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REVIVAL OF DEGRADED RIVERS IN PUNJAB

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Preamble

Pakistan's renewable water resources include precipitation and surface water. Part of the rainfall and surface water recharges the groundwater aquifer from where it is pumped out and used for supplementary irrigation and for meeting parts of drinking water requirements in urban and rural areas. Water availability in Pakistan is dwindling day by day with a growing gap between water demand and water supply. The average water availability is 104 MAF (128 BCM) and net water demand will be 134 MAF (165 BCM) by 2025. With no additional storage scenario, the water shortage would be in order of 30 MAF (37 BCM) by 2025. This water shortage is adversely affecting and has significant ramifications on Pakistan's economy which is predominantly agrarian, particularly agriculture mainly dependent on irrigation.

Agriculture is the largest contributor to the Pakistan economy. It employs nearly 35.9 % of the population, accounts for approximately 22% of the GDP and contributes to over 60 % of exports. Punjab is considered to be the food basket for Pakistan; the provincial share of Pakistan's GDP is nearly 60% with the agricultural sector contributing about 75% of the annual food grain production in the country. Agriculture in Punjab is supported by one of the largest contiguous and complex irrigation systems in the world. It's estimated that Punjab's irrigation system contributes 25 % of Pakistan's GDP and also engages 54 % of Punjab's labour force.

After Indus Water Treaty (1960), the eastern river reaches of Sutlej and Ravi rivers in Punjab (Pakistan) have been hydraulically and ecologically degraded due to lack of water flows and which are abnormally lower than original annual floods. These rivers have also been one of the main sources of recharge for groundwater aquifers in Punjab. With drying of the river channels, groundwater is also severely affected and the river channels are shrinking and population is moving in the river bed. It is important to have some water retained in these river channels even with very low flow so that major parts of the river channel get impounded. This will help in hydraulic and ecological revival as well as in recharging the groundwater in the surrounding areas and keeping people away from settling in the dried river bed. This can easily be done with inflatable rubber weirs in various river reaches of Punjab. Inflatable rubber weirs have been used worldwide and generally have a life of over 40 years. China has installed over 3,000 inflatable rubber weirs for improving water management in the river systems. Besides Sutlej and Ravi, the

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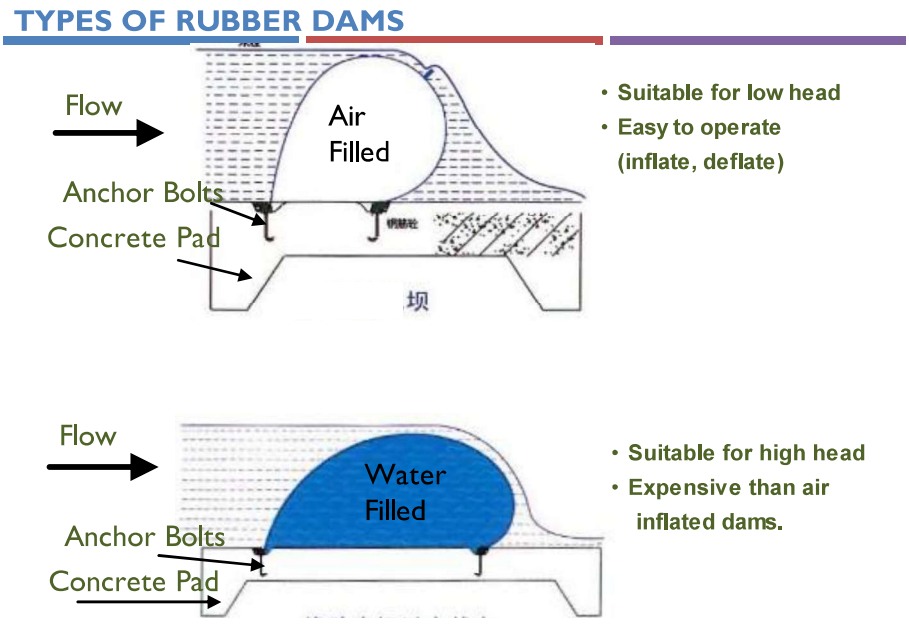
flow pattern in Chenab and Jhelum rivers have also become uncertain due to disputed interventions on these rivers in Indian territory and adverse climate change effects. Seasonal water shortages occur due to highly seasonal river flows, and inadequate storage. Yet, there is sizeable opportunity in the province to improve water availability, among other interventions, by constructing flexible structures like inflatable rubber dams across the Sutlej, Ravi, Chenab, Jhelum rivers and streams of Photohar area and other barani regions of the province.

Brief History of Inflatable Dams in the world, their uses & types:

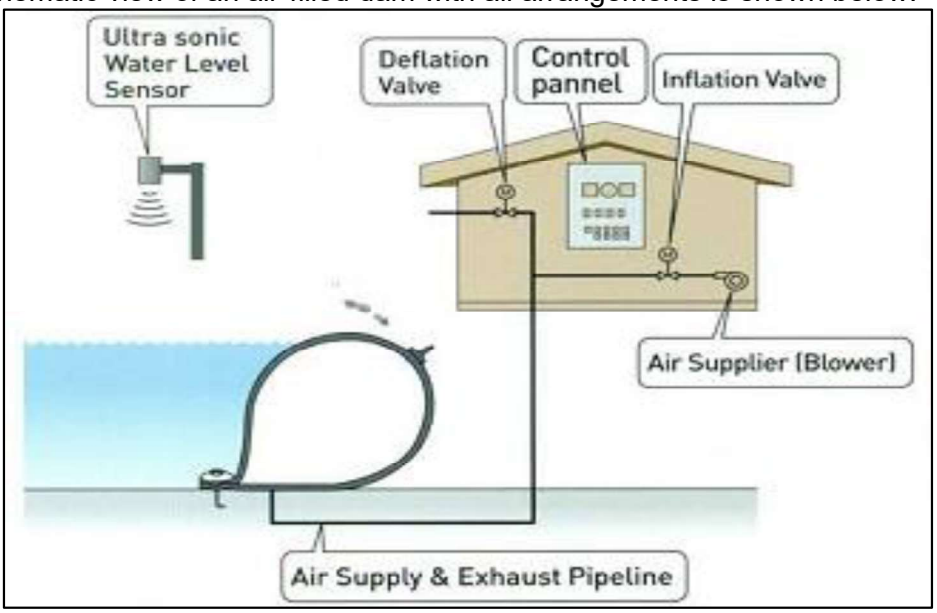
The concept of an inflatable rubber dam was first patented 70 years ago by a French Engineer M. Mesnager. Shortly after, the first working inflatable rubber dam was designed and installed by Norman Imbertson of the USA in the mid-1950s in Los Angeles. Rubber Dam technology gained popularity around the world in the 1960s after several large projects had been completed by Imbertson and the technology was licensed to Sumitomo Electric, A Japanese company. In the next 30 years, Japan became the biggest producer of rubber dams as Bridgestone, a rubber product manufacturer, entered the market. Inflatable dams have been extensively used for irrigation and water supply, ground water recharge, water storage, tidal and flood management, habitat restoration and hydropower, raising the crest of existing dams, weirs or as flash board replacement. Other applications include intake dam / diversion weir for small hydropower plants, tidal barrier to stop tidal surges, saline intrusion to prevent contamination of agriculture land, creating artificial lakes for recreation purposes, for controlling at water treatment plants, for water supply, as stop log and as silt control device.

Over 200 inflatable dams were installed since 1980, and the rate of their use on dam projects increased rapidly in recent years, inflatable dam technology has significantly advanced and become an economical solution for installing new and replacing old spillway crest gates up to 5.4 m. Thousands of rubber dams (Air/Water Filled) have been built all over the world with over 5000 only in China.

The main types of inflatable dams as illustrated below are i) air filled inflatable dam and ii) water filled inflatable dam. The air inflated dam is suitable for low head, cold climate and sensitive soil. However, the water inflated dam is suitable for high head and it retains its original shape better after deflation. The water inflated dams are more expensive than air inflated dams.



A schematic view of an air-filled dam with all arrangements is shown below:



Advantages of inflatable dam technology:

The inflatable rubber dam has numerous advantages over other types of water control gate, such as:

- Simple and inexpensive operating system

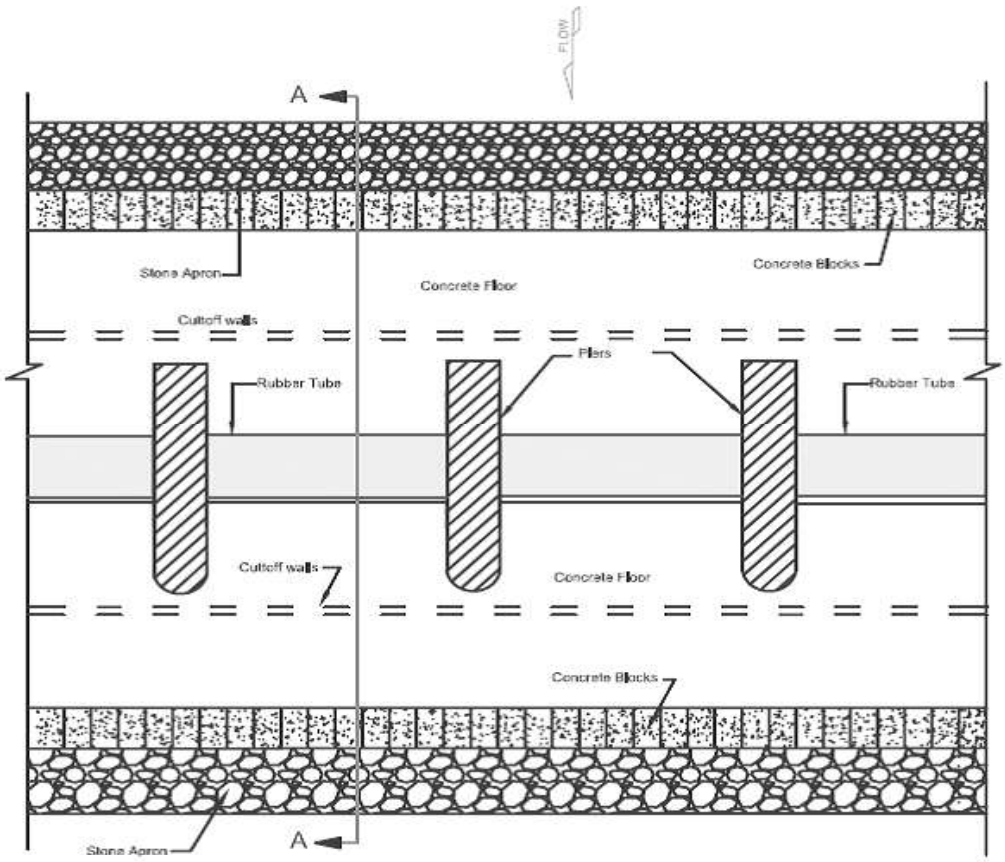
- Environmentally friendly
- Can be installed on almost any channel cross-section shape
- Relatively low capital cost
- Perfect sealing; no leakage
- Virtually maintenance free; no moving parts, no painting
- Long spans up to 100m; multiple spans of several hundred metres
- Easily designed to accept loading in both directions
- Light structure
- Earthquake resistant
- Clean operation; no hydraulic oil required
- Can always be “opened” (deflated); no possibility of jamming

The hydraulic and environmental advantages of inflatable dams have also made them an attractive solution for constructing new and replacing old run of the river low-head gravity weirs. Inflatable types dam has been installed in a wide variety of conditions, configurations and environments.

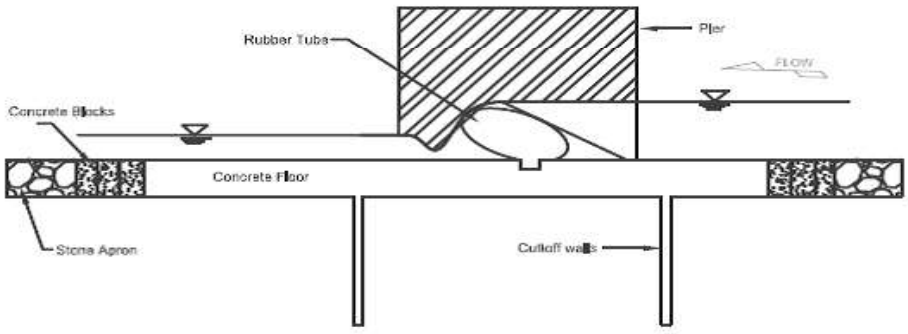
Conceptual layout and components of rubber dam

An inflatable rubber dam consists of a sealed inflatable rubber-coated fabric tube anchored to a concrete foundation constructed across a river is shown as Figure A. It is raised by inflating with air, water, or a combination of the two, the top of the inflated tube serves as the raised crest. Air filled are suitable for low head and are easy to operate whereas, water filled are adopted for high head and are relatively expansive. When it is inflated to full design height, it impounds water and acts like any other fixed dam in this respect. However, it is capable of being completely deflated to allow maximum run-off during a storm, thereby reducing upstream flooding, and to allow passage of sediment, debris, and ice. Broadly speaking, there are three (3) main components of the proposed dam: (i) Strong and flexible rubber coated fabric tube firmly fixed to concrete foundation by bars and anchorage bolts; (ii) Operating system that controls inflation and deflation during flood; and (iii) Automatic safety device that ensure tube deflation during flood.

The particular feature of inflated dams is the quick deflation for preventing excessive flooding. Deflation occurs automatically as the backwater reaches a certain level. Simple mechanical device is used for initiating deflation. An electronic system comprising water level sensors and valves can also be provided. Air (or water) can be pumped through supply line encased in concrete foundation under the rubber tube.



TYPICAL PLAN OF INFLATABLE DAM ALONG RIVER



TYPICAL CROSS SECTION A A OF INFLATABLE DAM

Figure A: Schematic Diagram of Inflatable Rubber Dam

Operation of Water/Air filled rubber dams

Water filled rubber dams are well-suited for headwater level regulation purposes and can be used, for instance, for hydropower applications. The feature of a strictly horizontal weir crest in all states allows a controlled lowering and rising of the rubber dam. Therefore, overflow at the dam can be accurately adjusted from none to the maximum flow, which is achieved if the rubber dam is fully deflated.

Important components of water-filled rubber dam system are the control shaft and rubber membrane, both of which are connected by concrete embedded pipework. As integrated vessels, the pressure of the rubber bladder is visible in the control shaft system. The system consists of a pump, filling, regulation and drainage shaft. If there is more the one independent weir system, there is a filling and a regulation shaft for each system. The pump and drainage shaft can be shared between these independent systems.

Water filled Rubber dams are filled by transferring water from the pump shaft into the filling shaft, where it will flow into the bladder. The dam is lowered by pumping water from the regulation shaft into the drainage shaft. This causes a gradient so water flows from the bladder into the regulation shaft.

The rubber dam is operated by a programmable logic controller (PLC). This can either be an autonomous system or integrated into power plant control. Many systems have an independent control setup and take defined parameters and triggers from the overhead control. Important parameters are the headwater level and the levels in the filling and regulation shaft.

The position of the weir crest is also measured. For information purposes, the flow over the rubber dam is calculated and displayed on the touch panel, which is the human-machine interface (HMI). It can also be sent along with other rubber dam parameters to overhead control.

Air filled Rubber dams can also be filled using pressurised air, which are inflated using blowers. Besides small differences in rubber dam design, the main variance is caused by different properties of air and water. Due to the lower density of air compared to water, the weir crest will form a V-notch if the pressure falls below a certain value. Therefore, air-filled rubber dams are better suited for operations in a fully inflated state, with occasional full deflation for continuous headwater level regulation.

Adaptation of rubber Dam technology in Punjab-Justification

Rapidly lowering of ground water and ecological imbalance in the river reaches deprived of perennial flows are the challenges to overcome the anticipated acute water shortage for agriculture and domestic water supplies and the loss of biodiversity. In order to combat with the aforementioned emerging challenges, Punjab Irrigation Department has initiated a phased program captioned, “Revival of degraded rivers in Punjab” by constructing inflatable rubber dams across the rivers and streams having very low perennial flows.

The program is truly in line with the policies and work plan of National and Provincial Visions and Growth Strategies. Its contribution towards ground water recharge and revival of lost biodiversity will result in increased food security, and reduced water-related climate risks.

Punjab Water Policy 2018, emphasizes on enhancement of water availability by constructing 'small dams in Potohar and other region of Punjab'. Launching of this program is in line with Govt. policy of constructing local storages in the areas to enrich the aquifer with sweet water.

The objective of the program is also in line with the Punjab Growth Strategy 2023. Its iimplementation will contribute to meet the targets of Key Pillar 1, "***Enhancing the focus on sectors in which Punjab has comparative advantage in the national context and harness the potential"***. Water stress, climate change, ground water exploitation and degradation of land and water base are the major challenges identified for Irrigation sector in the strategy. The program will ensure an increase in the agriculture produce by bringing the new agricultural area under irrigation command, alleviation of poverty by opening new agricultural avenues for the farmers, increased food security by ensuring increase in agricultural production, improvement of socio-economic and socio-cultural conditions in the area by improving the living standard and livelihood of the populace and enhancement of infra-structure and public facilities.

Feasibility Study of selected sites

The idea of building inflatable dams in Pakistan was firstly introduced in 2015 during implementation of a World Bank financed Punjab Barrages Improvement Phase-II (PBIP-II) project. During implementation review missions, in internal mission and wrap up meetings, World Bank team based on their global experience shared the concept of inflatable dams on Sutlej and Ravi rivers owing to anticipated saving from the loan for PBIP-II, Irrigation department agreed to the proposal of utilizing the anticipated savings from loan of PBIP-II for carrying out Feasibility studies for constructing Inflatable dams and take up the execution of the most feasible site at least one Feasibility study for constructing inflatable rubber dams in the starved reaches of Sutlej and Ravi rivers. Consultants studied three sites, one site on Ravi (Okara Faisalabad Bridge) and two sites on Sutlej River (Bahawalnagar-Arifwala Road Bridge and Bahawalpur-Lodhran Road Bridge N5). Based upon the ground water depletion, sweet ground water zone, minimum resettlement, maximum benefits to the adjoining cities (Bahawalpur and Lodhran) and minimum impact on the existing infrastructure, the Bahawalpur Lodhran Road Bridge site on river Sutlej was selected for the construction of such a facility as a pilot project. Comparison of the studied sites in respect of selected parameters are tabulated as follows:

Parameter	Okara	Bahawalnagar	Bahawalpur
Location of Project	D/S Okara-Faisalabad Road Bridge	D/S Arifwala-Bhawalnagar Road Bridge	D/S Bahawalpur Road Bridge N-5
River	Ravi	Sutlej	Sutlej
Height of Dam (ft)	10	10	10
Width of Dam (ft)	1450	2100	2300
Length of Dam (ft)	75	90	100
Length of Reservoir (km)	3	5	5
Area of Reservoir (acres)	425	3211	2965
Volume of Reservoir (acre-ft)	1174	34164	9438
River Flow Availability	Sufficient	Sufficient	Moderate
Groundwater Recharge Potential	Medium	Medium	High
Quality of Surface water	Acceptable	Acceptable	Acceptable
Quality of Groundwater	Acceptable	Acceptable	Acceptable
Groundwater Depth (ft)	10-15	15-20	36-70
Potential of Fish Farming	√	√	√
Saline Intrusion	-	-	Reverse
Potential of Drinking Water Supply	-	-	Positive
Increase in Agriculture Production	Marginal	Marginal	Medium
Revival of Degraded River Channel	Partial	Partial	Partial
Public Acceptance	Low	Low	High
Recreation Potential	Low	Low	High
Land Acquisition Issues	Medium	High	Low
Resettlement Issues	Medium	High	Low
Construction Period (Months)	12	12	15
Project Cost (Million US$)	12	17	25

Table 1: Comparison of related parameters for three sites.

The requisite Topographic Survey, Geological & Geotechnical Investigation, Layout Planning, Hydrological & Hydraulic Studies, Electro-Mechanical Studies, Groundwater Investigation, Agricultural Studies, Environmental & Social Impact Assessment, Quantity & Cost Estimation and Economical analysis were carried out by the Consultants to finalize the feasibility level design for Bahawalpur site on Sutlej river. Unfortunately, it could not be implemented due to closing of loan in

2017. Now the proposed project Bahawalpur site may be taken up as a pilot project and this idea may be replicated throughout the Punjab at the feasible sites.

Broader program at the province level

Based on the preliminary field surveys, 20 possible potential sites on Sutlej, Ravi, Chenab and Jhelum rivers listed in table 2 are selected for constructing inflatable dams. Proposed program may be implemented in a phased strategy. Phase-1 may include the feasibility, detailed design and construction of inflatable 4-6 dams, whereas under phase-2, the scope may include remaining dams on rivers & streams of Potohar area along with capacity building in groundwater monitoring and management in the focused areas.

ID. No.	Description of Dam	River
1	Victoria Bridge	Jhelum
2	Lahore Islamabad Motorway Bridge	
3	Khushab Bridge	
4	Jhelum Bridge on GT road	
5	Jhelum River near Kurpalka	
6	Jhelum River near Tetri	
7	Head Muhammad-wala Bridge near Multan bypass on Khushab road	Chenab
8	Muzaffargarh Chenab Bridge near Muzaffargarh road Multan	
9	Chenab River near Bhawana	
10	Chenab River near Garh Maharaja	
11	Ravi River at Kamalia Harappa Road	Ravi
12	Ravi River near Syed wala	
13	Okara Faisalabad road bridge	
14	Shorkot Kabirwala road bridge	
15	Toba Chichawatni road bridge	
16	Road bridge on river Sutlej near Pakpattan	Sutlej
17	Road bridge on river Sutlej near Mailsi Syphon	
18	Site near road bridge (N5) on river Sutlej near Bahawalpur	
19	Musa Shaheed bridge on river Sutlej at Jalalpur Road	
20	Bridge on Arifwala Sahiwal road near Bahawalnagar	

Table 2: Explored sites of Inflatable Dams in Punjab Province

Project design/scope in simple words

Project is meant for development of local storages on Sutlej, Ravi, Chenab, Jhelum streams of Potohar, through construction of inflatable dams along with its accessories. Physical surveys of flood plains of the river, hydrological and geo technical studies would be required to prepare the design of dam and its allied structures. Dam height and corresponding backwater extent in the river plain will determine the capacity of reservoir. Concrete foundation over which rubber tube is anchored, is designed hydraulically both for surface and sub-surface flow conditions in consideration of minimum and maximum flows and river/ stream bed characteristics.

Phase -1 will comprise the feasibility study for viable sites across all rivers/stream in Punjab and detailed design and construction of 6-8 sites on Sutlej and Ravi rivers.

Whereas, phase-II will comprise of detailed design and construction of remaining viable sites on other rivers/streams along with development of ground water monitoring and management'

Typical works to be included in the project scope of an inflatable dam are given as under:

Civil Works

- RCC concrete floor upstream and down steam of rubber coated fibre tube
- Steel sheet piles at end of concrete floors for boxing.
- Right and left abutments along with wing walls
- RCC piers and divide wall
- Gated sluiceways
- Control room building and site staff accommodations
- Recreational works

Mechanical & Electrical works

- Submersible pumps for inflation and vertical centrifugal pumps for deflation of rubber bladders along with piping and other accessories.
- Overhead crane for subsequent maintenance of pumping machinery
- Sluice bays gates with hoisting system
- Power supply works (HT/LT networks)
- Standby generators and lighting arrangements

Environmental and Social Action Plan works.

- Tree plantation
- Recreational parks
- Water sports
- Land acquisition and resettlement plan

Technical Analysis for proposed dam sites

The tentative locations have been identified as per developed design criteria using Google Earth software. 20 sites were selected for checking their suitability as shown in **Table 2**. The locations of selected sites are shown in **Figure B**.

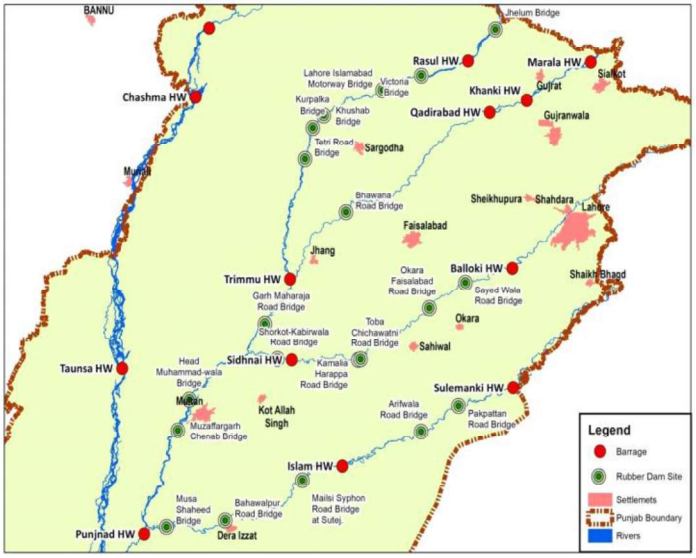


Figure B: The location of selected site

Water quality maps developed using 2012 ground water data have been used to analyse the ground water quality at the proposed locations. As per design criteria, the proposed sites must be located in sweat water zone and the ground water shows the trend of depletion. The ground water quality map at the proposed dam locations is shown as **Figure C:**

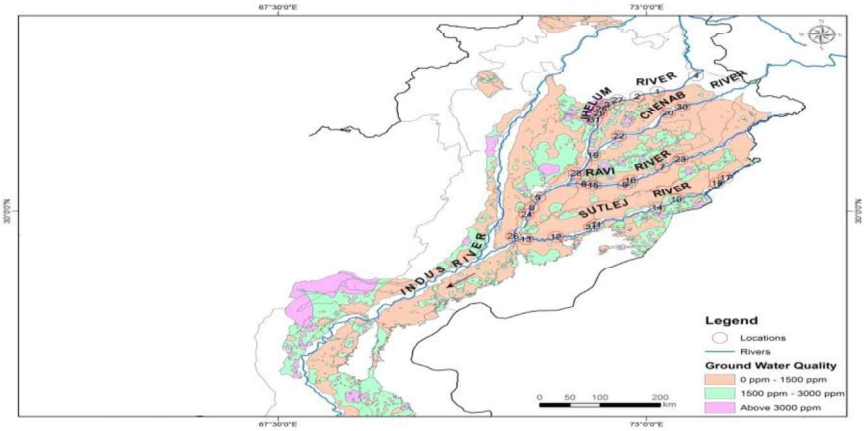


Figure C: Ground Water Quality

The ground water quality at the proposed location is generally good, as the inflatable dams are located on rivers. However, site on Sutlej River at Fatehpur is

observed in Bad ground water zone having TDS quantity greater than 3000 ppm and was discarded from the list of selected sites.

SRTM 90 m Digital Elevation database has been used to develop Digital elevation models (DEM) of all the selected sites. Google Mapper is then used to resample the data and to generate 3 m contours at the proposed dam sites for different heights. The pond area has been accessed at different dam heights. The selection of final dam height and pond area is subject to different parameters i.e. public buildings and instalments, resettlement of people, sufficient availability of pond etc. Moreover, after analysing different sites it has been observed that 3 m dam height is considered suitable for finding the reservoir area and capacity. The pond area of site is computed by taking the general slope of rivers in plain areas of Punjab i.e. 1in 4000. The exact capacity of reservoirs can only be determined by conducting Bathymetric survey.

Targeted beneficiary groups

The project is conceived with the main objective of reviving degraded reaches of the rivers/streams resulting in recharge of ground water and improved environmental management of the adjoining areas. Local storages will benefit urban as well as rural area population with improved water supply and improved flood management. Cropping cost will reduce considerably due to availability of sweet aquifer and pumping from shallow zone. Reservoirs/lakes developed by inflatable dams will supplement the fishery production to meet the food requirements of the province. Moreover, dams' sites will attract the public and private investments for development of recreation facilities.

Specifically study of Bahawalpur site revealed that the project will have significant positive impacts on groundwater and biological environment of the area and will also provide recreational facilities to the residents of Bahawalpur, Lodhran Districts and adjoining areas. Recharge a Gross Command Area of 12,850 acres. Yields will be at optimum levels enhanced up to 4.0 to 9.4% yield of various crops. Cropping intensities will increase by 6.7% in the rice crop area. Positive impact of the project on ecology of the area.

Project Cost and Financing Plan

The latest average cost of some inflatable dams around the world has been used to compute the cost of proposed inflatable dams in Pakistan. The latest average cost used in the analysis is $ 30,000 / m which includes the cost of concrete floor, pile-foundation, river training works i.e. guide banks, marginal bunds, saddle dam, rubber tube, automatic safety device, control system, operation and maintenance, contingencies and all the allied studies.

The computed average cost has been used to find out the cost of proposed inflatable dams in Pakistan. The ground water quality, dam height, dam length, reservoir area, reservoir capacity and project cost of all the proposed sites are shown in Table 3. Total estimated cost of selected dam sites works to be US$ 540 million.

As the above investment would be excessive in one go, it is proposed to prepare a phased program spanned over five years for feasibility, detailed design and constructionon of these inflatable rubber dams.

S. #	Description/Location	River	Dam Height (m)	Dam Length (m)	Reservoir Area (Million m^2)	Reservoir Capacity (Million m^3)	Tentative Cost (Million $)
1	Victoria bridge	Jhelum	3	856	5.1	7.65	25.68
2	M-2 bridge	Jhelum	3	868	5	7.5	26.04
3	Khushab bridge	Jhelum	3	716	10	15	21.48
4	GT road Bridge	Jhelum	3	1064	4.3	6.45	31.92
5	Kurpalka Bridge	Jhelum	3	1158	13.896	20.844	34.74
6	Tetri Bridge	Jhelum	3	381	4.572	6.858	11.43
7	Head Muhammad-wala Bridge	Chenab	3	600	6.5	9.75	18.00
8	Muzaffargarh road Multan Road Bridge	Chenab	3	595	6.45	9.70	17.95
9	Bhawana Bridge	Chenab	3	980	11.76	17.64	29.40
10	Shorkot -Garh Maharaja Bridge	Chenab	3	1114	13.368	20.052	33.42
11	Kamalia Harappa Road Bridge	Ravi	3	709	8.508	12.762	21.27
12	Syed wala Bridge	Ravi	3	1173	14.076	21.114	35.19
13	Okara Faisalabad road bridge	Ravi	3	791	9.4	14.1	23.73
14	Shorkot Kabirwala road bridge	Ravi	3	121	1.5	2.25	3.63
15	Toba Chichawatni road bridge	Ravi	3	417	6.4	9.6	12.51
16	Bridge near Pakpattan	Sutlej	3	633	7.595	11.395	18.95
17	Bridge on Mailsi Syphon	Sutlej	3	585	7.02	10.53	17.55
18	Road bridge (N5) near Bahawalpur	Sutlej	3	652	1.68	2.52	19.56
19	Musa Shaheed bridge at Jalalpur Peerwala Road	Sutlej	3	580	6.95	10.48	17.50
20	Arif wala Sahiwal Road Bridge	Sutlej	3	633.5	7.602	11.403	19.01
21	Lump sum provision for Potohar and other barani areas						100
Total							**540**

Table 3: Cost Summary of Suitable Sites of Inflatable Dams in Punjab as per preliminary assessment

Summary of the Proposed Project Cost based on the Tentative Cost shown above in **Table 3** is given as below.

S. No.	Description	Tentative Cost (Million $)
1	Feasibility Study, Detailed Design & Construction Supervision (Firm & Individual Consultants)	7.50
2	Project Management Cost	2.50
3	Inflatable Dams construction cost on Rivers/streams	540.00
Total Tentative Project Cost		**550.00**

The World Bank has expressed interest in financing the Proposed Project in a phased approach through IDA Credit for Project preparations and subsequently IBRD Loans as per provisions in the Country Assistance Programs. An advance from World Bank's Project Preparation Facility of about US $4 million would be requested and used for detailed design of Phase-I sites so that implementation can be started as soon as the project loan is approved.

Conclusions and Recommendations

Based on the studies carried out for selected sites on Sutlej and Ravi rivers, it is concluded that rapid lowering of ground water and ecological imbalance in the river reaches deprived of perennial flows are the challenges to overcome the anticipated acute water shortage for agriculture and domestic water supplies and the loss of biodiversity. Punjab Irrigation Department's initiative "Revival of degraded rivers in Punjab" by introducing technique of inflatable rubber dams across the rivers and streams having very low perennial flows is highly recommended to combat with the aforementioned emerging challenges.

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