal. - **R. S. Duncan.**
222 Efflorescence in Buildings and a New Method of Cure. - **Nand Gopal** and **M. L. Mehta.**
223 Re-flooring the Sukkur Channel Bridge. - **S. L. Kumar.**
224 Construction of a Concrete Track in Miles 306-310 G. T. Road (Near Lahore). - **D. P. Nayar.**
225 Intensity of Traffic on Punjab Roads. - **Brij Mohan Lal.**
226 Training Works, River Control and Methods of Regulation at Rupar, Khanki, Marala and Rasul. - **B. K. Kapur**
227 A Study of the River Conditions on a Model of Khanki Head works and Investigation of Methods for Obtaining Uniform Distribution of Flow and Minimum Silt Entry in the Canal. - **Harbans Lal Uppal** and **Thakur Das Gulhati.**
M228 Finances and Economics of Irrigation Projects. - **Kanwar Sain.**
229 River Diversion at Trimmu. - **Som Nath Kapur.**

VOLUME -XXVIII - 1940 (1940-41)

M230 Remodelling Distributaries and Distribution of Water to Areas irrigated by Colony Canals. - **A. W. M. Jesson.**
231 Theory and Physics of Seepage Losses from Canal. - **K.R. Sharma.**
232 Sidhnai Dam Bridge. - **C. L. Handa** and **Madan Lal.**
233 Shock in Regime Channels. - **Gerald Lacey.**
234 Note on Design and Construction of the Shujabad Branch and its Distributaries. - **S. L. Malhotra.**
M235 The Formation and the Reclamation of Thur lands in the Punjab. - **M. L. Mehta.**
236 Flow in Expansions in Open Canals. - **A. R. Thomas**
237 Improved Adjustable Proportionate Modules and Open Flume Outlets. - **K. R. Sharma.**
238 An Outline of Town Planning. - **U. A. Coates.**
239 Construction of Cement Factory in Patiala State. - **H. Holman.**
240 Lining of Channels. - **G. R. Sawhney.**

VOLUME - XXIX - 1941 (1941-42)

241 Construction of a Road Bridge over the Sohan at Dhok Pathan. - **G. H. Nangea.**
242 Control of Flow on Curves in Open Channels. - **A. N. Wilson.**
243 The Engineering Side of Fire-Fighting. - **Hukam Singh**
244 Construction of the Emerson Barrage at Trimmu. - **S. N. Kapur.**
M245 Rainfall Runoff. - **S. D. Khangar** and **N. D. Gulhati**
246 Some Modern Bituminous Resurfacing Methods. - **Murari Lal.**
247 Investigations of New Railway Schemes. - **K. B. Nizam-ud-Din.**
248 The Karol Tubewell Scheme. - **H. L. Wadhera** and **A. R. Talwar.**
249 Hydraulics of Irrigation Channels. - **Ishar Das.**
250 Rational Concrete Mixes Compared to Arbitrary Mixes Using Typical Punjab River Sand and Gravel. - **H. Holman.**

VOLUME - XXX - 1942 (1942-43)

M251 The Kalabagh Barrage. - **S.I. Mahbub**
252 Design of Channels in Alluvium. - **N. K. Bose** and **K. R. Erry**
253 Observations on Lined (Haveli) Canals. - **S. N. Kapur**
254 Waterway Required under Bridges with Special Reference to the Rohi Beas Bridge on North Western Railway. - **Karnail Singh** and **Gurdial Singh**
255 Effect of Capillarity on Drainage in Waterlogged Areas. - **V.I. Vaidhianathan** and **Chanan Singh**
256 Soil Stabilization as applied to Roads in India. - **S. R. Mehra**
257 Densification of Canal Banks. - **S. I. Mahbub**
258 Electric Transmission Tower. - **R. C. Talwar**

VOLUME - XXXI - 1943 (1943-44)

259 Water Requirements of Crops. - **H. R. Stewart**
KM260 Lining of Channels. - **S. I. Mahbub**

M261 Construction of a Motor Road Round Simla. - **W. A. R. Baker** and **Balwant Singh**
262 Air Raid Protection for Buildings. - **N. B. Shroff.**
263 A New Treatment of the Principles of Flow. - **P. Claxton.**

VOLUME - XXXII - 1944 (1944-45)

M264 Irrigation Outlets. - **S. I. Mahbub** and **N. D. Gulhati**
265 Hydraulic Research Station Malikpur. - **H. L. Uppal**
266 Modern System of Training Artisans and Technical Personnel. - **H. B. Adams**
M267 Chief Considerations Affecting the Design and Usage of Railway Sleepers in India. – **S. L. Kumar.**
268 Preliminary Investigation for Storage Schemes. - **S. D. Khangar** and **B. R. Palta.**
269 Soil Compaction as Applied to Airfield Construction and Stability of Runway Slabs in High Spring Level Areas. - **C. L. Handa.**
270 Construction of Aerodromes in the Punjab. - **A. R. Khanna.**

VOLUME -XXXIII-1945 (1945-46)

271 Behaviour of Drift Sand and Method of Dealing with it. - **M. A. Rahim**
272 Methods of Discharge Observations. - **S. L. Malhotra**
273 Modern Features of Road Design. - **W. A. R. Baker.**
274 Recent Road Construction and Proposed Future Development in the Punjab. - **Brij Mohan Lal** and **R. N. Dogra**
275 River Training and Control by Pitched Islands.- **A. M. R. Montagu** and **Dr. H. L. Uppal.**

VOLUME - XXXIV-1946 (1946-47)

276 Engineering Economics of the Design and Construction of Dams. - **S. I. Mahbub** and **C. L. Handa**
277 Silting Tanks on the Western Jumna Canal. – **Rai Bahadur H. L. Vadera**
278 Principles of Well - Foundations, River Training and Protection Works.- **R. O. C. Thomson**
279 Determination of Runoff from Rainfall on Punjab Torrents. - **R. B. Kanwar Sain,** and **I. P. Kapila.**
280 Design of Rails. - **R. P. Lall.**
281 Damages Caused on Kangra Valley Road by Floods of August 1944 and their Restoration. - **R. L. Sondhi** and **G. C. Khanna.**

VOLUME - XXXV - 1947 (1947-48)

282 Hydrologic Data - Its Importance and Collection. - **N. D. Gulhati**
283 Construction of Grain Storage Bins in the Punjab. - **D. P. Nayar**
284 Water-Logging in Western Punjab. – **Rai Bahadur S. D. Khangar**
285 Movement of Moisture in Soils. - **Dr. A. G. Asghar.**
286 Improvements to Delhi and Lahore Stations. - **Y. P. Kulkarni** and **Gurdial Singh.**
286-(1) Engineering Education in the Punjab – **L. A. Freak**

VOLUME - XXXVI - 1951 (1949-51)

287 Present Knowledge about Factors Influencing the Discharge of a Tubewell. - **Dr. Nazir Ahmad**

288 Corrosion Control Investigation at Attleboro Massachusetts (USA). - **S. Irshad Husain.**

289 Some Aspects of the Design of Weirs or Canal Falls in Relation to Scour. - **Dr. Mushtaq Ahmad.**

M290 Studies in Lysimeters:
Part-I Influence of the Pellicular Zone on the Proportion of Surface Application Reaching the Sub-soil. - **Dr. A. G. Asghar.**
Part-II Construction of Lysimeters and Building up of Soil Profiles. - **Dr. A. G. Asghar** and **H. S. Zaidi.**
Part-III Influence of Surface Application on the Sub-soil Watertable under Different Crops. - **Dr. A. G. Asghar, H. S. Zaidi** and **M. A. Qayyum**

291 Consolidation of Reclamation Operation. - **Dr. A. G. Asghar** and **Muhammad Shafi Sandhu**

292 Flood Control Investigations in West Pakistan. - **M. A. Rahim, I. A. Zafar** and **S. M. Niaz**

293 Liquid Flow and Silt Transport. - **Pir Muhammad Ibrahim.**

VOLUME - XXXVII –1952 (1951-52)

M294 Observation, Record and Analysis of Pressure Pipe Data of Weirs on Permeable Foundations. - **Dr. Mushtaq Ahmad**

295 Analysis of Heavy Rainfall in Short Periods at Lahore. - **Dr. S. N. Naqvi**

296 Cheap Specifications Adopted for the Construction of Multan Bosan Road. - **Ghias-ud-Din Habib**

297 Planning Hydro-Electric Development in Pakistan. - **S. S. Kirmani.**

298 Sub-Aqueous Construction Methods Adopted during the Execution of the Lahore Sewerage Scheme. - **Syed Irshad Husain.**

299 Flow Lines through Embankment with Hetrogeneous and Stratified Medium. - **Dr. Nazir Ahmad**

M300 Engineering Planning for Industrial Development in Pakistan. - **I. A. Zafar.**

VOLUME - XXXVIII -1954(1952-54)

301 On Silting of Distribution and Factors Affecting Sediment Exclusion from Canals. - **Pir Muhammad Ibrahim** and **Dr. Mushtaq Ahmad**

302 Stability of Earth Dams. - **Mohammad Nazir** and **J. A. Parvez.**

303 Some Salient Features of the Construction of Nishtar Medical College and Hospital at Multan. - **G. D. Habib**

304 The Design and Construction of Irrigation Structures - Some Important Factors. - **S. S. Kirmani**

305 Groundwater Flow Around a Well Installed in Rechna Doab. - **Muhammad Nazir** and **Dr. Nazir Ahmad.**

306 General Design Principles and Preliminary Selection of Turbine Units for a Low Head Hydro Electric Development. - **Mohammad Nazir**

M307 Construction Aspects of Balloki - Suleimanki Link. - **S. Allah Baksh** and **M. Muzaffar Ahmad.**

308 Restoration of Flood Damages to the Deg Nala Bridge. - **S. Mukhtar Ahmad.**

VOLUME - XXXIX –1955 (1954-55)

309 River Training Works of Empress Bridge Adamwahan. - **M. A. Wahidi.**

310 Tests of bs-Theory. - **Abdul Latif.**

311 Behaviour of Saline - Alkaline Punjab Soils Reclamation. - **Dr. A. G. Asghar** and **M. A. Hafeez Khan.**

312 Drainage of Irrigated Soils in Arid Region. - **Dr. A. G. Asghar** and **Dr. Nazir Ahmad.**

313 Water Allowance for Reclamation in High Watertable Areas. - **Dr. A. G. Asghar** and **Ch. Mohammad Ata-ur-Rehman.**

314 Planning of Tubewell Projects. - **I. A. Zafar.**

VOLUME - XL-1956 (1955-56)

M315-A Studies in Some Hydraulic Features of the Design of Taunsa Barrage. - **Dr. Mushtaq Ahmad.**

M315-B Studies in Some Hydraulic Features of the Design of Taunsa Barrage. - **Dr. Mushtaq Ahmad, Abdul Latif** and **Ch. Muhammad Ali.**

316 Foundation Investigations and Salient Features of the Design of Chichoki Power House Raft. - **S. Irshad Ahmad** and **Jamil Asghar.**

317 The Design and Construction of Deg Supper Passage on Marala - Ravi Link. - **S. M. Niaz** and **Nafis Ahmad**

318 Development of Foundation for Transmission Line Towers. - **R. A. Sheikh.**

319 Specific Discharge Gauges of Chenab River Sites. - **Abdul Latif.**

320 Foundation Treatment of the Baran Dam of Kurram Garhi Multipurposes Scheme, Bannu. - **D. M. Khanzada.**

321 Commercial and Industrial Uses of Kallar. - **Dr. A. G. Asghar.**

322 Foundation Problems at Karnafuli Project - East Pakistan. - **Khawja Azeem-ud-Din.**

VOLUME - XLI - 1957 (1956-57)

323 Use of Indigenous Sulphur for Lowering Soil Alkalinity. - **Dr. A. G. Asghar, Abdul Hamid** and **M. Abdullah**

324 Influence Line for Continuous Concrete Bridges. - **A. A. Jamal-ud-Din**

325 Sedimentation of Reservoirs on Indus River System. - **Nazir Ahmad** and **Abdul Hamid**

326 Chuharkana Aquifer Test. - **Sayyid Hamid** and **M. S. Minhas.**

327 Studies in Some Hydraulic Features of the Design of Taunsa Barrage - Part III. - **Dr. Mushtaq Ahmad** and **Muhammad Ali.**

VOLUME - XLII - 1958 (1957-58)

328 Use of Pre-Concreted Reinforcement in Slabs. - **Khan Mohammad Azam Khan**

M329 The Phenomena of Losses and Gains in the Indus River System. - **S. S. Kirmani**

330 Working the Right Bays of Balloki Barrage. - **Ahmad Tariq** and **Sarfraz K. Malik.**

331 Lessons from the Failure of Tando Masti Khan Fall. - **Abdul Latif Mirza**

332 Regirdering Ravi Bridge at Abdul Hakim. - **Mir Ghulam Sarwar.**

333 The Planning and Design of Modern Stadiums. - **Mohammad Ashraf.**

334 Training of River Loops and Currents on Head Works. - **S. Allah Bakhsh Khan.**

335 A Study of Thermal Properties of some of the Locally Available Building Materials to Improve the Summer Comfort in Residential Buildings. - **Khan Mohammad Azam Khan** and **Syed Irshad Hussain.**

VOLUME - XLIII - 1959 (1958-59)

336 Sediment Problems in the Indus Basin. - **S. S. Kirmani.**

337 Cofferdams for the Warsak Dam. - **Saeed Minhas**

338 Stress and Stability Analysis of Warsak Dam. - **Asrar A. Qureshy**

M339 Dewatering of Foundation. - **Dr. Nazir Ahmad** and **Zia-ul-Haq**

340 Some Aspects of Design of Flexible Pavements in West Pakistan. - **Mazhar-ul-Haq Saeed Ahmad.**

VOLUME - XLIV - 1960 (1959-60)

341 Sediment Exclusion Methods and Devices at the Intake of Canals. - **Dr. Mushtaq Ahmad, Mohammad Ali** and **Abdul Khaliq.**

342 Saline Characteristics of Waters in old Canal Colonies of West Pakistan. - **Dr. A. G. Asghar** and **Abdul Hamid.**

343 Diverting River Indus Through Taunsa Barrage. - **Mirza Mohammad Said.**

344 A Stable and Impervious Lining for Canals of West Pakistan. - **Dr. Nazir Ahmad** and **Abdur Razzaq.**

345 Construction Economy through Engineering Research and Design. - **I. A. Zafar.**

VOLUME - XLV -1961 (1960-61)

346 Fish Ladders or Fish Ways. - **Mushtaq Ahmad** and **Said Ahmad**

347 Sediment Transportation by Running Water and the Design of Stable Channels in Alluvial Soil. - **Prof. Ir. H. Vlugter.**

348 Rational Pattern of Sewage and Waste Disposal in Pakistan Part-I. - **Sheikh Abdur Rawoof** and **Sheikh Rafi Ahmad**

349 Diversion of Jammu Tawi and Protection of Upper Marginal Bund at Marala Headworks. - **B. A. Ghani.**

350 Silt Carrying Capacity of a Channel and Criteria for Canal Closure Against Excessive Silt Entry. - **Mushtaq Ahmad** and **Abdul Rehman.**

VOLUME-XLVI -1962 (1961-62)

KM351 Design of Alluvial Channels as Influenced by Sediment Charge. - **Dr. Mushtaq Ahmad** and **Ch. Abdul Rahman.**

M352 Artificial Cut-off at Islam Headworks. - **Khalid Mahmood** and **Abdul Basit Akhtar.**

353 Prestressed Concrete Road Bridge at Wazirabad. - **Muhammad Aslam.**

354 Hydrological Studies on Zhob River and Streams of the Kachhi Plain. - **Sarfraz Khan Malik.**

VOLUME - XLVII - 1963 (1962-63)

355 Design of Silt - Stable Canals. - **S. S. Kirmani**

356 Appraisal and Analysis of New Data from Alluvial Canals of West Pakistan in Relation of Regime Concepts and Formulae. - **Dr Mushtaq Ahmad** and **A. Rehman**

357 The Regime Concept and the River Nile. - **Gerald Lacey.**
358 Structural Analysis and Design of Multistoreyed Framed Buildings. – **Ghias-ud-Din Habib**
359 Inland Navigation in West Pakistan - A Few Proposals. - **Mohi-ud-Din Khan.**
360 Alternative Proposals for Remodeling Marala Headworks. - **H. J. Asar**
361 Influence of Parapet Walls on the Ventilation of Roof. – **Mian M. Hanif.**
362 Some Recent Trends in Barrage Design on Alluvial Rivers in Pakistan. - **Mohi-ud-Din Khan.**

VOLUME – XLVIII - 1965 (1963-65)

Golden Jubilee Publication

363 Slurry Trench Method of Cut-off. - **Ramiz Ahmed Malik.**
364 Marala Headworks - Site Investigation. - **H. J. Asar**
M365 The Engineering Profession in Pakistan. - **S. S. Kirmani**
366 Village Electrification Through Micro - Power Plants on Canal Falls. - **Mohi-ud-Din Khan.**
367 Design of a New Road Bridge over Jhelum River Near Jhelum. - **Abdus Salam**
368 An Estimate of Evaporation from Free Water Surface in West Pakistan. - **Nazir Ahmad, Mohammad Sarfraz** and **Mohammad Akram.**
369 Operating Bambanwala Ravi Bedian - Depalpur Link Canal in 1961. - **Mohammad Ali Chaudhry.**
370 Highway Financing in Pakistan. - **Saleem Akhtar Bhalli** and **Muzaffar Iqbal Sheikh**
371 Financial Planning of Water Supply Schemes. - **Iqbal Ahmed Beg.**

VOLUME - XLIX – 1966 (1965-66)

372 Diversion of the River Jhelum at Mangla. - **Mehtab Khan**
373 Electric Traction on Pakistan Western Railway. - **S. H. Nawab.**
374 Pumping Installation for the Warsak Lift Irrigation Scheme. - **Khan Sarwar Jan Khan**
375 Remodelling Balloki Headworks. - **Rana Muhammad Aslam Chohan**
376 The Sunshade Table. - **Ashfaq Hasan**
M377 A Study of the Effect of Suspension Parameters of Ride Index of a Railway Vehicle and Results of Trials on the Pakistan Western Railway. - **M. Z. Mozaffar.**
378 Earthwork on Irrigation Works in the Land of the Indus. - **Mazhar Ali.**
379 The Need for a Sound Housing Policy in West Pakistan. - **S. Sibt-i-Hassan.**
380 Determination of Firm Generating Capacity. - **A. Rahimtoola.**

VOLUME - L - 1968 (1967 - 68)

381 WAPDA Northern Grid System Need for Peaking Generating Capability 1970 - 75. - A. Rahimtoola.
382 A Steel Industry for Pakistan: An Appreciation. - S. Shafqat Ali.
383 Experimental Use of Hydrated Lime in Road Construction. - Tajamal Hussain Qureshi, and Hashmat Ali.
384 Scientific Land and Water Use for Increased Production in West Pakistan. - Ch. Muhammad Hussain
385 Design and Construction of Chichawatni Bridge. - Abdus Salam and S. U. Qureshi.
386 Road Problems in Slip Affected Areas. – **M. A. Waheed** and **Muzaffar Iqbal Sheikh.**

387 Immunisation of Signalling Equipment in Connection with Electrification of Lahore - Khanewal Section of Pakistan Western Railway. - **M. H. Bhaur.**

388 Crushed Brick in Road Construction. - **Mazhar-ul-Haq Saeed Ahmad.**

389 Adaptation of Equiangular Spiral as an Open Channel Curve. - **Khalid Mahmood.**

M390 Structural Investigations of Sukkur Barrage Arches. - **Mazhar Ali.**

VOLUME - LI - 1969 (1968 - 69)

391 Technical Appraisal of Salinity Control and Reclamation Project - 1 with Reference to Decline of Water Level. - **Ch. Ata-ur-Rehman.**

392 Railway Electrification (Power Supply System). - **Dr. F. A. Hamdani**

393 Design Aspects of Municipal Water Supply Pilot Projects. - **Syed Arshad Ali**

394 Land and Water Management in West Pakistan. - **Ch. Muhammad Hussain**

395 Some Methods of Computing Retrogression in Channels Due to Change in Sediment Charge. - **Mushtaq Ahmad** and **A. Rehman.**

396 Recording of Temperature Changes Inside the Concrete of Sukkur Barrage Arches. - **Dr. Nazir Ahmad.**

397 Design and Construction of Sutlej Bridge. - **Abdus Salam** and **Abdul Waheed Choudhry.**

VOLUME - LII - 1971 (1970 - 71)

398 Rasul Barrage. - **Rana Mohammad Aslam Chohan**

399 Marala Barrage Investigations for High Uplift Pressures under the Downstream Floor. - **Ramiz Ahmad Malik**

400 Model Tests for Assessing the Causes of Excess Uplift Pressure under Downstream Floor of Bays No. 31 - 40 of Marala Barrage and Remedial Measures. - **S. M. Ayoob** and **Ch. Mohammad Ali**

401 Design of a Two Miles Long Irrigation Tunnel for Khanpur Dam Project. - **S. Khalid Asmi** and **A. Aziz.**

402 West Pakistan 500KV Super Grid. - **Mahmood Ahmad Cheema**

403 Distribution System Protection and Safety. - **Javid Akhtar**

404 Surveying and Mapping for Road. - **Saleem Akhter Bhalli**

VOLUME - LIII - 1972 (1971 - 72)

405 Energy Dissipation and Expansion of Flow in Sharp Divergence Below a Flumed Fall. - **S. M. Ayoob** and **Ch. Mohammad Ali**

406 Evaluation of Well Performance and Water Management of Mona Reclamation. Experimental Project (1965 -1970). - **Ch. Ata-ur-Rehman.**

407 A Few Suggestions to Conserve Flood Run-off and to Recover Fresh Water From the Saline Water Zones of the Indus Plains. - **Dr. Nazir Ahmad.**

408 Case Study on Use of Natural Gas for Power Generation in Pakistan. - **A. U. Loan.**

409 Failure and Reconstruction of Sukhbeas Syphon on Balloki - Suleimanki Link-I. - **R. K. Anver** and **S. M. Ismail.**

410 Construction of Tarbela Dam Project. - **S. A. Hussaini.**

411 Modern Practice in Surface Dressing. - **Abdus Salam.**

412 Problems of Medium Voltage Earthing Practice in a Developing Power System. - **Mian Fazal Ahmad.**

VOLUME - LIV - 1974 (1972 - 74)

M413 Panjnad Headworks after 1973 Floods. - **Mohammad Aslam Chohan.**

414 Limit State Design of Reinforced Concrete Structures. - **Dr. Khalid Mahmood.**

415 A Review Report on Collapsible Soils for the Design and Construction of Roads. - **Syed Fayyaz Ali Shah** and **Hashmat Ali.**

416 Dominant Problems in the Design of Harbour Structures on Mekran Coast. - **Dr. Javed Yunas Uppal** and **Izzat Ullah Sheikh**

417 Public Sector: Its Organization and Management. - **Amanullah Khan.**

418 Design Standards for Water Supply Schemes in Pakistan. - **Iqbal Ahmad Beg.**

419 A Comparative Study of Five Approximate Methods of Computing Uplift Pressures, Exit Gradient and Seepage Rate Under Hydraulic Structures on Permeable Foundations. - **Dr. Mushtaq Ahmad**

VOLUME - LV - 1975 (1974 - 75)

420 Problems and Needs of Engineering Education in Pakistan. - **Prof. Dr. M. Islam Sheikh.**

421 Towards Higher Productivity. – **Amanullah Khan.**

422 Variation of Loss with Specimen size of Alcomex III at 50 HZ Excitation. - **Parvez Rashid.**

423 Selection of Hydraulic Machines for SCARP Tube Wells. - **Sardar Allah Bakhsh and Dr. Akmal Hussain.**

424 Economics of Mechanization with Reference to Earthmoving Operation in Pakistan. - **S. Nisarul Haque.**

425 A Computer Program for Raft Analysis with Specific Reference to WAPDA House Raft Foundation. - **Dr. Javed Yunas Uppal** and **Dr. M. Talib Chaudhry.**

426 Breakthrough in Development - An Imperative for Pakistan's Future. - **Imtiaz Ali Qazilbash.**

427 Traffic Organization in Pakistan. - **M. Sadiq Swatl.**

428 Alignment and Shape of a Spur Head. - **S. M. Ayoob** and **Ch. Muhammad Ali.**

429 An Appraisal of Rural Electrification in Pakistan. - **Mian Fazal Ahmad.**

430 Some Problems of Technology Transfer. - **Engr. Masood Hasan.**

VOLUME - LVI - 1978 (1977 - 78)

431 Hydraulic Design Features of Outlet Works for Tarbela Left Bank Irrigation Tunnel. - **M. Aslam Rasheed** and **Bashir Ahmad.**

432 Controlling Marine Bifouling. - **Dr. Amjad Parvez Sheikh** and **Chaudhry Mohammad Abdullah.**

433 Hydrologic Design of Sukh Beas Surface Drainage Project. - **Mian Barkat Ali, S. N. H. Mashhadi** and **Maqsood Ahmad Malik.**

434 Some Aspects of Hydraulics of Bridge Water Ways. - **S. M. Ayoob** and **Ch. Muhammad Ali.**

435 Rawalpindi Earthquake Feb. 14, 1977. - **N. Z. Adhami** and **Mansur Ahmad.**

436 Wind Generated Waves and their Effects on River Bunds. - **Syed Mansoob Ali Zaidi.**

437 Construction of Prilling Towers with Slipform at Pakarab Fertilizers Factory, Multan. - **Mian M. Hanif.**

438 Wind Effect Study on An Ogival Masjid Dome. - **Shaikh Wajeehuddin, Bakhtiar Ali** and **Mohammad Azim**

439 Design of Earthen Dikes. - **Tahir A. Malik.**

VOLUME - LVII - 1980 (1978 - 80)

440 Severity of Water-Logging and Salinity Problem in Pakistan. - **Dr. S. M. H. Bokhari.**

441 Pre-fabricated Gypsum Boards. – **S. Sibtul Hassan Shah** and **Ali Muhammad.**

442 Comparison of Load Following Capabilities of Various Types of Commercially Proven Nuclear Power Plants and Their Impacts on the Grid System Reliabilities. - **Dr. S. M. Bhutta** and **Prof. Ir. F. R. Vanmassenhove**

443 Water-Table Depletion, Non-Steady Flow to Wells Effects of Soil Evaporation. - **Muhammad Saleem.**

444 Construction and Working of Spurs for Protection of B. R. B. D. Link Canal. - **Ahmad Tariq, Khursheed Mahmud** and **Riaz Ahmad.**

445 Irrigation System in Pakistan: Measures to Improve Irrigation Efficiency at the Farm Level. - **I. A. Khaliq.**

446 Irrigation Requirements of Crops in the Punjab. - **Abdur Rehman, Nur-ud-Din Ahmad** and **Muhammad Akram.**

447 Fading on Indus Valley Microwave Link. - **Muhammad Javed.**

448 Supply of Drinking Water to Rural Population. - **A. N. Cheema**

VOLUME - LVIII - 1982 (1981- 82)

449 Performance Analysis of Scarp – 1. – **Engr. Dr. N. M. Awan and Engr. Mohammad Latif**

450 Role of Management, Training and Research in Rail - Road Operations. - **Engr.Mian Ghias-ud-Din.**

451 Addition to Guddu Thermal Power Station. - **Engr. M. Hussain Ali.**

452 Design and Construction of Simly Dam. - **Dr. Izhar-ul-Haq.**

453 An Estimate of Water Loss by Evaporation in Pakistan. - **Dr. Nazir Ahmad.**

454 Flushing Operations of Warsak Reservoir Sediment. - **M. R. Chaudhry**

455 Third IRBD Highway Project. - **Engr. E. I. Johri.**

M456 Construction of River Training Works on the Left Bank of River Ravi from Babu Sabu to Chung near Lahore. - **Syed Mansoob Ali Zaidi.**

457 Utilizing Gypsum for the Agricultural Development of Pakistan. - **Dr. Amjad Parvez Sheikh.**

VOLUME - LIX - 1983 (1983 - 84)

458 Concept, Planning and Design of Khairwala Drainage Project. - **Syed Mansoob Ali Zaidi.**

M459 A Study on Dieselization of Sibi - Khost Section with GEU-15 and GMU-15 Group-IV Diesel Locomotives. - **Engr. Mian Ghias-ud-Din.**

M460 Improvement of Bearing Capacity for Foundations of Kotri Gas Turbines Extension Project. - **M. R. Chaudhry.**

461 Khanpur Dam Project. - **Dr. Izhar-ul-Haq.**

462 Hydrologic Evaluation of Marh-Chiniot Surface Drainage System Design. - **Engr. Dr. N. M. Awan** and **Engr. Saleem Bashir.**

463 Selection of Busbar Schemes for Grid Stations, a Mathematical and Graphic Approach. - **Engr. Mohammad Irfan Akhtar.**

464 Pumped Storage as Peaking Station in an Interconnected Grid System. - **Engr. Daud Beg**

465 Remodelling of Rohri Canal System. - **Engr. Barkat Ali Luna** and **S. N. H. Mashhadi.**

466 Socio-Economic and Financial Aspects of International Water Supply and Sanitation Decade for Pakistan. - **Engr. Masih Ullah Khan.**

467 Obtaining Results from Research and Development - Some Requisites. - **Engr. Masud Hassan.**

VOLUME - LX -1985 (1984 - 85)

468 Diverting River Indus through Ghazi Ghat Road Bridge. - **Brig. (Retd.) Ghazanfar Mohammad Khan** and **Mohammad Aslam Chohan.**

469 Site Selection Kala Bagh Dam Project. - **Dr. Izhar-ul-Haq.**

470 Theory of Minimum Rate of Energy Dissipation and its Applications. - **Chih Ted Yang.**

471 Remedial Measures of Rasul Barrage. - **M. R. Chaudhry**

M472 Construction of Khairwala Drainage Project. – **Syed Mansoob Ali Zaidi.**

473 Gypsum as an Amendment for the Reclamation of Saline Sodic Lands. - **Mohammad Altaf Hussain and Mohammad Asghar.**

474 Methodology of Construction of Hot Mix Asphalt Paving and our Experiences on the Execution of Lahore - Pathoki Section of Third Highway Project. - **Ch. Ghulam Hussain and Raja Karamat Ullah.**

475 Road Safety in Developing Countries. - **Engr. M. Sadiq Swati.**

476 Some Aspects of Planning. - **Masood Hasan.**

477 Transformer Losses Evaluation Factors for the Generator Transformer of Proposed Kalabagh Hydro Power Station - A Case Study. - **Muhammad Irfan Akhtar.**

478 An Over view of Irrigation and Drainage Projects in Pakistan. - **Dr. Nazir Ahmad and Sarfraz Ahmad.**

479 Development of Synthetic Unit Hydrographs in Small Ungauged Catchments of Pakistan. - **Muhammad Mahboob Alam.**

VOLUME - LXI -1986 (1985 - 86)

M480 Transport Options for Developing Countries. - **Engr. Mian Ghias-ud-Din**

481 Mechanism of the Doomsday – The Ultimate Fate of Universe. - **S. Bashiruddin Mahmood**

482 Introduction of Dry Hydrate Lime as a Building Material in Pakistan. - **Muhammad Iqbal, Ali Muhammad** and **K. L. Khawaja.**

483 Development of Lahore at West Bank of Ravi. - **Dr. Javed Yunas Uppal.**

M484 Remodelling Marala Barrage and Link Canal for Silt Control. - **Engr. Rana Mohammad Aslam Chohan.**

485 Drainage Study of Coastal Area. - **Bagh Ali Shahid** and **S. M. A. Zaidi.**

486 Optimum Moisture Content as Related to Grain Size of Cohesive Soils. – **Mr. I. H. Hamdani.**

487 Foundation Protection of Tarbela Hydro Power Building Units 5 - 8. - **M. R. Chaudhry.**

488 Interceptor Drains. - **Dr. Izhar-ul-Haq.**

489 Reclamation of Saline Sodic Lands with Chemical Amendments. - **Ch. Altaf Hussain.**

490 Monitoring of Mangla Dam Project. - **Ch. Altaf-ur-Rehman.**

491 Experimental Errors in Measurement of Alluvial Channels. – **Mr. Ahmad Masud Ch.**

VOLUME - LXII -1987 (1986 - 87)
Diamond Jubilee Session

M492 Combating High Sulphur in the Coal at Lakhra Power Plant. - **Ghulam Murtaza Ilias.**

M493 Estimation of Maximum Discharge for the Design of Hydraulic Structures. - **Dr. Mushtaq Ahmad.**

494 Design and Construction of Chashma Right Bank Canal Project. – **Engr. Mian Muhammad Akhtar** and **Dr. Izhar-ul-Haq.**

495 Drainage Well Design Option for Saline Zones. - **Engr. Ch. Ata-ur-Rehman.**

496 Management of Engineering Projects. - **Engr. B. A. Chowdhry.**

497 Un-exploited Available Potential for Higher Train Speed. - **Engr. M. Amir Chaudhry**

498 Trial of Sand Bitumen Mix Pavement on Naukot Mithi Road (Sind). - **Engr. Sajjad Haider**

499 Comprehensive Sewerage and Drainage Scheme Multan. - **Engr. Syed Zia-ul-Hasan**

500 Reclamation of Saline Sodic Soils with Brackish Water. - **Engr. Muhammad Altaf Hussain**

501 Waste Water Treatment and Reuse in Irrigation. - **Engr. Mian Muhammad Amin**

502 Use of One-Point Proctor Standard Compaction Method for Computing Modified Aasho Compaction Parameters. – **Mr. I. H. Hamdani**

503 Development of Cholistan. - **Engr. Rao Riaz-ur-Rehman, Engr. Ghulam Ahmad Asghar** and **Engr. C. M. Ashraf.**

504 Technician Education in Developing Countries. - **Shafqat Hussain Qureshi.**

505 Water Conservation through Water Course Improvement. - **Ch. Ata-ur-Rehman.**

VOLUME - LXIII -1988 (1987 - 88)

506 Utilization of Bubbling Fluidized Bed Combustion Technology for Lakhra Coal. - **Engr. M. H. Masud Butt**

507 Future of Science and Technology in Pakistan. - **Engr. A. R. Memon.**

508 Upgrading and Rehabilitation of Sewerage System. - **Engr. Mian Muhammad Amin.**

509 A Computerized One - Step Cut-Flow Method for Measurement of Soils Water Diffusivity. - **Engr. Zia-ul-Haque.**

510 Digital World. - **Engr. Khalid Jalil.**

M511 Sub-Surface Pipe Drainage Methodology. - **Engr. Javed Salim Qamar.**

512 Tarbela Dam Project - Seepage Problem and Remedies. - **Dr. Izhar-ul-Haq.**

513 Mass Balance Calculation Method in Methane Steam Reforming. - **Engr. Mrs. Zulekha Soomro**

514 Steam Reforming Propane over a Nickle - Alumina Catalyst. - **Engr. Muhammad Yaqoob Soomro** and **Engr. Mrs. Zulekha Soomro.**

515 A Feasible Inland Navigation Route from Kalabagh to Port Qasim. - **Engr. Mohiuddin Khan**

516 Rapid Reclamation of Unbroken Saline-Sodic Lands with Ground Water. - **Engr. Muhammad Altaf Hussain** and **Engr. Muhammad Asghar.**

517 Determination of Cohesion and Angle of Internal Friction of Partially Saturated Soil from Stress Strain Model. - **Mr. I. H. Hamdani.**

518 Use of Brackish Water for Reclamation and Crop Production. - **Engr. Muhammad Ramzan Chaudhry, Engr. Ch. Bashir Ahmad** and **Engr. Muhammad Abaid Ullah.**

519 Automated Structural Analysis. - **Engr. Muhammad Naimet Ullah Cheema.**

520 Experiences of Inspections of Dams in Pakistan. - **Engr. Altaf-ur-Rahman.**

521 Cheapest Method of Steel Production. - **Engr. J. K. Jafferi.**

VOLUME - LXIV - 1990 (1989 - 90)

KM522 Alluvial Channels Redesign Procedure. - **Engr. M. Naimetullah Cheema, M. Hasnain Khan** and **Tahir Hameed**

523 Water Management Strategies for Optimizing Productivity. - **Ch. Nuruddin Ahmad** and **Dr. Nazir Ahmad.**

524 Lining of Irrigation Channels with Particular Reference to CWMP. - **S. N. H. Mashhadi** and **Ch. Muhammad Akbar.**

525 The Long Term Behaviour of Qadirabad - Balloki (QB) Link Canal. - **Tariq Altaf**

526 A Model for Efficient Distribution of Irrigation Supplies Among Distributaries. - **Muhammad Shafique** and **Dr. Muhammad Latif.**

527 Causes and Control of Water-Logging and Salinity. - **Brig. (Rtd.) Khurshid Ghias Ahmad**

528 Non-Reclaimable Lands made to Blossom. - **Muhammad Altaf Hussain** and **Dr. Zahid Hussain**

529 Salvation of Baluchistan Kachhi Plain through a Water Supply Project. - **A. N. Cheema** and **M. Saleem Chaudhry.**

530 Appropriate Technology Options for Waste Water Treatment in Tropical Developing Countries. - **Mian Muhammad Amin.**

531 A Study of Problems of Water Supply and Drainage of Lahore Zone using the Numerical Modelling. - **Dr. Nazir Ahmad** and **Dr. Muhammad Akram.**

532 Failure of Sukkur Barrage Gate No. 31 and Replacement Programme Study. - **A. R. Memon.**

533 Roller-Compacted Concrete and its Applications. - **S. M. A. Zaidi.**

534 Warsak Dam Project Problems and Remedies. - **Dr. Izhar-ul-Haq.**

535 Energy Conservation by Improving Locomotive Utilization. - **M. Aurangzeb Khan.**

536 Modelling and Design of Construction Process and Operations. - **S. M. A. Zaidi.**

537 A Plan for Self-sufficiency in Power for Pakistan. - **Engr. Mohi-ud-Din Khan.**

VOLUME-LXV -1994 (1992- 94)

538 Performance Evaluation of Existing Lined Canals in Pakistan and Suggestions for Improvement. - **Dr. Nazir Ahmed, S. N. H. Mashhadi** and **Amir-ur-Din Qureshi**

539 Measurement of Inelastic Deflection by Laser Speckle Technique. – **Muhammad Akram Tahir, Bilal Ahmad Goraya** and **Ahmed Sana.**

540 Open Channel Design in a Minute. - **Farooq Khan Niazi.**

M541 Remodelling Bambanwala Cross-Regulator. - **Usman Akram.**

542 A New Approach for the Design of Alluvial Canal System in Pakistan. - **Dr. Bagh Ali Shahid** and **Fredericks J. Watts.**

M543 Drainage of Irrigated Lands of Pakistan - A Critical Review. - **Dr. Nazir Ahmed.**

544 Geometric Design of Faizabad Interchange. - **E. I. Johri.**

545 Problems Related with Sedimentation of Reservoirs in Pakistan. - **Qazi M. Anwar-ul-Haq.**

546 Microprocessor Controlled Robot Arm for Light Engineering Tasks. - **Dr. Israr Ahmed Chaudhry** and **Dr. Tariq Mahmood.**

547 A Comparative Study of Sm-Co S Nd-Fe-B Permanent Magnets. - **Dr. A. Ahmad** and **Engr. G. A. Awan.**

548 Shelter for the Shelterless - Design and Evaluation. - **Ghulam Mustafa Qazi**

549 Post Yielding Deflection of R. C. Beams. - **Akram Tahir, Bilal Ahmad Goraya** and **Ahmad Sana**

550 Remodelling Approach for Kabul River Canal System in View of Changing Agro- hydrological Conditions. - **J. A. Tariq**

551 Emergency Plan for Rapid Development of Water Resources and Overcoming Power Load Shedding. - **Mohiuddin Khan.**

552 External Pressurized Gas Journal Bearing and their use in High Technology and Some Performance Characteristics. - **M. Uneeb, I. A. Chaudhry** and **Dr. R. Gohar**

VOLUME - LXVI - 1996 (1994 - 96)

553 Privatization and Commercialization of Irrigation Management: Are the New Strategies Workable in Pakistan Setting? - **Asrar-ul-Haq, Dr. Bagh Ali Shahid** and **Usman Akram**

M554 On the Flood Frequency Analysis at Important Discharge Measuring Sites of Pakistani Rivers. - **Prof. Dr. Ing. Syed Ali Rizwan** and **Muhammad Azim Chaudhry.**

555 Impacts of Planning and Design Changes on Channel Behaviour and Environment: A case Study of fall at RD 64357 Muzaffargarh Canal. - **Asrar-ul-Haq, Muhammad Hasnain Khan** and **Syed H. Gilani**

556 Restoring Design Capacity of Marala Ravi Link Canal. - **Dr. A. S. Shakir, Asrar-ul-Haq** and **Dr. Bagh Ali Shahid**

557 A Proposal to Raise the Maximum Capacity Level (MCL) of Mangla Reservoir Based Upon Downward Revision of Mangla PMF and Improved Flood Forecasting and Warning Facilities. - **Abdul Majid**

558 Mangla Dam Project: A Proposal for Flood Mitigation by 4.5 ft Raising of Dam. - **Abdul Khaliq Khan** and **Saleem-ud-Din**

559 Flood Control Techniques for Effective Alluvial River Management. - **Prof. Dr. Ing. Syed Ali Rizwan, Muhammad Azim Chaudhry** and **Salamat Ali**

560 An Introduction to Time Series Modeling and its Application in Water Resources Engineering. - **Tahir Hameed, Tahir Ahmad Malik** and **Muhammad Safadar Chishti.**

561 Proposed Revisions to the Pakistan Highway Code for Seismic Design of Reinforced Concrete Bridge Piers. - **Muhammad Tariq Amin Chaudhry.**

562 Engineering Industry, Problems and Prospects. - **Dr. S. M. Naqi**

563 Methodology for Improvement of Capacity of Urban Roads. – **Engr. E. I. Johri**

564 Performance of Lifelines during Recent Earthquakes. - **Muhammad Tariq Chaudhry**

M565 The Incidence of Rutting on Bituminous Roads. - **Shaukat Ali.**

566 Privatization of Transportation Infrastructure in Developing Countries. - **Muhammad Mursaleen.**

567 A Simplified Approach for the Analysis and Design of Two Way Joist Floors. - **Prof. Dr. Ing Syed Ali Rizwan** and **Azhar Ali Bhatti.**

568 Construction of Bored Cast-in Situ Concrete Piles on Chashma Right Bank Irrigation Project Stage-II. - **S. N. H. Mashhadi** and **Syed Manzoor Hussain Rizvi.**

VOLUME - LXVII-1998 (1996-98)

569 Analysis of Two Way R. C Joist Floors Having Different Configurations. – **Prof. Dr. Ing. Syed Ali Rizwan, Syed Ali Debaj** and **Husnain Ahmad**

570 Behaviour of Geometrically Imperfect Slender Steel Columns. - **Prof. Dr. Ing. Syed Ali Rizwan, Syed Ali Debaj** and **Husnain Ahmad**

571 Computer Analysis of Composite Space Structures. - **M. Ashraf, Zahid A. Siddiqui** and **Afzal Javaid**

572 A Convenient Method for Design of Reinforced Concrete Members. - **Z. A. Siddiqui** and **M. Ashraf**

573 Segmental Cantilever Bridges at Karote and Kohala. - **Sameer Z. Khan**

574 Prevention of Salt Attack by Using Pozzolanic Admixtures. - **Rana Nisar Ahmad**

575 Curve of Infinite Plate with a Crack Lying on Elastic Base by Dynamic Loading. -**Dusembayev Isim Nacievich, Travush Vladimir Ilich**

576 Decision Support System for Reservoir Operation to Manage Severe Floods in Pakistan. - **Shahbaz Khan**

577 Salinity Extent and Management in Irrigation Commands - **M. Azhar Javaid, Ch. Karamat Ali** and **Muhammad Javed**

M578 Experience Gained from Interceptor Drains Installed in LBOD Stage-I Project. - **Yawar Hamid**

579 Performance of Tarbela Reservoir. - **Sardar Muhammad Tariq** and **M. Mushtaq Chaudhry**

580 Drainage Management to Control Salinity and Alkalinity for Better Crop Production. - **Muhammad Altaf Hussain**

581 Managing Water Resources Through Users Associations. - **Mian Hafizullah**

582 Multi-Stage Lift Irrigation - Some Adverse Economic and Environmental Aspects - A Case Study. - **B. A. Malik**

583 A Mateorological Approach to Forecast the Seasonal (Khareef) Inflow Volume for Mangla Reservoir. - **Abdul Majid**

584 Irrigation Management Information System: The Framework and Implementation Strategies for Pakistan. - **Asrar-ul-Haq** and **Muhammad Hasnain Khan**

585 A Framework for Performance Evaluation of River Training Works. - **A. S. Shakir, Asrar-ul-Haq** and **Nasir Ali**

586 Design, Principle and Uses of Tensiometers. - **Zia-ul-Haque** and **Gul Muhammad Shah**

587 Evaluation of Completed Contracts for Future Pre-qualification of Contractors. - **Daud Nasir Fakher Raza**

588 Causes of Delay in the Construction Industry of Pakistan. - **Muhammad Muneer Ali** and **Riaz Ahmad Goraya**

589 Towards Total Quality Management Control (TQM) For Construction in Pakistan. - **Muhammad Muneer Ali**

590 Biological Nutrients Removal - Application of Software Packages for Plant Design. - **Bushra Waheed** and **John P. Barford.**

591 Biodiversity and Species Extinction. - **Javed A. Aziz**

592 Application of Clean Technology for Industrial Waste Pollution Control. - **Javed A. Aziz**

593 Global Warming. - **Javed A. Aziz**

594 Treatment Options for Waste water reuse. - **Javed A. Aziz**

595 Concept of Rapid Intercity Train Service for Passenger Traffic on Pakistan Railways. - **Abdul Qayyum**

596 Rutting of Bituminous Concrete Pavements. - **Zubair Emran Khawaja**

597 Surge Transfer Behaviour of Power Transformers. - **Suhail Aftab Qureshi** and **Humayun Pervaiz**

598 Subcube Migration in Multistage Interconnection Networks (Part-I). - **Muhammad Naeem Ayyaz**

599 Subcube Migration in Multistage Interconnection Networks (Part-II). - **Muhammad Naeem Ayyaz**

600 Minimizing Flow Time Genetic Algorithms in Machine Scheduling. - **Nasir Hayat** and **Andrew Wirth**

601 Injection Moulding of Co-Cr-Mo Alloy Powder. - **M. Y. Anwar, H. A. Davies** and **P. F. Messer**

602 Processing of North Waziristan Copper - Sulfide Ore and Prospects for the Establishment of a Concentrate Plant. - **M. Mansoor Khan, Khan Gul Jadoon Ehteshamulla Khan** and **Mazhar Rafiq**

603 A Review of Parameters Influencing the Performance of Tunnel Boring Machines. - **Saad N. Cheema** and **Jamal Rostami**

604 Criteria for Selection and Application of TBMs in Tunneling Projects. - **Saad N. Cheema** and **Jamal Rostami**

605 Noise Pollution and its Environmental Impacts. - **Khurshid Ahmad**

VOLUME - LXVIII - 2000 (1998 – 2000)

605-A A New Transport Policy in Asia For Poverty Alleviation and Pakistan's Role in its Implementation. - **Mohi-ud-Din Khan.**

M606 Effects of Upstream Storages on the Present Eco Systems in Areas Downstream of Kotri Barrage. - **Barkat Ali Luna** and **Muhammad Jabbar.**

607 Development of Storages for Addressing the Emerging Water Scarcity in Pakistan Bridging the Crisis of Conflicting Interests. - **Asrar-ul-Haq, Abdul Sattar Shakir** and **Dr. Bagh Ali Shahid.**

608 Design and Construction of Scarp Sukh Beas Sukhnai Outfall Channel Project. - **Ch. Ghulam Hussain.**

609 Flood Management of Deg Nullah by Part Diversion into Basanter Nullah. - **Liaquat Rabbani** and **Dr. Muhammad Latif.**

610 Modern Flow Meter and Application to Pakistan Irrigation System. - **Mazhar Hussain.**

611 Rights and Responsibilities of Lower Riparians of Kalabagh Dam on Indus River. - **Dr. Iqbal Ali** and **Ghulam Murtaza Abro.**

612 Safety of So-Called Small Dams in Pakistan. - **Altaf-ur-Rehman.**

613 Case Study and Risk Assessment of Scour around Bridge Piers. - **Muhammad Khalil (Late)**

614 Implementation of Participatory Irrigation Management in Pakistan, its Engineering, Legal and Financial Aspects. - **Ahmed Usmani** and **Zulfiqar Ali.**

615 Problems of Irrigated Agriculture, Need Removal to Efficiently Use Water of Indus River System. - **Fatah Ullah Khan.**

616 Drinking Water Quality in Punjab. - **Prof. Dr. Javed Anwar Aziz.**

617 A Two Zone Model for Longitudinal Dispersion in Channels with Idealized Pools and Riffles. - **Dr. Zulfiqar Ali.**

618 Provision of Calcium Ions for Reclamation of Sodic Soils. - **Muhammad Altaf Hussain.**

619 Experimental Investigations on Reinforced Brick Slabs. - **Zahid A. Saddique and Muhammad Ashraf.**

620 Shear Strength of Reinforced Concrete Beams without Web Reinforcement. - **Dr. Muhammad Saeed Ahmad.**

621 A Comparative Study of Modified Concretes. – **Prof. Dr. Ing. Syed Ali Rizwan** and **Kafeel Ahmad.**

622 Evaluation Study for Determining Premature Pavement Cracking of a Section of Jhang Shorkot Road. - **Zubair Emran Khawaja.**

623 Maintenance and Rehabilitation of Roads and Highways. - **Shahid Majid, Muhammad Aslam** and **Muhammad Javaid.**

624 A Revolutionary Prepackaged Polymer Modified Super Plasticized Mortar with Field Application and Economic Advantages. - **Musarat Ullah Khan Afridi, Prof. Dr. Ing. Syed Ali Rizwan** and **Javaid Iqbal Memon.**

625 Effects of Arc Model and Trapped Charge on very Fast Transient over Voltage in GIS. - **Sohail Aftab Qureshi** and **Muhammad Ahmad.**

626 Evaluation of Lightening Surge Effect on 11KV Distribution Lines. - **Sohail Aftab Qureshi** and **Shakir Hafiz.**

627 Productivity and Quality; The Two Simultaneous Imperatives for Pakistan. - **S. M. Naqi.**

628 Nonlinear System Analysis and Design Using Matlab and Simulink Tutorial. - **Farrukh Nagi** and **Fawad Ahmed.**

629 Review and Comparison of Rock Mass Classification System. - **Saffet Yagiz** and **Saad Cheema.**

630 Floatation of Copper Minerals from North Wazirastan Copper Ore at Pilot Scale. - **Muhammad Mansoor Khan, Mazhar Rafique** and **Ihtasham Ullah Khan.**

631 Effect of Die-Temperature on Age Hardening Characteristics of Aluminium Copper and Aluminium Copper Magnesium Alloys. - **Yousaf Anwar** and **Syed Qasim Hasan Zaidi.**

VOLUME - LXIX - 2004 (2001–2004)

632 Performance of Tarbela Dam Project. - **Riaz Nazir Tarar**

633 Problems of Plunge Pool Development and Remedial Measures at Tarbela Dam Service Spillway. - **H. D. Bangash**

634 Addressing the Emerging Water Sector Challenges in Pakistan: A Case Study of Punjab's Aging Irrigation Infrastructure. - **Asrar–ul–Haq**

635 Remodelling of Thal Canal – Main Line Upper Damage to Concrete Lining its Causes and Remedies. - **Barkat Ali Luna and Engr. Khalid Javed**

636 Production of Fused Silica Cores Using Powder Injection Moulding Techniques. - **Dr. M. Yousaf Anwar**

637 Factors Affecting the Performance of Steel in Concrete. - **Dr. S. E. Benjamin**

638 Development of the Modified Concrete Seepage Barrier. - **K. Ahmed, Engr. Husnain Ahmad and Prof. Dr. Ing. Syed Ali Rizwan**

639 Sediment Management for Reservoirs. - **Altaf-ur-Rehman**

640 Strategies for Safe Exploitation of Fresh Water Through Multi-Strainer Skimming Wells in Saline Groundwater Areas. - **Dr. M. Mehboob Alam, Hassan Mehtab Jaffery** and **Muhammad Hanif**

641 Prepackaged Polymer – Modified Mortar Proves Effective Construction Material – Field and Laboratory Observations. - **Dr. M. U. K. Afridi, Anwar Ahmed Khan, Prof. Dr. Ing. Syed Ali Rizwan** and **Dr. Ghous Bux Khaskhali**

642 Using Locally Available Fly Ash for Modifying Concrete Properties. - **Prof. Dr. Ing. Syed Ali Rizwan, Shamas-ur-Rehman Toor** and **Engr. Husnain Ahmad**

643 Effect of Test Procedure on Shear Strength Obtained Using the Newcastle Dilatometer. - **A. Akbar** and **B. G. Clarke**

644 Liquefaction Assessment of Indus Sands Using Shear Wave Velocity. - **Sohail Kibria, M. Javed** and **Muhammad Ali**

645 Development of Regional Scale Soil Erosion and Sediment Transport Model; Its Calibration and Validation. - **Dr. M. Habib-ur-Rehman** and **Engr. M. Naeem Akhtar**

646 Troubles Experienced with the Silt Ejectors on Taunsa Canals and Remedial Measures. - **Shafaat Ahmad Qureshi**

647 Hydrologic Assessment of Small Dams in Potohar Area : Case Study of Jammergal Dam. - **Dr. Ata-ur-Rehman Tariq**

648 A Perspective Scenario of Water for Irrigated Agriculture in Pakistan. - **Dr. M. Nawaz Bhutta** and **Dr. A. B. Sufi**

649 Exploiting Huge Natural Resources of Lime in Pakistan for Construction Industry. - **Prof. Dr. Ing. Syed Ali Rizwan, Shamas-ur-Rehman Toor** and **Engr. Husnain Ahmad**

M650 Failure of 2–meter DIA and 54 Meters Long Piles No. 3/1, 3/2, 3/3, 4/3, 6/2, Cracks in Transom No. 6 and other Problems of West Channel Bridge Over River Chenab Near Chiniot on Faisalabad – Sargodha Road. - **Engr. Muhammad Iqbal Qureshi**

M651 Performance of Subsurface Drains in Mirpur Khas Area of LBOD Stage-I Project. - **Yawar Hamid** and **Irshad Ahmed Bohio**

652 The Effect of Alloy Additions on the Magnetic Properties of RFeB Sintered Magnets. - **Dr. A. Ahmad**

653 Testing the Detonator Accuracy Using Velocity of Detonation and Airblast Meters. - **Dr. Syed M. Tariq**

654 Organizational Methodology for Innovating Products and Processes. - **Tauseef Aized**

655 Cybernetics in Water Resources Management. - **Naveed Alam**

M656 Using Environment Friendly Finely Divided Materials in Brittle Matrix Composites. - **Prof. Dr. Ing. Syed Ali Rizwan** and **Engr. Husnain Ahmad**

657 A Comparative Study of Calculated and Measured Particle Velocities. - **Dr. Syed M. Tariq**

VOLUME - LXX - 2006 (2004 – 2006)

658 Role of Water Resources Development in the Economy of Pakistan. - **M. Mushtaq Chaudhry, Dr. Muhammad Siddique and Dr. Allah Bakhsh Sufi**

659 Sedimentation of Tarbela and Mangla Reservoirs. - **Dr. Izhar-ul-Haq and S. Tanveer Abbas**

660 Analysis of Different Models to Predict the Mean Flow Velocity in Hyper-concentrations, Mudflows and Debris Flows. – **Engr. Hammad Hussain**

661 Use and Limitations of Sprinklar and Drip Irrigation Systems in Pakistan. - **Dr. Muhammad Mehboob Alam, Dr. Muhammad Nawaz Bhutta** and **Dr. Aftab H. Azhar**

662 Damages to the right Pocket of Sukkur Barrage and Emergency Restoration Works (2004-2005). - **Barkat Ali Luna, Malik Ahmad Khan, Ch. Muzaffar Hussain** and **Dr. Muhammad Salik Javed**

663 Geotechnical Evaluation of a Morning Glory Spillway Failure Founded on Expansive and Dispersive Clay. - **Farhat Javed** and **Brig. Asghar Nasim**

664 Resettlement Aspects of Mangla Dam Raising. - **Muhammad Saleem Sheikh**

665 Second Remodelling Proposed for Balloki Headworks. - **Muhammad Aslam Chohan**

666 Environmental Management Concerns in Water Sector and Institutional Capabilities. - **Engr. Muhammad Shafiq**

667 Meeting Future Food Demands of Pakistan under Scarce Water Situations. - **Shehzad Ahmed, Naveed Alam, Abdul Shakoor** and **M. Kaleem Ullah**

668 Numerical Simulation of Canals Irrigation Systems in Pakistan. - **Mazhar Hussain**

669 Tackling Landslides during Extension of KKH. - **Sohail Kibria and Basit Masud**

670 Self-Compacting Concrete - A Useful Technology. - **Prof. Dr. Ing. Syed Ali Rizwan, Thomas A. Bier** and **Engr. Husnain Ahmad**

671 Effect of Temperature and ph on the Binding of Chloride by Calcium Aluminate. – **Dr. S. E. Benjamin**

672 Engineering and Entrepreneurial Thrust. - **Dr. S. M. Naqi**

673 University-Industry Linkage for the Rapid Growth of Engineering Industries in Pakistan. - **Air Commodore (R) Mansoor Malik**

674 Grid Computing: Potential Opportunities for Pakistan. - **Dr. Arshad Ali**

675 Developing Countries and Intellectual Property Rights. - **Saad Nusrullah**

676 Synthesis and Applications of TIO_2 Nanoparticles. - **Dr. A. Ahmad, Gul Hameed Awan** and **Salman Aziz**

677 A Study on Thermal Cracking of Cast Iron. - **Dr. M. Yousaf Anwar**

678 Sustainable Pakistan through Matching Grant Programme: 21st Century Vision. - **Qamar-ul-Islam, Dr. Awais Piracha** and **Muhammad Shahzad**

679 Comparative Study of Nylon and PVC Fluidized Bed Coating on Mild Steel. - **R. Ahmad, S. Aziz** and **J. Iqbal**

VOLUME - LXXI - 2011 (2006 – 2011)

Part-1

680 Pakistan Need for Storages for Different Uses. - **Riaz Nazir Tarar**

681 Diamer Basha Dam Project. - **Dr. Izhar ul Haq** and **Syed Tanveer Abbas**

682 Performance Based Seismic Evaluation and Retrofitting of Unsymmetrical Medium Rise Buildings- A Case Study. - **Jimmy Chandra, Pennung Warnitchai, Deepak Rayamajhi, Naveed Anwar** and **Shuaib Ahmad**

683 Cofferdam Construction and Dewatering Taunsa Barrage Rehabilitation Project. - **Muhammad Nadeem, PhD, PE**

684 Selection of Dam Type and Planning Aspects of Dasu Hydropower Project. - **M. Saleem Sheikh**

685 Construction of Taunsa Barrage Rehabilitation Project Works. - **S.M.A Zaidi, M. Akhter Chaudhry** and **Malik Ahmad Khan**

686 Tarbela Reservoir: Towards a Sustainable Future. - **Amjad Agha**

687 Planning and Design of Taunsa Barrage Rehabilitation Project. - **S.M.A Zaidi, M. Akram Khan** and **Saif ur Rehman**

688 Kalabagh - A Superior Dam Designers' View Point. - **Engr. Barkat Ali Luna** and **Engr. Muhammad Jabbar**

689 Jinnah Hydropower Project Development of Surge due to Sudden Shutdown. - **Dr. Muhammad Siddique** and **Maqsood Shafique Qureshi**

690 Quality Management for Taunsa Barrage Rehabilitation Project. - **S.M.A Zaidi, Malik Ahmad Khan** and **Javed Asad**

Part-2

691 Fall Structures on Open Flow Canals (Design Concept and Methodology). - **B. A. Shakir**

692 Experience of Bio-Saline Approach for Rehabilitation of Salt-Affected Lands in Pakistan. - **Ali Hassan Shah, Khalid Hussain Gill** and **Najaf Iqbal Syed**

693 To Look into the Possibility of using Penetration Grade Asphalt Binder in Stone Matrix Asphalt (SMA) for Highways and Heavy Traffic Roads in Pakistan. - **Shamim Zafar**

694 Rehabilitation of Lower Chenab Canal (LCC) System Punjab Pakistan. - **Engr. Mazhar Hussain**

695 Assessment of Groundwater Development Potential in District Nowshera using Groundwater Modeling. - **Engr. Muhammad Basharat, Dr. Muhammad Siddique** and **Muhammad Ismail**

696 Factor of Accessibility as a Catalyst towards Disaster Management – Case Study of Lyari Expressway, Karachi. - **Dr. Noman Ahmed**

697 Hydraulic Simulation of Lower Bari Doab Canal (LBDC) Punjab Pakistan. - **Engr. Mazhar Hussain**

698 Drinking Water Shortage - A Solution. - **S. E. Benjamin**

699 Well Test Analysis of Two-Layered Oil Reservoir in Commingled Flow System. - **Abdul Majeed**

700 Irrigation Water Pricing & its Sustainability in Pakistan. - **Dr. Allah Bakhsh Sufi**

701 Occupational Health and Safety Issues in Sihala Flour & General Mills (Pvt.) Limited in I-9 Industrial Zone, Islamabad: A Case Study. - **Sajida Rasheed** and **Zahir-ud-Din Khan**

702 Drinking Water Quality Monitoring within a Distribution Network: F-8 and E-7 Sectors of Islamabad. - **Sara Qaiser, Syeda Asma, M. Talal Ali Khan** and **Imran Hashmi**

703 Field Testing of Film Hole Irrigation on Borders for Water Saving and Sunflower Production. - **Muhammad Saeed** and **Sajid Mahmood**

704 Water Quality Assessment of River Ravi around Lahore City. - **Ms. Afaf Ayesha**

705 Performance Evaluation of Taunsa Barrage Emergency Rehabilitation and Modernization Project. - **Engr. S.M.A. Zaidi Engr. Mehr Muhammad Amin** and **Engr. Muhammad Ajmal Ahmadani**

706 The Reality of Net Hydel Profit. - **Azhar Masud Panni**

707 Flashflood Risk Assessment in Pakistan. - **Husnain Ahmad, Javeed Iqbal Bokhari** and **Qazi Tallat Mahmood Siddiqui**

VOLUME - LXXII - CENTENARY CELEBRATIONS (1912 – 2012)

708 Engineering of Headrace Tunnel for Neelum Jhelum Hydropower Project. - **Engr. Abdul Khaliq Khan**

709 Evolution of Design of Barrages in Indus Plains - **Dr. Izhar ul Haq, Riaz Nazir Tarar**

710 Modern Approaches in Flood Disaster Risk Management - **Asjad Imtiaz Ali, Javeed Iqbal Bokhari, Qazi Tallat M. Siddiqui**

711 Water Resources of Pakistan **Irshad Ahmad, Dr. Allah Bakhsh Sufi, Imran Tariq**

712 Managing Water Resources for Food Security in Pakistan - **Irshad Ahmad, Dr. Allah Bakhsh Sufi, Talib Hussain**

713 Mangla Dam - Past, Present & FutureM. **Saleem Sheikh**

714 Recent Trends in High Altitude Temperatures and River Flows in Upper Indus Basin - **Dr. Muhammad Siddique, Danial Hashmi**

715 Management of Surface and Groundwater Resources in Cholistan Desert of Pakistan for Drinking and Farm Production - **Muhammad Akram**

716 Intervention of Irrigation Management Transfer in Punjab - An Overview And Assessment - **Engr. Muhammad Shafiq**

717 Groundwater Management in Pakistan: The Question of Balance - **Asad Sarwar Qureshi**

718 Water Resources Management in Pakistan: The Challenges, Climate Change Implications and Way Forward - **Engr. Asrar-ul-Haq, Muhammad Aamir Khan, Muhammad Hasnain Khan**

719 Development of Low Head Hydropower Projects on Canals in Punjab Pakistan - **Engr. Mazhar Hussain**

720 Design, Local Manufacturing, Development and Installation for Practical Demonstration of very low Head Micro Hydro Power Plant at Canal in Pakistan - **Prof. Dr. Engr. S. M. Bhutta**

721 Accelerated, Innovative and Participatory Mechanism for Combating Nation's Crises - Dr. **Engr. Javed Yunas Uppal**

722 Hydel Generation and its Role in Tackling Pakistan's Power Crisis - **Engr. Khurram Feroze**

723 Solar Energy – Today and Tomorrow - **Engr. Riaz Ahsan Baig**

724 Role of Technocrats in Nation Development - **Engr. Aftab Islam Agha**

725 Pollution of Water Bodies: Challenges and Strategies - **Afaf Ayesha**

726 Cost and Time Overruns in Highway Projects in Pakistan - **Rafiq Muhammad Choudhry, Abdur Rehman Nasir, Hamza Farooq Gabriel**

727 Effect of Load on Friction & Wear Characteristics of Tin Coatings Under Boundary Lubrication Condition - **B. Waseem, M. Irfan, S. Alam, B. D. Soomro, M. Shahid, A. K. Aziz**

728 Selection of Aggregate Gradation for Hot Mix Asphalt - **Shamim Zafar**

729 Nanoscale Metamaterial Energy Conversion Devices - **Prof. Nasrullah Khan, Naeem Abas**

730 Right Cost for Sustainable Construction - **Engr. M. Mazhar-ul-Islam**

731 Performance Evaluation of Bench Scale Membrane Bioreactor (MBR) Systems - **Aman Ahmad, Babar Abbas, Rasikh Habib, Humayun Khan, Sher Jamal Khan**

VOLUME - LXXIII - 2013 (2011 – 2013)

732 Proposal for Remodeling of Khanki Headwork Vs New Barrage Construction – **Muhammad Aslam Chohan**

733 Sediment Management of Tarbela Reservoir – **Dr. Izhar ul Haq**

734 Solution to Energy Crises Bridging Gap between Demand and Power Supply – **Riaz Ahsan Baig**

735 Role of Sediment Transport in Operation of Irrigation Canals – **Sarfraz Munir, Javaid A. Tariq, Bart Schultz**

736 Effects if Harmonics on Power & Communication Systems – **Eng. Fayyaz Ali Shah**

737 An Alternative to Deep Foundations in Marginal Soils of Karachi – **Tariq Hamid, Qamar Jawaid**

738 Impact and Puncturing of Jari Tunnel and Enlargement of Existing Tapping's for Additional Water Supply and Power Generation – **Javed Munir, Syed Abbas Ali, Irfan Mahmood**

739 Design of Steel Fibre Reinforced Concrete Beams using the new FIB Model Code 2010 – An Evaluative – **Ammar Abid, K. B. Franzen**

740 Numerical Modeling and Simulation of a Masonry Arch in ANSYS Subjected to Impact Loading – **Sajjad Ahmad, Giuseppe Andrea Ferro, Abdul Qadir Bhatti, Rao Arsalan Khushnood, Aitizaz Arshad**

741 Impact Response Analysis of Retaining Wall under Falling Weight Impact Load – **Abdul Qadir Bhatti, Guilio Ventura, Asim Bashir, Muhammad Yousaf Anwar, Ihsan Ullah Shah**

742 A Comparative Study on Highway Bridge Barriers Reinforced with Steel and GFRP Bars – **Rao Arsalan Khushnood, Giuseppe Andrea Ferro, Sajjad Ahmad, Fawad Ahmed Najam**

743 Analysis of the Indo-Pak Indus Waters Treaty 1960 – **Engr. Asjad Imtiaz Ali, Engr. Javeed Iqbal Bokhari, Engr. Dr. Qazi Tallat M. Siddiqui**

744 Addressing Water and Power Needs of Pakistan Through Construction of Major Storage Dams – **Muhammad Munir Ch., Zia-ul-Hasan, Dr. Allah Bakhsh Sufi**

745 Combating Natural Disasters - Engineers' Responsibility – **Eur Ing Sarfraz Ahmad**

746 Hill Torrent Management Initiatives in Southern Part of Punjab An Overview, Impact Analysis & Way Forward – **Ch. Muhammad Shafiq**

747 Temporal and Spatial Variations In Summer Flows of Upper Indus Basin, Pakistan – **Muhammad Yaseen, Haris Akram Bhatti, Tom Rientjes, Ghulam Nabi, Muhammad Latif**

748 Channelization of Natural Nullahs in Himalayans for Flood Control Using Hec Ras – **Engr. Dr. Mazhar Hussain, Engr. Muhammad Atif Mian**

749 Impact of Pollution in Ravi River on Groundwater Underlying the Lahore City – **Ghulam Zakir Hassan, Ghulam Shabir, Faiz Raza Hassan, Saleem Akhtar**

VOLUME - LXXIV – 2015 (2013 – 2015)

750 Coal Exploitation and Utilization for Economic Development – **Prof. Dr. Shahid Munir**

751 Irrigation Scheduling – **Mohammad Ashraf, Arif Anwar, Muhammad Aslam**

752 Efficient Application of Water on Farm – **Bakshal Khan Lashari, Arif Anwar, Muhammad Aslam**

753 Rainwater Harvesting – **Abdul Wahab Kakar, Arif Anwar, Muhammad Aslam**

754 Groundwater Issues – **Ahmad Khan Bhatti, Arif Anwar, Muhammad Aslam**

755 Surface Water Issues – **M. Waseem Asghar, Arif Anwar, Muhammad Aslam**

756 Minimizing Flood Damages to Agriculture – **Nazir Ahmed Memon, Arif Anwar, Muhammad Aslam**

757 Capture of Flood Waters – **Yawar Hamid, Arif Anwar, Muhammad Aslam**

758 Effective Regulations for Sustainable Construction – **Engr. M. Mazhar-ul Islam**

759 Geomorphological and Geological Investigation using Dem of Islamabad District, Pakistan – **Sajid Rashid Ahmad, Usman Ahmad, Muhammad Asim Rizwan**

760 Groundwater Management using Modflow- A Case Study of Rechna Doab, Punjab, Pakistan – **Ghulam Zakir Hassan, Faiz Raza Hassan, Sultan Ahmad Rizvi**

761 Impacts of Climate Change on Water Resources of Pakistan – **Javeed Iqbal Bokhari, Ather Hameed Awan, Dr. Qazi Tallat M. Siddiqui**

762 Pakistan's Water Security Issues and Addressing Strategy – **Riaz Nazir Tarar**

763 Rail Link Between Pakistan and China- Pre-Feasibility Study – **Stephan Tischler, Abdul Rehman Chaudhry**

764 Physical Hydraulic Model Studies of Neelum Jhelum Hydroelectric Project, Pakistan – **Khalid Mehmood, Engr Muhammad Sehroosh, Dr. Engr Mazhar Hussain**

765 Water Security for Sustained Development of Pakistan – **Engr. Ishteqaq Ahmad Kokab, Engr. Husnain Afzal**

766 On-Farm Water Storage – **Mushtaq Ahmad Gill, Arif Anwar, Muhammad Aslam**

767 Modeling of Chlorine Decay in Nust Drinking Water Distribution System – **Wajeha Tauqir, Syeda Rida E Zanib, Ifrah Imtiaz, Zohaib Mansha, Imran Hashmi**

768 Hill Torrents of Pakistan – **Tariq Altaf, Abdul Khaliq Hashmi**

769 Instream Hydrokinetic Power Technology – A Case Study of Ghazi Barotha Power Channel – **Muhammad Mohsin Munir, Tariq Altaf, Javed Munir, Muhammad Muneeb Khan**

770 Water Security Issues and Way Forward – **Dr. Izhar-ul-Haq, Abdul Khaliq Khan**

M771 Flood Management Challenges in Pakistan: Shaping Improvement Strategies in the Context of Prevailing Constraints, Conflicting Interests and Global Experiences – **Asrar ul Haq**

772 Groundwater Pollution and Threat for Environment in Mega City Faisalabad – **Engr. Dr. Muhammad Saeed, Engr. Hafeer-ur-Rehman, Engr. Syed Javed Sultan, Shaukat Hayyat, M. Noman Younis**

773 Water Policy Issues and Options: Some Ideas to use Economic Tools to close the Growing Supply and Demand Gap – **Dr. Mahmood Ahmad**

VOLUME - LXXV – 2017 (2016 – 2017)

774 WATER ACCOUNTING AND AUDITING TO MANAGE WATER SCARCITY -- GLOBAL EXPERIENCE AND POSSIBLE GUIDELINES FOR PAKISTAN – **Dr. Mahmood Ahmad**

775 A WAY FORWARD FOR FLOOD RISK MANAGEMENT IN PAKISTAN – **Dr. Qazi Tallat Mahmood Siddiqui**

776 PLANNING, DESIGN, CONSTRUCTION AND MONITORING OF FLOOD BUNDS – **Engr. Syed Mansoob Ali Zaidi**

777 TARBELA 4TH EXTENSION HYDROPOWER PROJECT – **Dr. Izhar ul Haq, M. Mushtaq Ch.**

778 CLIMATE CHANGE IMPACT ON WATER RESOURCES OF PAKISTAN – **Muhammad Munir Ch., Maqsood Shafique Qureshi, Dr. Allah Bakhsh Sufi**

779 SUSTAINABLE DEVELOPMENT AND MANAGEMENT OF GROUNDWATER- LAHORE CITY – **Ghulam Zakir Hassan, Faiz Raza Hassan**

780 COMPARISON OF TEMPORAL CHANGES IN GROUNDWATER DEPTH WITH RESPECT TO DROUGHT AND NORMAL YEARS IN IRRIGATED AREAS OF SINDH AND BALUCHISTAN – **Engr. Ijaz Javed, Engr. Muhammad Saeed, Engr. Muhammad Jawad, Engr. Muhammad Shoaib, Dilbar Hassan**

781 PCRWR IRRIGATION ADVISORY SERVICES FOR DIFFERENT AGRO-CLIMATIC ZONES OF PAKISTAN – AN IMPACT ANALYSIS – **Muhammad Ashraf, Ashfaq Ahmad Sheikh, Ahmad Zeeshan Bhatti, Adil Altaf**

782 FARMER MANAGED IRRIGATION SYSTEM AND ITS IMPACT ON WATER SERVICE DELIVERY: A CASE OF SINDH-PAKISTAN – **Nazir Ahmed Memon, Masroor Ahmed Shahwani**

783 CROP WATER BUDGET ESTIMATION USING GIS – **Muhammad Awais, Muhammad Mohsin Munir**

784 ROOF TOP RAINWATER HARVESTING OPTIONS FOR WATER CONSERVATION – A CASE STUDY OF LAHORE – **Dr. Ghulam Nabi, Muhammad Tarique**

785 AWARDING CONTRACT WITHOUT COMPETITIVE BIDDING: IMPLICATIONS – **Engr. M. Mazhar-ul-Islam**

786 IMPACT OF SOIL CHARACTERISTICS ON FAILURE OF FLOOD BUNDS- CASE STUDY FROM PUNJAB PAKISTAN – **Ghulam Zakir Hassan, Ghulam Shabir, Adnan Hassan, M. Shahzad Abdul Rahim**

787 HISTORY OF TOLERABLE DEFORMATION OF FOUNDATIONS – **Sohail Kibria, Sajid Iqbal**

788 FINANCIAL AND ECONOMIC ANALYSIS OF PROJECT OF UP-GRADATION / REHABILITATION OF MAIN LINE-2 of PAKISTAN RAILWAYS – **Abdul Rehman Chaudhry, Muhammad Inam**

789 INTERPRETATION OF PROBLEMATIC SONOGRAPHS IN SONIC INTEGRITY TESTING OF PILES – **Sohail Kibria, Asim Masud, M. Tayyab Javed**

790 BARRAGE PROJECTS-FLOOD MANAGEMENT – **Amjad Saeed, Muhammad Sajid Nazir**