

RESEARCH ARTICLE

Renewable Energy in Pakistan: Assessment of Hydropower Potential of Pakistan's Irrigation Infrastructure for Renewable Energy Generation: A Case Study of the BRBD Canal

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Abstract: This research investigates the hydropower capacity of the BRBD Canal, specifically focusing on four divisions within the Lahore zone of the Punjab Irrigation Department: Lahore, Kasur, Shahdara, and Pandoki. There is very large contiguous irrigation system exists in Pakistan having so many canal falls, head regulators and outlets which can be used as off grid / on grid hydropower sites. The study involved comprehensive data collection, pertaining to the entire BRBD Canal. The analysis primarily concentrated on Head Regulators, Canal Falls, and Outlets, extracting vital information related to available head, discharge, and the estimation of potential of power and energy generation. The aim of this study was to assess the hydropower potential at the head regulators, canal falls, and outlets along the BRBD Canal for renewable energy generation. The outcomes of the study aim to contribute to the development of sustainable renewable energy generation strategies by utilizing the available hydropower resources within the canal. The results obtained from this investigation can provide valuable insights for policymakers, engineers, and energy planners to assess the feasibility and economic viability of utilizing this untapped energy source of the BRBD Canal for renewable energy generation to significantly meet the region's growing energy demands.

Keywords: Renewable Energy, Pakistan, Hydropower, Irrigation Infrastructure, BRBD Canal

Introduction

Pakistan has a predominantly agricultural economy and is striving to develop and expand its industrial base. Pakistan despite the enormous potential of indigenous energy resources remains energy deficient and has to rely heavily on imports to satisfy its needs. Today, the primary energy supplies are not enough to meet even the present demand. So, Pakistan, like other developing countries of the region, is facing a serious challenge of energy deficit. Renewable energy sources can play an important role in meeting this challenge. Pakistan has a huge potential for producing electricity from water and a wealth of hydropower. Pakistan's overall hydroelectric capacity is thought to be around 60,000 MW. The nation is only utilizing roughly 16% of its potential, falling short of its hydropower potential overall. Hydropower isn't being used to its full potential for a number of reasons, including the high investment costs associated with the installation of hydro plants, the expansion of the electrical transmission network, and the need to relocate the affected people. The installed capacity for hydropower is 10,251 MW at the moment, or around 25% of the total installed capacity.

Hydropotential assessment is the most important step in determining the potential of water resources, particularly in a canal system, to generate energy. The primary aim of such an assessment is to evaluate the viability of converting the potential energy within the water system into electricity (Vaclav, [2016](#)).

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Hydropower is one of the oldest renewable sources for electricity generation. Pakistan has a long canal system, mainly within the Indus Basin it provides source of irrigation and water supply to agriculture and other sectors in it. Along this canal there are head regulator canal falls and outlets, which can harness the flow of water to generate hydropower. These structures act as potential locations for the development of small to medium-scale hydropower projects (Loots et al., [2015](#)).

Problem Statement

Pakistan faces a persistent issue of high electricity costs, burdening consumers and impeding socio-economic development. The reliance on expensive imported fuels and limited diversification in the energy mix contributes to elevated electricity tariffs. To address this challenge, there is a pressing need to explore untapped local energy generation potential, particularly at canal fall head regulators and outlets, as viable sites for affordable electricity production.

Key challenges within the Problem Statement Include

The reliance of Pakistan on imported fuels for electricity generation, including oil and liquefied natural gas, makes the electricity generated highly cost-ineffective due to fluctuations in international fuel prices and transport costs. Therefore, the electricity generated is costly for most consumers. The share of fossil fuel-based energy is the highest, especially thermal power plants, leading to higher costs of electricity. Inadequate policy frameworks and regulatory barriers can hinder the exploration and development of local energy generation projects.

Developing energy generation infrastructure requires specific technical expertise and considerations. Upgrading or constructing new facilities, implementing turbines, transmission lines, and grid integration systems, and ensuring efficient operation and maintenance present challenges that need to be addressed to harness the local energy potential effectively.

Pakistan's canal system, comprising numerous head regulator canal falls and outlets, offers untapped potential for local energy generation. These sites present opportunities for hydropower installations, leveraging the abundant water resources available in the country. However, the lack of exploration and investment in utilizing these sites for energy generation hampers the realization of this potential. The lack of diversification in the energy sources restricts the country's ability to tap into cost-effective renewable energy options, such as hydropower, solar, and wind, which can be harnessed at local sites like canal fall head regulators and outlets.

Objectives

The main objectives of the project are:

1. To assess hydropower potential and energy at canal falls
2. Head regulators to assess hydropower potential and energy
3. To assess hydropower potential and energy at Outlets

Hydropower and energy assessment shall have an overall goal to ensure that the sustainable development of hydropower projects at canal fall head regulators and outlets in Bambawali-Ravi-Bedian Canal (BRBD) shall be supported with evidence-based decision-making. It shall therefore help to maximally exploit the use of local energy resources, increase diversity in the energy mix, and thus ensure the affordable and sustainable energy supply to the nation.

Literature Review

Renewable Energy Landscape in Pakistan

Pakistan has an ongoing energy crisis due to a large discrepancy between the supply and demand for electricity. The nation's energy mix is primarily derived from fossil fuels, which make up roughly 64% of it,

with renewable energy making up only 4% (National Electric Power Regulatory Authority [NEPRA], [2021](#)). In particular, hydroelectric, solar, and wind have enormous promise for renewable energy in Pakistan. Only over 11,000 MW of the estimated 60,000 MW of hydropower's potential have been developed, making it the most popular renewable energy source (Asian Development Bank [ADB], [2017](#)). The government of Pakistan has recognized the importance of renewable energy and has set ambitious targets under the Alternative and Renewable Energy Policy 2019, aiming to achieve 30% renewable energy in the national grid by 2030 (Government of Pakistan, [2019](#)). Given its dual advantages of managing water and producing energy, hydropower is anticipated to be crucial in reaching this goal.

Hydropower Potential in Pakistan

Hydroelectric potential is available in Pakistan's northern areas, especially Khyber Pakhtunkhwa (KP), Gilgit-Baltistan (GB), and Azad Jammu and Kashmir (AJK). Among these, the Indus River, along with the Jhelum, Chenab, and Kabul rivers, have perfect conditions for massive hydropower projects (Sangal et al., 2015). Even with major hydropower projects like the Tarbela Dam, which boasts a capacity of 4,888 MW; Mangla Dam, which boasts 1,000 MW; and Neelum-Jhelum Hydropower Plant with 969 MW capacity, yet the untapped potential is substantial (Mirza et al., [2008](#)).

There is also growing popularity of small-scale and micro-hydropower projects, particularly in off-grid and rural locations. Such projects can be integrated with the existing irrigation infrastructure to generate electricity for home and agricultural consumption. Hydropower is also cost-effective and environment-friendly (Qureshi & Akintung, [2014](#)). Apart from being a source of clean energy, hydropower plays a critical role in water resource management, especially in irrigation. The agriculture sector is one of the largest sectors of Pakistan, with 38% of the labor force and producing around 19% of its GDP (Young et al., [2019](#)). Hydropower projects can integrate irrigation infrastructure, and irrigation systems that are supplied by rivers and canals, which improve water efficiency and allow for the generation of renewable energy to support the operations of agricultural production.

Irrigation Infrastructure in Pakistan

With its irrigation system covering more than 18 million hectares of agricultural land, Pakistan boasts one of the biggest and most intricate systems in the world. A vast network of canals, 19 barrages, and three large reservoirs (Tarbela, Mangla, and Chashma) make up the Indus Basin Irrigation System (IBIS), which serves as the foundation of this infrastructure (Qureshi, [2011](#)). The system is essential to Pakistan's agriculture, which employs 38% of the workforce and accounts for 19% of the country's GDP (Young et al., [2019](#)).

However, the irrigation system faces several challenges, including water scarcity, inefficient water use, and aging infrastructure. Climate change exacerbates these issues, with unpredictable rainfall patterns and glacial melt affecting water availability (Lee, [2023](#)). The integration of hydropower projects with irrigation infrastructure can address some of these challenges by improving water management and providing renewable energy. For instance, run-of-river hydropower projects can be constructed on existing canals and barrages without significant alterations to the irrigation network. These projects can generate electricity while maintaining the flow of water for agricultural purposes.

BRBD Canal: Overview and Hydropower Potential

In Punjab, Pakistan, the Bambanwala-Ravi-Bedian-Depalpur (BRBD) Canal is an essential part of the irrigation system. The canal, which runs from the Balloki Barrage on the Ravi River, provides water to farms in the Sheikhpura, Lahore, and Kasur districts. With a planned discharge capacity of 8,600 cusecs, the BRBD Canal is essential to the region's agricultural industry (Irrigation Department Punjab, [2020](#)).

The consistent flow rate and gradient of the BRBD Canal make it an ideal location for small hydropower plants. Various potential locations in the canal were identified by studies for the placement of micro-hydropower units, which can generate electricity for a small number of villages and farming activities (Qureshi & Akintung, [2014](#)). Such actions may be done with minimal damage to the environment and without interfering with the overall irrigation goal of the canal. For example, the BRBD Canal's installation of micro-hydropower units will enhance the economic viability of farm operations, reduce dependence on fossil fuels, and provide a reliable source of renewable energy (Finance Division of Pakistan, [2021](#)).

Benefits of Hydropower Integration with Irrigation Infrastructure

There are various advantages to combining hydropower projects with irrigation infrastructure, such the BRBD Canal:

- **Energy Generation:** By lowering reliance on fossil fuels and enhancing energy security, hydropower projects can offer a dependable renewable energy supply.
- Hydropower projects can improve water management by controlling flow, thereby lowering evaporation and seepage losses, and boosting the efficiency of the irrigation systems.
- **Economic Development:** Electricity production can boost agricultural productivity, help rural electrification, and generate jobs.
- **Climate Resilience:** By offering a reliable supply of water and energy despite climate unpredictability, hydropower projects can help promote climate resilience.

Challenges and Barriers

Despite the possible advantages, a number of obstacles prevent Pakistani hydropower projects from developing:

- **Financial Restrictions:** Two significant obstacles are the high initial costs of hydropower projects and the restricted availability of funding.
- **Technical Restrictions:** One major obstacle to small-scale hydropower projects is the absence of infrastructure and technical know-how.
- **Regulatory Obstacles:** Complicated regulatory processes and administrative hold-ups frequently make it difficult to execute projects.
- **Environmental Concerns:** Community dislocation and ecosystem disruption are just two examples of the negative social and environmental effects that large-scale hydropower projects may have.

Case Studies and Success Stories

The possibility of combining renewable energy sources with irrigation infrastructure is exemplified by a number of prosperous hydropower projects in Pakistan. For example:

- **Renala Khurd hydroelectric power plant:** This 1.1 MW run-of-river hydroelectric power plant, located on the Lower Bari Doab Canal, has been in service since 1925 and is still providing electricity to local populations (Pakistan Water and Power Development Authority [WAPDA], [2021](#)).
- -Another very effective example of hydropower and irrigation infrastructure integration is the Chianwali Hydropower Project, a 2.4 MW project on Punjab's Upper Chenab Canal (Qureshi & Akintung, [2014](#)).

These initiatives demonstrate the viability and advantages of Pakistan's small-scale hydropower development.

Hydropower and Renewable Energy Sources in Pakistan

Hydropower is the biggest source of renewable energy. Though other sources such as wind and solar are getting more popularity day by day. However, from almost a century hydropower is the major source of clean energy.

Pakistan has massive hydropower potential of approximately 60,000 MW; however, only about 16% of that is utilized. Major issues which affect the maximum exploitation of hydropower

are the high cost of installation, the development of an electricity transmission network, and the problem of resettlement. Installed hydropower capacity presently is at about 10,251 MW and about 25% of total capacity.

Table 1
Major Hydropower Projects in Pakistan

Sr #	Names	Capacity (MW)
1	Tarbela Dam	4888
2	Mangla Dam	1100
3	Ghazi Barotha Hydropower Project	1450
4	Neelum-Jhelum Hydropower Project	969
5	Dasu Hydropower Project	2160
6	Diamer-Bhasha Dam	4500
7	Bunji Hydropower Project (Proposed)	7100
8	Patan Hydropower Project (Under Construction)	2800
9	Golen Gol Hydropower Project	108
10	Allai Khwar Hydropower Project	121
11	Jinnah Hydropower Project	96
12	Duber Khwar Hydropower Project	130
13	Khan Khwar Hydropower Project	72
14	Malakand-III Hydropower Project	81
15	Suki Kinari Hydropower Project	884
16	Karot Hydropower Project	720
17	Azad Pattan Hydropower Project	700
18	Kohala Hydropower Project (Under Construction)	1124

Hydropower plants can be started and stopped more rapidly and economically than fossil fuel and nuclear plants, so the use of hydropower plants to meet pea loads is particularly advantageous. The large hydropower plants were originally base-load plants but are being used more and more for peaking power as large fossil fuel and nuclear power plants become operative in the region to supply the base load.

Methodology
Data Collection and Review

The project begins with collecting and reviewing relevant data related to the BRBD Canal. This includes historical water flow records, canal infrastructure details, Longitudinal section of canal, topographic maps, and any available studies or reports. The data collection phase will involve engaging with canal authorities, water resource departments, and other relevant stakeholders to obtain necessary information.

This research involves an assessment of the hydropotential at the canal fall, head regulator and outlets that are all present in Bambawali-Ravi-Bedian-Dipalpur (BRBD) Canal Pakistan. In this project we collected the data in the form of L-section from Punjab irrigation department and other division which are monitoring BRBD canal. Then we assess the potential for hydropower generation along the BRBD Canal, considering factors such as water flow rates, head, and elevation differences. It aims to identify and evaluate suitable sites for hydropower installations.

To perform this study for our topic of “Estimation of Hydropower Potential of Bambanwali-Ravi-Bedian-Depalpur-Canal” we need all the related data from a reliable source. And for Our case we contacted

Punjab Irrigation Department for required data. The second main step after data collection was data analysis. And after data analysis we tried to interpret the results that can be used to have an idea about power that can be generated from point of head and discharge availability.

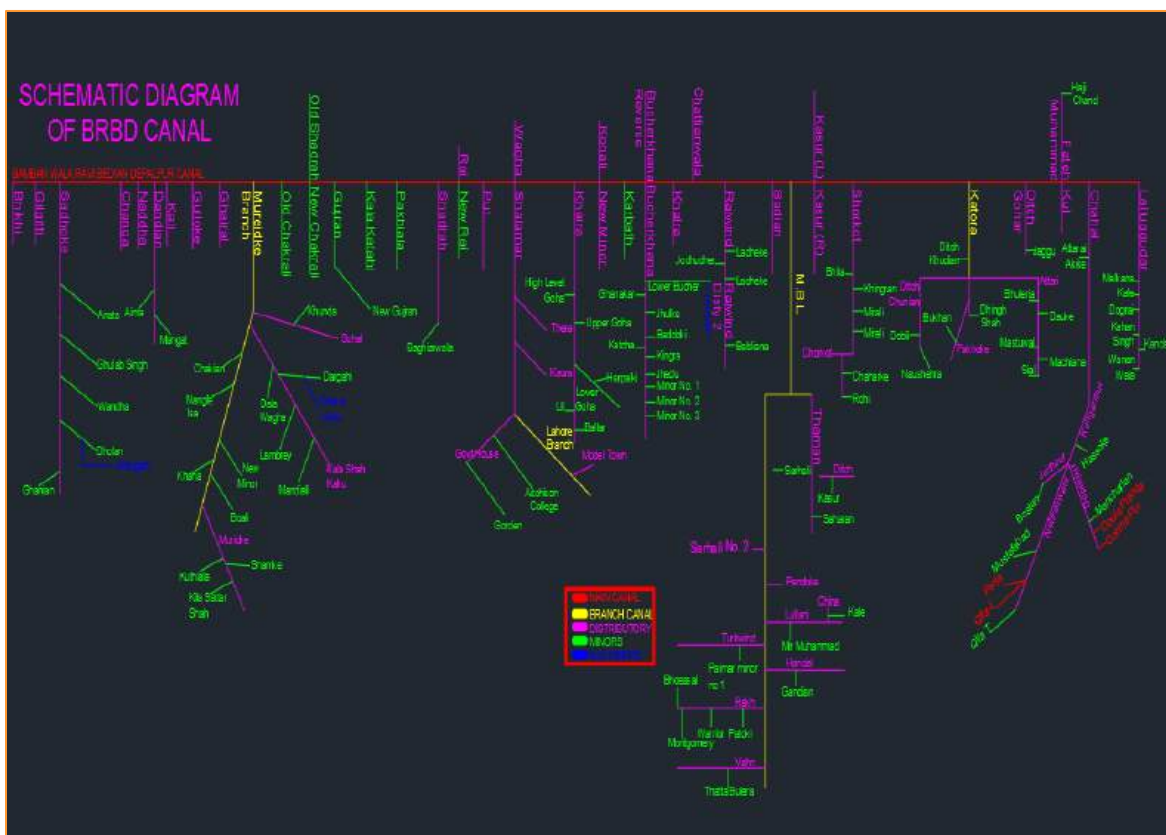
The line diagram below illustrates the canal along with its branch, distributaries and minors.

- A. Origination: Bambawala Village
- B. Other Names: Ichogil Canal
- C. Length: 165Km Approx
- D. Discharge: 7260 Cusecs
- E. 4 Divisions
 - 1. Muridke division
 - 2. Lahore division
 - 3. Pandoke division
 - 4. Kasur division

Main Branch Canals

- 1. Muridke Branch Canal
- 2. Lahore Branch Canal
- 3. Main Branch Lower (MBL)
- 4. Depalpur Canal

Figure 1



There are three locations on any canal where we generally design energy dissipation devices. And we are targeting these three main locations for our study. These are

- a) Canal falls
- b) Head regulator
- c) Outlets

The procedure for data collection for head regulator and canal fall is same while for outlet data we used irrigation website to get data.

To get data first of all we wrote a letter to Punjab irrigation department and we meet there with Dr Muhammad Riaz he is a senior water resource modeler in PID. He gave us instruction about how to perform this task. He then directed us to visit following sub-offices that are managing irrigation canal of BRBD network. On his instructions we contacted following offices and visited some of them.

1. PMIU Program Monitoring and Implementation Unit
2. Office of Executive Engineer Pasrur Link Sialkot
3. Office of Executive engineer Chakbandi Division Link Circle Lahore
4. Office of Executive Engineer Shahdara Sub Division UCC
5. Office of the Executive Engineer CBDC Lahore
6. Office of Executive Engineer Pandoki Division CBDC Lahore
7. Office of Executive Engineer Kasur Division DCC Kasur

From these offices we collected L-sections of canals. Take down their snaps and merged them in a pdf for later use. We done this procedure for different types of available outlets For outlet data we got help from PMIU (department P. i., n.d.). They gave us login to their website and we simply searched for distributaries and minors for which we need outlet data. We compiled data for distributaries and minors in separate excel sheets.

At our places we used L-sections in soft from that we have created to get values of head and discharge available on canal falls and head regulators. For sample a typical L-section of main BRBD canal is attached.

The main output that we need for power output at a point is Discharge and head available at that location. To get head for canal falls we simply subtracted upstream and downstream F.S.L (full supply levels) to get head at that point. And simply read discharge available at that location from L-section.

For head regulator head is mentioned at the start of L-section. We can subtract F.S.L of parent canal and F.S.L of off-taking branch canal/distributary/minor to get head and discharge is actually the flow in of taking canal.

Figure 2

Longitudinal Section of BRBD Canal (Punjab Irrigation Depart

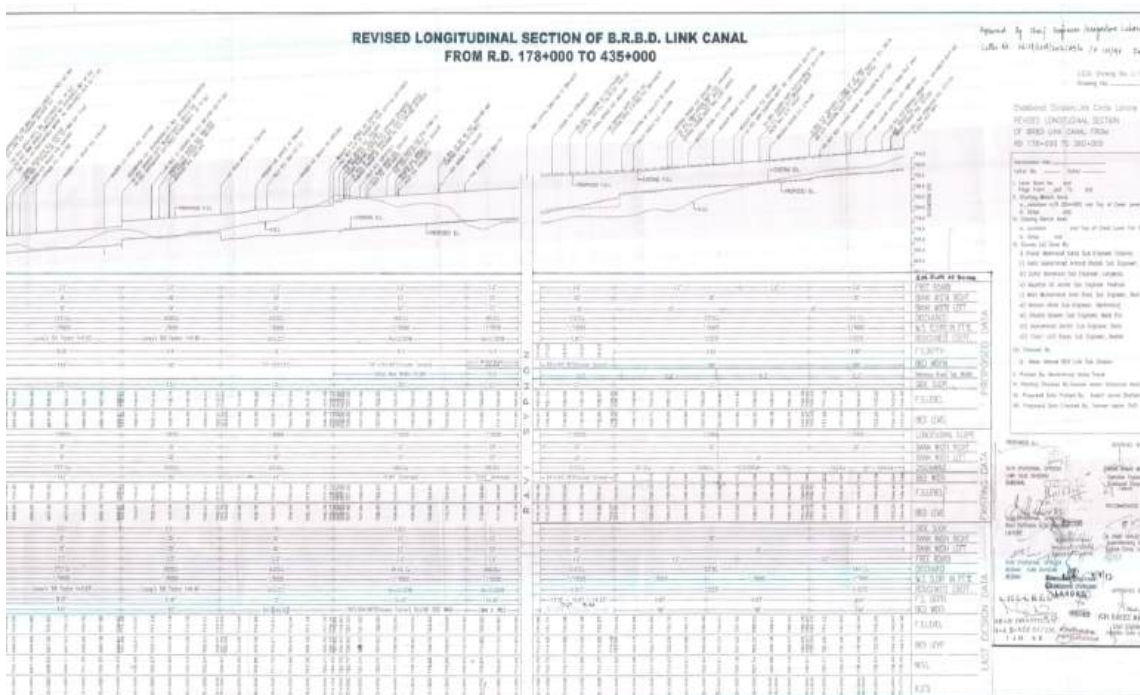
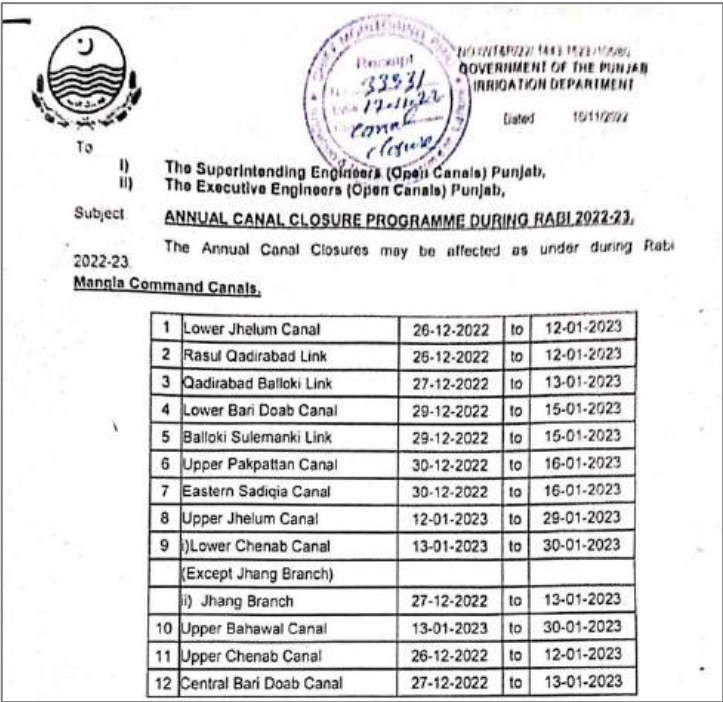


Figure 3
Annual Closure Period of Canal (Punjab Irrigation Department)



Results and Discussion

We have analyzed available data and tried to interpret results for energy and power available. Calculations are simple just we analyzed L-Sections visually and got required data of discharge and head available at points of our interests (head regulators and falls)

We have all the terms available except efficiency. And this term creates a lot of confusion for us. The typical values range from 75 to 85 percent we picked a middle value of 80% and mechanical efficiency of generates is from 95 to 95 percent we picked lower value and multiplied both to get vale of electromechanically efficiency that is 0.76

Putting all the values we get Power available at each location. To estimate energy, we need time in which canal is carrying water. If we look at annual closure period for Upper Chenab canal it is closed for 18 days only. We are going to use 20 days as annual closure period to be on safer side.

Power And Energy Calculation at Head Regulators
At Bambawali Ravi Bedian Depalpur Canal

Table 2
Power and Energy Calculations on Head Regulators from Main Canal

Sr. #	Parent Canal	Offtaking Canal/Disty	RD of Parent Canal	FSL in Canal	FSL in Off taking Chanel	Q	H	Power	Yearly Energy
			ft	ft	ft	ft ³ /s	ft	kW	kWh 10 ³ /year
1	UCC	BRBD canal	-	783.16	780.45	7260	2.71	1250.66	10356
2	BRBD	HR Gilgitty Disty	87065	763.81	759.40	5	4.41	1.40	12
		HR Sadoke Disty	91175	762.56	759.20	362	3.36	77.25	640
		HR Changa Disty	110500	756.40	754.80	12	1.60	1.22	10
		HR Dandian Disty	125500	753.76	750.50	106	3.26	21.95	182

		HR Kali Disty	137800	751.55	749.44	10	2.11	1.34	11
		HR Guluke Disty	144000	750.49	748.27	59	2.22	8.33	69
		HR Hachhar disty	154502	748.50	746.10	19	2.40	2.90	24
		Gharial Disty	166200	746.52	743.10	17.67	3.42	3.84	32
		HR Muridke Branch Canal	177174	744.66	740.80	714	3.86	175.19	1451
		HR Sohl Disty	177174	744.66	742.40	76	2.26	10.92	90
		HR Chakrali minor	184000	743.33	735.47	7	7.86	3.50	29
		HR New Chakrali Minor	202000	740.83	735.47	7	5.36	2.39	20
		HR Shahdara Minor	204800	739.67	736.91	8	2.76	1.40	12
		New Shahdara Disty	224500	737.51	731.44	29	6.07	11.19	93
		HR Kala Khatai disty	244870	734.69	724.53	45	10.16	29.06	241
		HR Pakhiala minor	265300	732.28	715.94	24	16.34	24.92	206
		HR Shahdara Disty	274500	731.04	717.21	263	13.83	231.21	1914
		HR Rai minor	308385	723.66	720.46	3.36	3.20	0.68	6
		Pumping Station Pull Disty	323113	722.19	721.70	10	0.49	0.31	3
		HR Shallamar Dist	334062	721.09	721.00	45	0.09	0.27	2
		HR Lahore Branch	334121	721.09	720.00	400	1.09	27.66	229
		HR Thera pumping station	334296	721.07	723.02	15.6	-1.95	-1.93	-16
		HR of Khaira Disty	337144	719.92	718.97	130	0.95	7.85	65
		HR Karbath minor	391380	711.37	710.10	12	1.27	0.97	8
		Hr Bucharkana Disty	400000	710.29	707.66	10	2.63	1.67	14
		HR Khalra Disty	431500	704.01	703.20	11	0.81	0.57	5
		HR Old Chathianwala minor	433958	703.62	700.90	1	2.72	0.17	1
		HR Ditch Disty	433958	703.62	701.20	19	2.42	2.92	24
		Main Branch Lower	433958	703.62	702.77	1532	0.85	82.78	685
		Ditch Disty	433958	703.82	701.20	17.4	2.62	2.90	24
		HR of chorkot disty	45600	642.11	640.60	350	1.51	33.60	278
		Katora branch	56100R	641.65	639.87	891	1.78	100.82	835
		sodi disty	56100R	641.65	640.45	69.36	1.2	5.29	44
		Bakerke Disty	86500L	636.29	634.42	82	1.87	9.75	81
		Usman wala disty	91500 R	635.45	633.17	41.54	2.28	6.02	50
3	UDC	Fateh muhammad disty	156860R	619.15	618.00	129	1.15	9.43	78
		Kangan pur disty	157017R	617.95	614.87	237	3.08	46.40	384
		KUL disty	157399R	617.95	616.08	25	1.87	2.97	25
		Laluguddar disty	208367L	606.45	604.76	152	1.69	16.33	135
		Kelar kalen disty	208367	606.45	604.15	165	2.3	24.12	200
		Gohar ditch disty	56728	640.00	639.60	14.5	0.4	0.37	3

At Branch Canal

Table 3

Power and Energy Calculations on Head Regulators from Branch Canal

Sr. #	Parent Canal	Offtaking Minor/Disty	RD of Parent Canal	FSL in Canal	FSL in Offtaking Disty/Minor	Q	H	Power	Yearly Energy
			ft	ft	ft	ft ³ /s	ft	kW	kWh 103/year
1	Muridke Branch canal	Kala shah kaku disty	58789	726.36	724.75	265	1.61	27.12	225
		Nangle isa minor	109000	713.20	712.06	11	1.14	0.80	7
		Khanna	117795	711.28	709.79	23	1.49	2.18	18
		Boali	130600	706.39	704.80	16	1.59	1.62	13
		Khuthiala	139063	703.69	702.80	32	0.89	1.81	15
		Shamke minor	167863	695.58	693.64	14	1.94	1.73	14
		Kila satar shah	181500	692.17	691.40	10	0.77	0.49	4
		Chakian minor	32635	733.75	732.63	49	1.12	3.49	29
		New minor	113150	710.62	708.98	9.5	1.64	0.99	8
2	Lahore Branch	Shalamar Disty	334062	725.50	724.85	30	0.65	1.24	10
		Khaira disty	337144	725.50	719.92	86	5.58	30.50	253
		Thera Disty	218400	725.50	724.82	15.5	0.68	0.67	6
		Kaura Disty	22000	715.15	715.08	35	0.07	0.16	1
		Governer House disty	264850	707.51	704.93	24	2.58	3.94	33
		Model Town Disty	280704	702.94	701.54	13	1.40	1.16	10
		Niaz Baig Disty	314000	691.50	690.50	167	1.00	10.62	88
3	MBL	Thaman disty	270886L	702.71	700.94	269	1.77	30.27	251
		Raiwind disty	270890 R	702.18	700.41	85	1.77	9.56	79
		Bendia Disty	271074R	702.86	701.83	10.52	1.03	0.69	6
		Sarhali disty	271074L	702.78	700.70	11.23	2.08	1.48	12
		Sarhalidisty no 2	292374L	694.07	693.13	3.31	0.94	0.20	2
		Daftu disty	303700L	693.28	691.85	10.93	1.43	0.99	8
		Lulliani disty	303810L	693.26	692.76	38.86	0.50	1.24	10
		Pandoki disty	304720R	692.70	691.90	4.5	0.80	0.23	2
		Pandoki disty	304720R	692.70	691.90	4.5	0.80	0.23	2
3	Katora Branch	Khudian ditch disty	12340R	636.30	635.88	12.03	0.42	0.32	3
		Jaggain ditch disty	12340R	636.30	635.69	12.2	0.61	0.47	4
		Attari disty	42900	631.41	629.47	434	1.94	53.52	443
		ChunianDitch Disty	42900	631.41	629.91	34	1.50	3.24	27
		Chunian disty	42900	631.41	625.27	179	6.14	69.86	578
		Pakhoke disty	43400	629.31	626.24	133.36	3.07	26.03	215

At Distributaries

Table 4

Power and Energy Calculations on Head Regulators from Distributaries

Sr#	Parent Canal	Offtaking Minor/Disty	RD of Parent Canal	FSL in Canal	FSL in Offtaking Disty/Minor	Q	H	Power	Yearly Energy
			ft	ft	ft	ft ³ /s	ft	kW	kWh 10 ³ /year
1	Shahdara Disty	HR new pakhiala minor	21500	712.86	711.60	33.00	1.26	2.38	20
		Baghiarwala minor	199500	684.69	682.90	17.79	1.79	1.82	15
		HR anata minor	8356	757.11	755.35	9.00	1.76	0.91	8
		HR gulab singh minor	19980	754.20	751.00	28.00	3.20	5.13	42
		Hr wandoh minor	48500	746.58	745.04	41.00	1.54	3.61	30
		HR dholan minor	79595	737.20	737.10	86.85	0.10	0.50	4
		Ghanian minor	119600	724.44	723.12	9.00	1.32	0.68	6
		tamboli minor	119500	724.47	723.15	12.00	1.32	0.90	7
2	Kala shaha kaku disty	dala wahga minor	20150	719.46	718.90	12.00	0.56	0.38	3
		HR Dargahi minor	21500	719.10	718.25	94.00	0.85	4.57	38
		HR chaura rajput	43995	712.40	712.00	4.10	0.40	0.09	1
		HR lambre ninor	51300	710.49	709.20	12.83	1.28	0.94	8
		HR mandhiali	122900	686.87	686.36	15.12	0.50	0.44	4
3	Dandian Disty	Mangat minor	-	741.95	741.09	11.00	0.86	0.54	4
4	Sohal Disty	Mugalwala minor	55300	725.00	724.50	12.11	0.50	0.35	3
5	Khaira Disty	Hr Upper Ghowa Minor	21200-R	713.57	713.07	6.50	0.50	0.19	2
		HR Lower Ghowa Minor	21+700 R	714.42	712.05	3.51	2.37	0.48	4
		harpalke minor	39+000	710.10	709.59	8.50	0.51	0.25	2
		ballar minor	55+000 L	706.77	706.02	18.59	0.75	0.80	7
6	Naiz Baig disty	hr ramkot minor	44+918 L	682.90	681.40	11.00	1.50	0.94	8
		jalleki minor	156+081	660.92	660.21	25.00	0.71	1.02	8
		hr thatti minor	175+612	655.56	654.40	16.00	1.16	1.06	9
		hr rode minor	185+240	651.10	650.02	31.00	1.08	1.92	16
		Sariach monor	90606L	701.82	700.81	11.00	1.01	0.64	5
		Jhedu Minor	132159 L	694.57	690.31	9.00	4.26	2.19	18
		Julke Minor	103405	699.07	697.17	9.41	1.90	1.02	8
		Badoke minor	112412L	697.02	695.45	15.95	1.57	1.43	12
7	Bucher khanna disty	kacha minor	118415	695.20	693.93	5.95	1.27	0.43	4
		Kingra minor	118412L	695.20	694.16	694.16	1.04	41.30	342
		Bucher Minor	66500L	709.20	707.66	24.90	1.54	2.19	18
		Minor No 3	198025	676.46	676.30	14.23	0.16	0.13	1
		Minor 2	185200 L	679.11	676.30	2.73	2.81	0.44	4
		Minor 1	143554	689.40	688.63	7.75	0.77	0.34	3
8	Raiwind disty	jhedu minor	68000	683.94	682.42	12.70	1.52	1.10	9
		Ladekhi Minor	60500L	685.94	682.91	7.70	3.03	1.33	11
9	Lulliani disty	Sattoki minor	18900L	687.28	686.28	12.60	1.00	0.72	6
		Mir Muhammad minor	28500L	684.69	683.94	17.44	0.75	0.75	6
		Sattoki minor	18900L	687.28	686.28	12.60	1.00	0.72	6
		Mir Muhammad minor	28500L	684.69	683.94	17.44	0.75	0.75	6
10	Ditch Disty	Weighai minor	15238	696.70	696.02	5.43	0.68	0.21	2

11	Sarhali disty	Sarhali minor	13500L	696.65	696.00	5.40	0.65	0.20	2
12	Turkewind disty	Bhoe Asal Minor	48280L	660.00	659.30	11.37	0.70	0.46	4
13	Handal Disty	Gandian Minor	51000 R	660.46	659.66	3.27	0.80	0.15	1
14	HR of charko disty	Bhila minor	34200	634.77	633.85	41.64	0.92	2.19	18
		Chaharke minor	87800L	623.69	620.99	50.00	2.70	7.72	64
		Gaggu minor	10000l	637.90	637.10	8.62	0.80	0.39	3
15	Bakerke Disty	Usman minor	18164	630.00	627.93	24.00	2.07	2.84	24
		Ganga Minor	24500L	628.40	626.02	55.93	2.38	7.62	63
16	Fatech Muhammad Disty	hazi chand minor	48318	607.76	605.79	17.52	1.97	1.97	16
17	Kangan pur disty	attari akkike minor	20524R	612.00	611.00	52.00	1.00	2.97	25
		Makhnewala minoir	33748	606.81	605.99	19.90	0.82	0.93	8
		hassoke minor	52453	601.30	600.60	6.38	0.70	0.26	2
		jandran link	65000	600.39	599.41	16.30	0.98	0.91	8
18	Attari Disty	bhulerian minor	58000	615.18	613.00	9.70	2.18	1.21	10
		Machiana minor	77300	611.36	610.40	56.00	0.96	3.08	25
		Mostual minor	77300	611.36	610.30	53.58	1.06	3.25	27
19	Chunian	Dobli minor	53300	613.54	610.20	20.65	3.34	3.95	33
		Naushera minor	91500	604.20	603.20	18.00	1.00	1.03	9
20	Chorkot disty	Marali minor	56877	629.94	629.10	30.00	0.84	1.44	12
		Rohi minor	108500	616.30	614.90	23.00	1.40	1.84	15
21	Jandran link	Jethpur disty	12500	597.78	597.03	12.00	0.75	0.51	4
22	Khanwah branch	Beganpur disty	81000	597.98	596.45	10.00	1.53	0.88	7
23	Kaler kalan disty	dograi minor	31900	597.74	593.93	40.00	3.81	8.72	72
		Malkana minor	-	603.18	600.00	31.79	3.18	5.78	48
24	Malkana minor	Gulab singh sub minor	11200	597.67	596.67	6.45	1.00	0.37	3
25	Pakhoke disty	bukan minor	95645	600.80	597.98	11.12	2.82	1.79	15

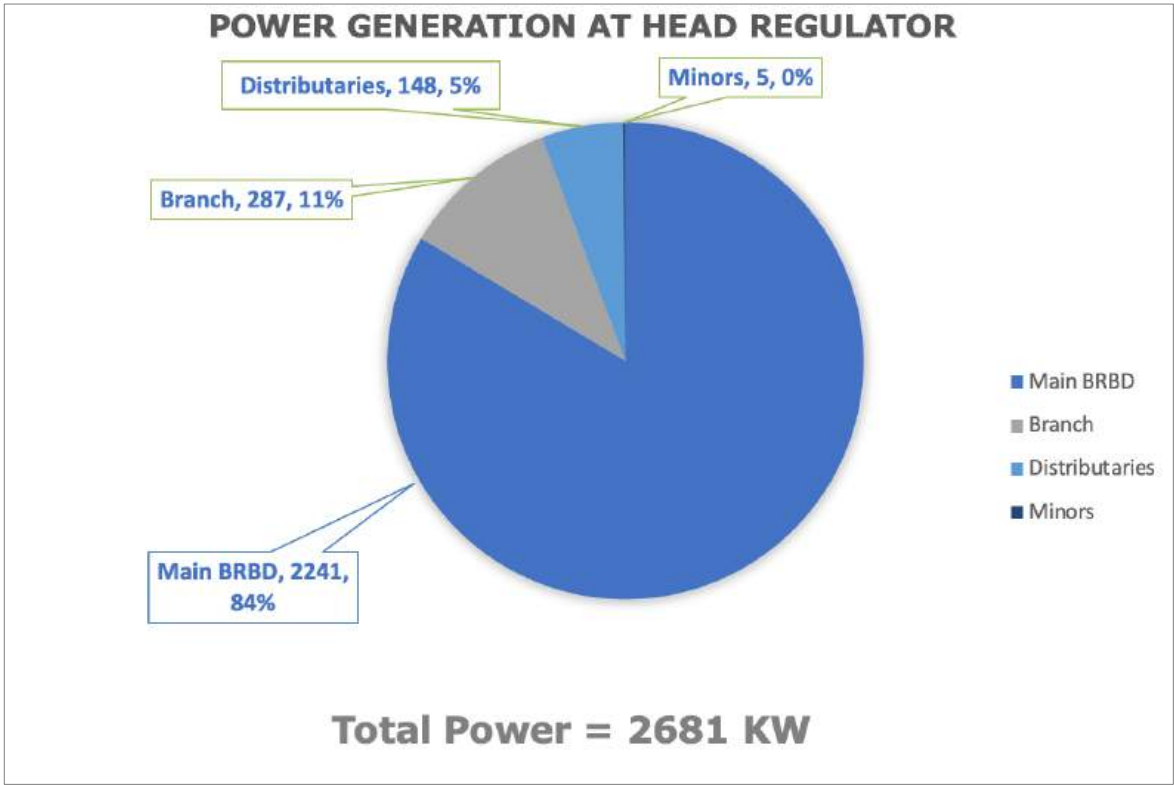
At Minors

Table 5

Power and Energy Calculations on Head Regulators from Minors

Sr#	Parent Minor Name	Offtaking Sub-Minor	RD of Parent Minor	FSL in Canal	FSL in Off taking Minor	Discharge	Head	Power	Yearly Energy
			ft	ft	ft	ft ³ /s	ft	kW	kWh 10 ³ /year
1	Dholan Minor	Hr Sher Ghar sub minor	17500	731.85	730.50	22.50	1.35	1.93	16
2	Dargahi sub-Minor	dharar hindu sub minor	19300	712.19	708.53	4.38	3.66	1.02	8
3	Kasur Minor	Kasur sub minor	51050	679.00	678.70	4.05	0.30	0.08	1
4	Kasur Minor	Lakhne Sub Minor	8120	693.78	693.04	17.94	0.74	0.84	7
5	Charke minor	Chaharke sub minor	10168	618.65	617.95	17.00	0.70	0.76	6

Figure 4
Power and Energy Calculations at Canal Falls



At Bambawali Ravi Bedian Canal

Table 6

Power and Energy Calculations of Canal Falls on BRBD

Sr. #	RD (ft)	Discharge ft ³ /sec	Head ft	Power kW	Yearly Energy kWh 10 ³ /year
1	68600	7260	1.50	691.57	5726
2	91400	7120	1.62	732.50	6065
3	105000	6689	1.14	484.26	4010
4	125500	6660	0.20	84.59	700
5	144000	6498	0.20	82.53	683
6	177174	6384	0.13	52.70	436
8	204805	5441	0.60	207.32	1717
9	260000	5375	0.13	44.37	367
10	282769	5187	5.50	1811.72	15001
11	337000	4845	1.00	307.68	2548
12	337144	4845	1.63	501.53	4153
13	400000	4005	2.28	579.89	4802
14	433958	3721	5.58	1318.58	10918
15	465300	2266	5.00	719.52	5958
16	481760	2266	6.25	899.40	7447
17	509712	2266	19.27	2773.02	22961
18	513650	2266	2.38	342.49	2836

At Branch Canal

Table 7

Power and Energy Calculations of Canal Falls on Branch Canal

Sr. #	RD (ft)	Discharge ft ³ /sec	Head ft	Power kW	Yearly Energy kWh 10 ³ /year
1	68600	7260	1.50	691.57	5726
2	91400	7120	1.62	732.50	6065
3	105000	6689	1.14	484.26	4010
4	125500	6660	0.20	84.59	700
5	144000	6498	0.20	82.53	683
6	177174	6384	0.13	52.70	436
8	204805	5441	0.60	207.32	1717
9	260000	5375	0.13	44.37	367
10	282769	5187	5.50	1811.72	15001
11	337000	4845	1.00	307.68	2548
12	337144	4845	1.63	501.53	4153
13	400000	4005	2.28	579.89	4802
14	433958	3721	5.58	1318.58	10918
15	465300	2266	5.00	719.52	5958
16	481760	2266	6.25	899.40	7447
17	509712	2266	19.27	2773.02	22961
18	513650	2266	2.38	342.49	2836

At Distributaries

Table 8

Power and Energy Calculations of Canal Falls on Distributaries

Sr. #	Name	RD (ft)	Discharge ft ³ /sec	Head ft	Power kW	Yearly Energy kWh 10 ³ /year
1	Begumpura disty	17100	26.37	2.72	4.56	38
2	Begumpura disty	23680	18.46	1.77	2.07	17
3	Begumpura disty	29+900	12.21	1.00	0.78	6
4	Handal disty	57205	29.00	2.33	4.29	36
5	Handal disty	69920	18.00	2.05	2.34	19
6	Handal disty	72325	10.00	1.00	0.64	5
7	Kaura Disty	11900	5.00	0.82	0.26	2
8	Khaira Disty	39069	46.60	1.67	4.94	41
9	Niaz Baig diaty	165885	42.00	1.67	4.45	37
10	Niaz Baig diaty	175612	19.00	1.47	1.77	15
11	Niaz Baig diaty	183635	11.25	1.00	0.71	6
12	Niaz Baig disty 43	59975	148.52	1.04	9.81	81
13	Niaz Baig disty 44	76817	123.48	2.00	15.68	130
14	Shahdara disty	21500	203.00	5.56	71.68	593
15	Shahdara disty	134000	192.00	1.33	16.22	134
16	Shahdara disty	139650	179.00	2.09	23.76	197
17	Shahdara disty	154820	159.00	2.31	23.32	193

Sr. #	Name	RD (ft)	Discharge ft ³ /sec	Head ft	Power kW	Yearly Energy kWh 10 ³ /year
18	Shahdara disty	179780	118.00	0.29	2.17	18
19	Shahdara disty	101500	73.00	0.71	3.29	27
20	Thera Disty	12200	5.00	2.08	0.66	5
21	Thera Disty	15160	2.50	1.88	0.30	2
22	Turkwind Disty	900	90.00	0.48	2.74	23
23	Turkwind Disty	26900	61.97	3.37	13.26	110
24	Escape channel lahore branch	4500	2.50	11.41	1.81	15
25	Sadhoke disty	36000	0.45	291.00	8.32	69
26	Sadhoke disty	86000	1.26	203.00	16.24	134
27	Sadhoke disty	92542	0.90	102.00	5.83	48
28	Sadhoke disty	95593	0.59	85.50	3.20	27
29	Sadhoke disty	119600	1.07	98.00	6.66	55
30	Sadhoke disty	127776	3.09	31.00	6.08	50
31	Sadhoke disty	146618	5.08	6.00	1.94	16
32	Gulloki disty	13000	45.30	1.00	2.88	24
33	Gulloki disty	23000	28.00	1.50	2.67	22
34	Dandian disty	10000	102.00	0.25	1.62	13
35	Dandian disty	45500	38.32	6.30	15.33	127
36	Dandian disty	56000	25.00	2.00	3.18	26
37	Wahdho disty	24000	12.00	3.23	2.46	20
38	Wahdho disty	29000	6.00	4.00	1.52	13
39	Changa disty	4000	7.50	1.20	0.57	5
40	Changa disty	14000	12.00	1.40	1.07	9
41	Shahdara disty	4112	262.50	0.30	5.00	41
42	Shahdara disty	21750	203.00	5.62	72.45	600
43	Muridke disty	19275	714.00	0.50	22.67	188
44	Muridke disty	32+735	616.00	0.51	19.95	165
45	Muridke disty	43+550	599.00	1.63	62.00	513
46	Muridke disty	58789	304.00	2.00	38.61	320
47	Chorkot disty	17000	304.00	0.70	13.51	112
48	Chorkot disty	35937	210.00	1.21	16.14	134
49	Chorkot disty	56877	153.00	1.00	9.72	80
50	Chorkot disty	87800	69.00	2.78	12.18	101
51	Chorkot disty	96400	54.00	0.73	2.50	21
52	Chorkot disty	117422	24.00	2.16	3.29	27
53	Chorkot disty	144908	8.00	1.65	0.84	7
54	Khangan pur disty	20527	161.00	2.65	27.09	224
55	Khangan pur disty	39088	128.00	1.29	10.49	87
56	Khangan pur disty	52473	105.00	1.05	7.00	58
57	Khangan pur disty	65000	52.00	1.98	6.55	54
58	Khangan pur disty	76000	27.00	1.38	2.37	20
59	Khangan pur disty	85858	16.00	2.17	2.20	18
60	Chahal ditch disty	7175	11.97	0.52	0.40	3
61	Kaler kalan disty	31+900	30.00	1.00	1.91	16
62	Fath Mohammad disty	33150	99.00	2.01	12.64	105
63	Fath Mohammad disty	47043	38.00	0.65	1.57	13

Sr. #	Name	RD (ft)	Discharge ft ³ /sec	Head ft	Power kW	Yearly Energy kWh 10 ³ /year
64	Fath Mohammad disty	71158	11.00	1.30	0.91	8
65	Lalugubddar disty	36275	103.00	0.76	4.97	41
66	Lalugubddar disty	47475	56.00	0.32	1.14	9
67	Lalugubddar disty	79225	11.50	1.53	1.12	9
68	Bakerke disty	24800	4.00	3.89	0.99	8
69	Usmanwala disty	1500	41.03	2.55	6.64	55
70	Chunian disty	25050	171.00	1.00	10.86	90
71	Chunian disty	53592	99.00	1.01	6.35	53
72	Chunian disty	65500	87.00	0.75	4.14	34
73	Chunian disty	91500	19.00	1.05	1.27	10
74	Chunian ditch disty	15000	14.00	81.00	72.02	596
75	Pakhoke disty	21572	125.22	0.80	6.36	53
76	Pakhoke disty	29585	118.60	1.49	11.22	93
77	Pakhoke disty	63500	79.87	2.16	10.96	91
78	Pakhoke disty	98645	70.89	2.03	9.14	76
79	Jethpur disty	8044	9.00	0.83	0.47	4
80	Attari disty	20+553	399.00	0.50	12.67	105
81	Attari disty	30880	302.00	3.13	60.03	497
82	Attari disty	77300	100.00	0.60	3.81	32
83	Attari disty	87000	80.00	1.59	8.08	67
84	Attari disty	87500	64.00	3.12	12.68	105
85	Attari disty	107000	31.00	0.78	1.54	13
86	Feeder no 1	40658	16.00	1.28	1.30	11
87	Feeder no 2	48961	6.00	1.32	0.50	4
88	Depalpur canal	92000	63.00	5.00	20.00	166
89	Depalpur canal	113412	62.00	2.00	7.87	65
90	Depalpur canal	140967	62.00	0.22	0.87	7
91	Depalpur canal	174007	38.00	0.50	1.21	10
92	Khalra	3152	11.00	0.30	0.21	2
93	Lulliani	18900	34.00	1.00	2.16	18
94	Daftu	9508	2.50	3.20	0.51	4
95	Butcher khana	143554	81.00	0.85	4.37	36
96	Ditch	15235	8.90	0.86	0.49	4
97	Thaman	700	269.00	0.57	9.74	81
98	Thaman	17300	175.00	1.31	14.56	121
99	Thaman	25764	71.00	1.06	4.78	40
100	Thaman	84000	12.00	0.50	0.38	3

At Minors

Table 9

Power and Energy Calculations of Canal Falls on Minors

Sr. #	Name	RD (ft)	Discharge ft ³ /sec	Head ft	Power kW	Yearly Energy kWh 10 ³ /year
1	Baghiarwala Minor	8850	8.40	2.30	1.23	10
2	Rode Minor	183690	30.00	1.13	2.15	18
3	Garden Minor	1840	6.00	0.22	0.08	1
4	New Minor 33	500	12.66	5.07	4.08	34
5	New Minor 34	6290	9.88	1.00	0.63	5
6	New Minor 35	8290	7.27	0.80	0.37	3
7	Upper Gohowa Minor	9300	6.50	0.50	0.21	2
8	Mangat minor	5500	7.10	3.00	1.35	11
9	Mangat minor	6750	7.10	2.25	1.01	8
10	Dhollan Minor	19900	45.00	3.68	10.52	87
11	Dhollan Minor	25000	31.83	1.65	3.34	28
12	Dhollan Minor	26000	31.83	0.30	0.61	5
13	Anta minor	7885	6.00	0.50	0.19	2
14	Gulab singh minor	0+500	28.00	0.71	1.26	10
15	Kali disty Tamboli minor	6500	7.00	2.50	1.11	9
16	Tamboli Minor	3515	12.00	1.95	1.49	12
17	Tamboli Minor	9620	6.00	3.30	1.26	10
18	Moghawala minor	6000	7.00	1.00	0.44	4
19	Kala Katai Minior	5800	38.16	2.50	6.06	50
20	Kala Katai Minior	500	45.00	1.25	3.57	30
21	Kala Katai Minior	17500	23.39	10.00	14.85	123
22	Baghiarwala Minor	8850	8.40	1.80	0.96	8
23	Chaharke minor	168000	19.00	0.50	0.60	5
24	Rohi minor	15000	11.16	0.70	0.50	4
25	Marali minor	4225	25.00	0.51	0.81	7
26	Marali minor	16980	15.00	1.00	0.95	8
27	Khingrawala minor	12030	28.25	0.77	1.38	11
28	Khingrawala minor	23653	16.56	0.53	0.56	5
29	Dobli minor	14270	10.74	1.99	1.36	11
30	Naushera minor	5000	8.00	0.53	0.27	2
31	Kasur minor	60	3.00	1.60	0.30	3
32	Sub Chaharke minor	12256	4.00	1.41	0.36	3
33	Haji chand minor	14700	8.30	2.00	1.05	9
34	Attari akkike minor	16240	30.00	0.95	1.81	15
35	Attari akkike minor	26250	17.00	0.20	0.22	2
36	Lower ganja minor	5000	49.67	0.37	1.17	10
37	Machiana minor	19238	34.00	0.72	1.55	13
38	Mastuwal minor	10700	41.81	0.70	1.86	15
39	Mastuwal minor	26000	18.53	0.64	0.75	6
40	Minor	19238	34.00	0.72	1.55	13
41	Dhingh shah minor	10800	36.00	0.60	1.37	11
42	Dhingh shah minor	23245	22.00	0.76	1.06	9
43	Bukan minor	4000	7.74	0.69	0.34	3
44	Bhoe asal minor	8000	5.11	0.94	0.31	3
45	Lower bucher minor	11700	7.50	1.03	0.49	4

Figure 5

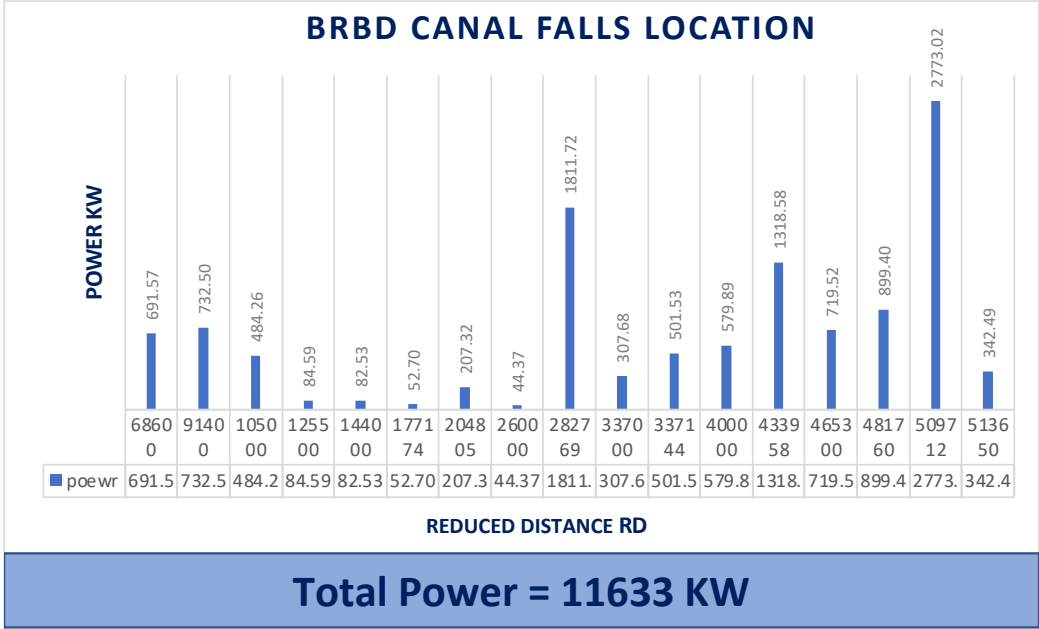


Figure 6

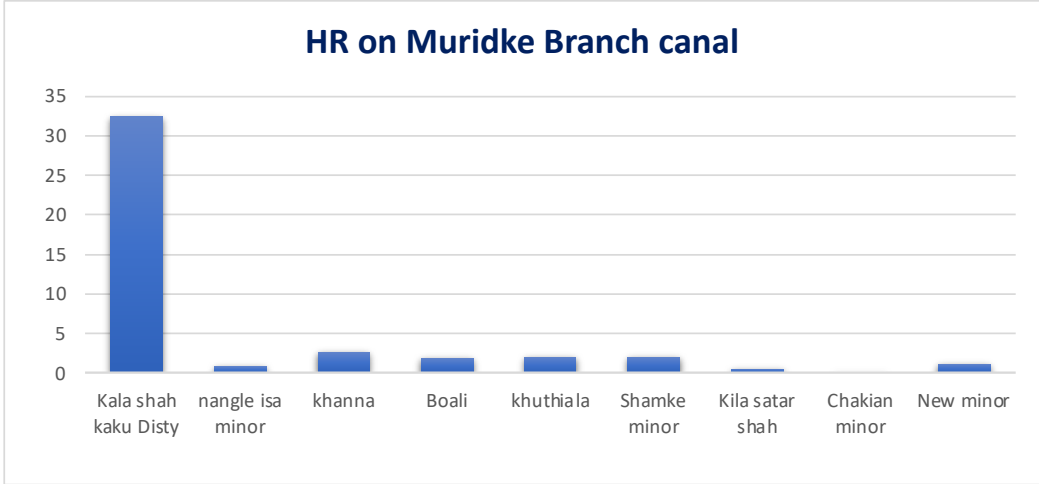
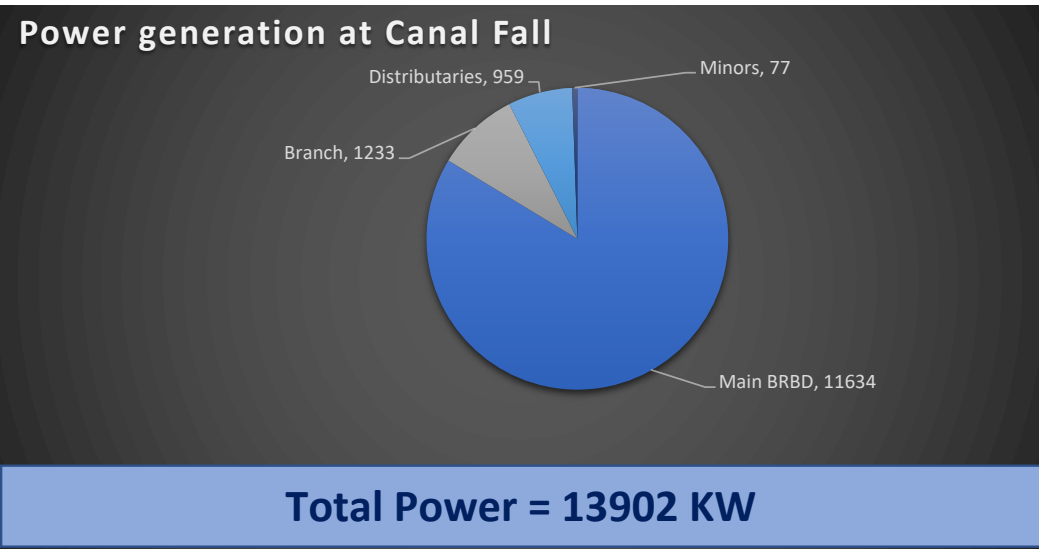


Figure 7



At Outlets

We have performed limited calculations on outlet data because we don't get a suitable approach to get available head at the outlet. We have used efficiency factor equal to 1 because we are using the minimum modular head for the outlet and in field head would be greater than the minimum modular head. Assuming that we have taken efficiency factor equal to 1.

So, in order to perform actual calculation, we need to have a field survey by that way we can have actual value of available head at each outlet.

We have data available for 3761 outlets and the total discharge going out from outlets is 5697 cusecs. So, presenting such a large amount of data would be a foolish approach not only because this data set is very larger but also because we are going for approximate calculations. We are presenting few tables below that will help to get idea about type discharge and power available at outlets.

Table 10

Type of Outlets in BRBD System (PID, 2023)

With respect to type of Outlet		
Type	No. of Outlet	%
Pipe outlet	1157	31.5
Adjustable proportional module	1373	59.5
open flume	787	34.1
Scartchley outlet	34	1.5
OFRB outlet	106	4.6
Unknown	214	9.3

Table 11

Separation of Outlets w.r.t Power (PID, 2023)

Separation w.r.t power		
Power watt	No. of Outlet	%
greater than 200 W	289.00	7.87
between 100 and 200 W	559.00	15.23
between 100 and 50 W	749.00	20.40
less than 50 W	2074.00	56.50

Table 12

Separation of Outlets w.r.t Discharge (PID, 2023)

Separation w.r.t outlet discharge		
Discharge Q	No. of Outlet	%
Discharge greater than 2 cs	761.00	20.7
Discharge b/w 1.5 and 2 cs	581.00	15.8
Discharge b/w 1 and 1.5 cs	1104.00	30.1
Discharge b/w 0.5 and 1 cs	605.00	16.5
Discharge than 0.5 cs	620.00	16.9

Discussions
Comparative Analysis
Figure 8

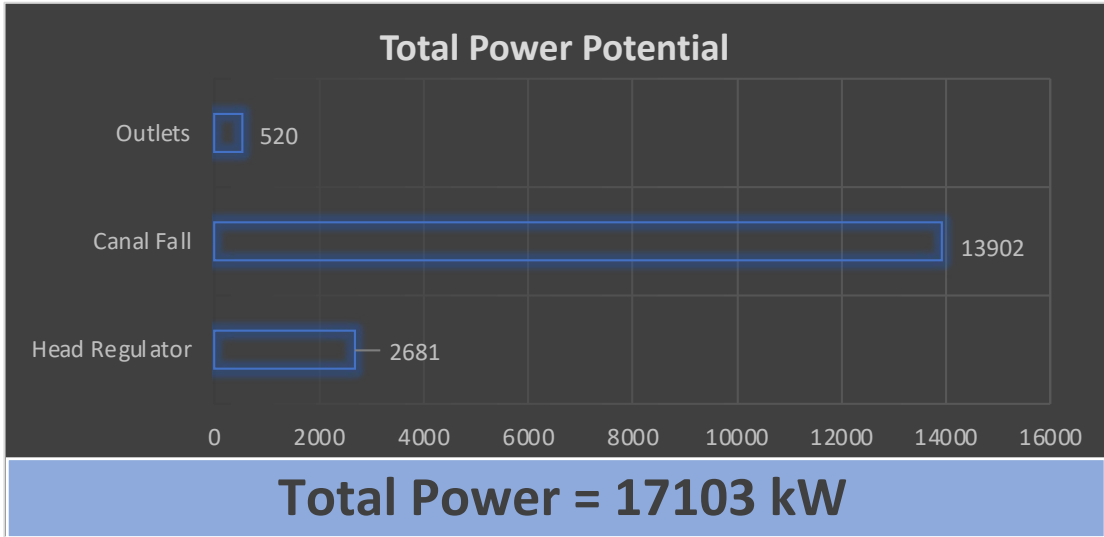
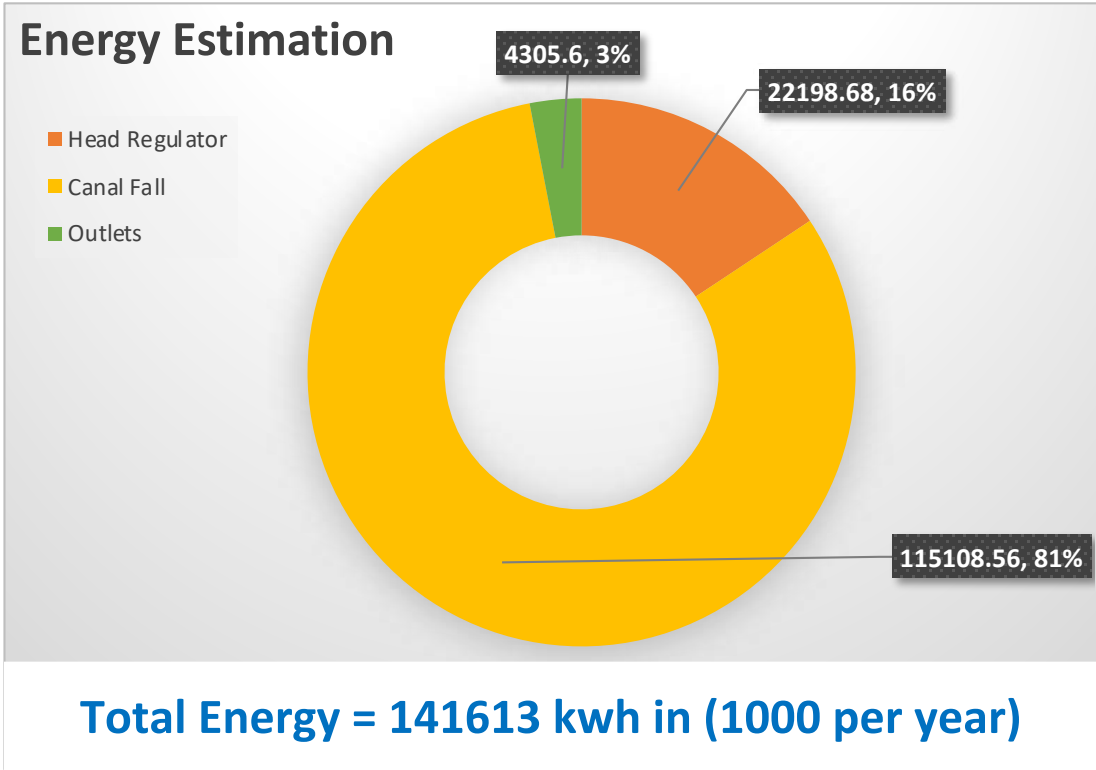


Figure 9



Promising Sites for Hydropower Generation

In this section, we will explore various locations with significant hydropower potential and categorize them based on the available capacity. The following tables present a compilation of sites that exhibit a potential greater than 100 kW, highlighting their respective details.

By identifying these hot spots for hydropower potential, we aim to provide valuable information for evaluating and harnessing renewable energy resources. The inclusion of sites with considerable capacity underscores the viability and significance of hydropower as a sustainable energy solution.

Potential Greater than 1000kW

Table 13

Sites having potential greater then 1000kW

Falls/Head Regulators	RD (ft)	Discharge ft ³ /sec	Head ft	Power kW	Yearly Energy kWh 1000/year
Fall BRBD	282769	5187	5.5	1811.72	15001
Fall BRBD	433958	3721	5.58	1318.58	10918
Fall BRBD	509712	2266	19.27	2773.02	22961
HR of BRBD		7260	2.71	1250.66	10356

Potential Between 500 to 1000 kW

Table 14

Sites having potential between 500 to 1000kW

Falls/Head Regulators	RD (ft)	Discharge ft ³ /sec	Head ft	Power kW	Yearly Energy kWh 1000/year
Fall BRBD	68600	7260	1.5	691.57	5726
Fall BRBD	91400	7120	1.62	732.50	6065
Fall BRBD	337144	4845	1.63	501.53	4153
Fall BRBD	400000	4005	2.28	579.89	4802
Fall BRBD	465300	2266	5	719.52	5958
Fall BRBD	481760	2266	6.25	899.40	7447

Potential Between 250 to 500 kW

Table 15

Sites having potential between 250 to 500kW

Falls/Head Regulators	RD (ft)	Discharge ft ³ /sec	Head ft	Power kW	Yearly Energy kWh 1000/year
Fall BRBD	105000	6689	1.14	484.26	4010
Fall BRBD	337000	4845	1	307.68	2548
Fall BRBD	513650	2266	2.38	342.49	2836
M.B.L	304870	1244	4.27	337.33	2793

Potential Between 100 to 250 kW

Table 16

Sites having potential between 100 to 250kW

Falls/Head Regulators	RD (ft)	Discharge ft ³ /sec	Head ft	Power kW	Yearly Energy kWh 1000/year
Fall BRBD	204805	5441	0.6	207.32	1717
HR Muridke Branch Canal	177174	714	3.86	175.19	1451
HR Shahdara Disty	274500	263	13.83	231.21	1914
Katora branch	56100R	891	1.78	100.82	835
Lahore Branch	218+000	402.33	6.49	165.82	1373
Fall M.B.L	328000	1227	1.92	149.61	1239
Fall M.B.L	375311	707	4.41	198.00	1639

Based on our calculations, the total potential of the system amounts to approximately 17,100 kW. Remarkably, the locations mentioned above have the capability to generate around 13,978 kW, which accounts for approximately 81% of the total energy potential within the system.

By focusing on these high-potential sites, we can optimize the utilization of available resources and achieve efficient energy extraction. This approach allows for a cost-effective and environmentally sustainable means of maximizing hydropower generation.

The per capita electricity consumption in Pakistan is estimated to be around 447 kWh, with data from the World Bank up to 2014 (Bank, n.d.) suggesting a per capita consumption of 420 kW. Considering an average household size of 6.4 persons.

Addressing the issue of transmission losses is crucial for Pakistan's energy sector. Efforts should focus on upgrading and maintaining infrastructure, reducing technical losses, combating power theft, and implementing smart grid technologies to improve overall grid efficiency and reliability. Additionally, promoting energy conservation and awareness among consumers can contribute to a more sustainable and efficient electricity distribution system. Plant capacity to serve 500 houses:

Capacity(kW) =
$$\frac{\text{per capita consumption} \times \text{no. of houses} \times \text{average house holds}}{\text{active hours of plant}}$$

Capacity = 172.8 kW

So, if we have a plant of 172.8kW it can serve a small town of 500 houses. Small-scale power plants can effectively reduce transmission and distribution losses by generating electricity closer to the point of consumption. They offer localized and reliable energy supply, especially in remote areas with limited grid connectivity.

One significant challenge encountered in harnessing hydropower from irrigation canals is the limited head available, which often renders the installation of hydropower plants economically unfeasible. However, a potential solution to overcome this challenge is to consolidate or merge adjacent falls that have minimal distance between them. By doing so, the total available head can be increased, resulting in a higher potential energy output.

Implementing such an approach requires careful planning, hydraulic analysis, and engineering expertise to ensure the optimal integration of falls within the irrigation canal system.

Table 17

RD (ft)	Discharge ft ³ /sec	Head ft	Power kW	Yearly Energy kWh 1000/year
465300	2266	5	719.52	5958
481760	2266	6.25	899.40	7447

If we look above table the distance between two fall structures it is 16460 ft that is around 3.13 mile. But if we can merge both fall at a single suitable location then we can have a head of 11.25ft.

Table 18

RD (ft)	Discharge ft ³ /sec	Head ft	Power kW	Yearly Energy kWh 1000/year
509712	2266	19.27	2773.02	22961
513650	2266	2.38	342.49	2836

In this particular scenario, the distance between the fall structures measures 3,939 feet, equivalent to approximately 0.75 miles. However, by consolidating these falls, it becomes possible to achieve a total head of 21.65 feet or 6.6 meters. This head presents a promising opportunity for the development of a low-head hydropower plant at this location. The merging of these falls offers the potential to leverage the available hydraulic resources more effectively. By combining the individual falls, the resultant increased head height allows for enhanced energy generation capabilities (Ali, [2010](#)).

Conclusions

In BRBD canal system there are in total 181 canal falls, 144 canal head regulators and 3671 outlets which can be used as on grid/ off grid hydropower generation sites. The assessment of hydropotential at the canal falls, head regulator and outlets in the BRBD canal has provided valuable insights into the water resources power and energy generation potential in the canal system. Based on the findings and analysis conducted during this assessment, the following conclusions are drawn:

- The majority of power can be derived from canal falls, accounting for 81% of the total energy in the system, equivalent to 13,902 kW and 115108×10^3 kwh energy in a year
- The head regulators also possess significant potential, contributing around 15.67% (equivalent to 2,681 kW) of the total power in the system. Whereas total energy potential is 22198×10^3 kwh in a year
- Outlets has a very low power potential of about 502kW.and has energy potential is 4305.6×10^3 kwh in a year
- Total calculated power potential of the whole BRBD canal system is coming out to be 17103 kW total energy potential is 141613×10^3 kwh in a year

Recommendations

1. When the distance between waterfalls is minimal, merging them becomes a viable option to increase the available head at the location.
2. Focusing on specific locations within the system with high hydropower generation potential to maximize energy output and optimize cost-efficiency.
3. Installing small-scale power plants near the point of consumption. This approach will reduce transmission losses and ensure reliable energy supply to areas with limited grid connectivity.
4. Small hydropower sites can be used for local use. while large sites can be connected to national grid.

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