The Lower Damodar River, India

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The Lower Damodar River, India

Understanding the Human Role in Changing Fluvial Environment

by

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Springer

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This book is dedicated to the memory of my late Parents
Shri Mohini Mohan Bhattacharyya
Smt Jyotirmoyee Bhattacharyya

Foreword 1

This is a time when the global impacts of human society are pushing governments around the world to actively search for new strategies to protect their social and economic assets from the threat of rapid climate change and its ecological and geomorphic consequences. Nowhere is this more apparent than in South and East Asia. China has recently engaged in the largest river impoundment project in this planet's history. In 2007 the Supreme Court of India orders the national government to proceed with planning for an engineering feat of unprecedented scope and scale: the hydrologic interlinking of all of the subcontinents major river basins for the purpose of equitable distribution and use of monsoon rains. In 2009 South Korea began its Four Major Rivers Restoration project. Already well underway, the government is committed to spending over $14 billion dollars in a little as 3 years to massively alter channel storage and conveyance capacities; ostensibly in response to anticipated water shortages to come. Rivers and coastlines, because they are the most obvious interfacing between the hydrosphere and our continental homes, are the front lines along which much of drama of human adaptation to climate change will play out.

It is appropriate then, that we find ways now to step back, and carefully review our experiences and history with regard to that age-old dance between humans and rivers, a relationship that spawned the earliest civilizations of man. A relationship where man often masters river, but not infrequently river masters man. K. Bhattacharyya's study of the Damodar River provides us with just this opportunity. Set in a lower tributary of the mighty Ganga (Ganges) this is a story of human ecology, river geomorphology, and hydrologic engineering. Adaptation by both the riparian communities and the river itself to a trajectory of mutually induced change make it also a fascinating ecological study in the truest sense of the word. In this drama of riparian ecology man is not a bystander nor a reference point for determining "ecosystem values", but an actor and participant. The authors attention to fine detail in the data, and also to the history of geographic and geomorphic concepts required to provide perspective make this a scholarly work of great value. Her personal connections with the riparian community, and with the academic and engineering community as well provide valuable insight into the human aspects of this story; this contributes to a certain compelling sense of drama that emerges from this study. I understand entirely M.G. Wolman's and others push to have Kumkum publish her work in book form. It is a recounting of a particular history, relevant to our current and future negotiation with nature, which is both compelling and informative.

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March 20, 2010

Foreword 2

Industrialization, urbanization, economic development, and rapid population growth have necessitated deliberate human interference with most rivers from all the major basins in the world in order to exploit their water and control their courses. The Damodar River is no exception to this. Although such interference in this relatively small river valley started more than three centuries ago, it intensified after the independence of India from Britain in 1947. Since then, the water of the Damodar River has been used to irrigate farm lands during the dry season, for hydro-power development, as well as for navigation, fisheries, and industrial development. Many flood control structures have also been put in place to reduce the impacts of destructive floods. These and other changes made to control river flow and to use its water have benefited residents of this river valley, but not without social and environmental cost. Valley residents have struggled to adapt to these changes and maximize their limited resources while the river ecology has suffered over the decades.

I was born and brought up in Bangladesh, a country criss-crossed by rivers, most of which are either tributaries or distributaries to three great rivers of the world: the Ganga, the Brahmaputra, and the Meghna (GBM). These three rivers form the GBM basin, one of the largest trans-boundary river basins in the world. With a total catchment area of the 1.74 million km^2, this densely populated basin contains one of the richest agricultural areas in the world and its rivers are intricately linked with the very survival of millions of people. Rivers supply much needed irrigation water for crop cultivation and serve as arteries of commercial transportation. Since the GBM basin receives heavy annual rainfall and approximately 85% of that rain occurs in the summer, rivers of this basin, carry a large discharge and a heavy sediment load. This causes these rivers to be extremely unstable, with channels that are literally, constantly migrating. As a result, the GBM basin experiences annual flooding, which adds fresh silt to crop fields making the land very fertile. While most floods rejuvenate land and lives, some bring misery and death.

The Damodar River is contained within this basin. All school-going children in West Bengal and Bangladesh have heard stories about the mighty Damodar and how Ishwar Chandra Vidyasagar – a great scholar, philosopher, educator, and reformer of Bengal during the colonial period – swam across this river in a storm in order to obey a summons from his mother. Later, as a graduate student of geography, I learned about the pioneering endeavor of the Indian government, the Damodar Valley Corporation (DVC). While my interest in the Damodar River is personal, what has happened and what is happening now in terms of exploiting the water resource of the Damodar is no different from any other river in the GBM basin, or for that matter, any other populated major basin of the world.

Therefore, irrespective of geographic area, this book will be of tremendous value to scholars, researchers, teachers, students, and others interested in how public policies change river morphology and how such change affects both the physical and human environment.

This excellent book is based on Dr. Bhattacharyya's Ph.D. dissertation, which she completed from The University of Burdwan under the expert supervision of Manjusri Basu, Reader in Geography of the same University. Her Ph.D. committee members included prominent and famous personalities like M. Gordon (Reds) Wolman, B. Howard Griswold Professor of Geography and International Affairs, Johns Hopkins University, USA and Monotosh Bandyopadhyay, Professor of Geography, University of Calcutta. Since she completed her dissertation, Dr. Bhattacharyya updated all information. She spent a tremendous amount of time collecting relevant information through intensive field work and in doing so she followed rigorous scientific procedures. Other sources have been utilized to gather pertinent information. Her depth and knowledge about the subject matter of this book are reflected in her holistic and thorough interpretation of the field data. It presents well-documented research findings in an engaging style. Dr. Kumkum Bhattacharyya is new to academia in North America, but she has a very high potential to become one of the top in her field of research in the near future.

In writing this book, Dr. Bhattacharyya uses a broad perspective, which makes this book interesting not only to physical and human geographers, but also to scholars from other related disciplines interested in the environmental dynamics of rivers in general and the Damodar River in particular. I am honored to write a foreword for this insightful, valuable, and useful book which will advance our knowledge and understanding of how humans have interacted and interfered with rivers to their benefit. I congratulate Dr. Kumkum Bhattacharyya for presenting us with this outstanding book, and I invite all of you to read it.

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Foreword 3

Kumkum Bhattacharya's Book has a novel approach. Ecological considerations have been emphasized starting from the completion of the Damodar River Valley Project and also during his partial completion. Emphasis by the scholars was given to study the economic consequences with significant reference to displacement of famers caused by the constructions of canals and reservoirs. Geographers then contributed to the research of socio-economic advantages of the Damodar Valley research. Two Geography departments belonging to the states of West Bengal and Bihar – Calcutta University and Patna University – contributed to a specialized research funded by the government studying the socio-economic effects of the Damodar River Valley (DVC) project. Professor Kanangopal Bagchi who headed the Calcutta University, Department of Geography, based research team concluded in one of his papers:

> The DVC developments will improve the economic situation by creating infrastructures; in fact, rural electrification, construction of hard surfaced roads, and sinking of tube-wells, have already started although the pace has not been up to expectations so far. Even within this limited growth, villages and urban centers are progressing, striving to promote measures which fight drought, which is more or less endemic within the upper catchment, and floods, which are chronic in the delta. (K. Bagchi "The Damodar Valley Development and Its Impact on the Region", In Allen G. Noble and Ashok K. Dutt Editors: *Indian Urbanization and Planning: Vehicle of Modernization*, 1977, New Delhi, Tata McGraw-Hill Publishing Company Limited: pp. 232–241).

Bhattacharya book considers ecological and human repercussions of the project. It aptly recommends "better human and environment interactions". The construction of dams and reservoirs changes the natural flow of the rivers with ecological consequences. This book suggests a change of strategy to suit the interest of the people. The book also recognizes that in Bihar the project generates electricity that supplies vast area helping industrialization, city lighting and pump irrigation while in West Bengal (Lower Damodar Region), the effect of the project is primarily to control in floods and provide irrigation through canals. The ecological alterations are felt more in the lower Damodar region because here floods have been controlled and river water has been redirected-both changing the local ecology. One additional aspect needs to be considered, the aspect of climate change which is likely to cause excessive rainfall or drought occasionally. One encouraging aspect of such change is that the Damodar Valley area is not affected by excessive floods caused by melting of Himalayan and Tibetan snow.

The book is based on extensive research and field work, it is written well. It is based on conceptualization of different ideas and has strong theoretical basis; making a sound scholarly contribution. It is highly recommended for libraries all over the world. It also makes an excellent reading for those interested in developing country river geography and consequences of dam and reservoir construction.

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Preface

Since ancient times, river floods and control structures have been the basis for riverine civilizations of riparian landscapes. One can argue that civilization as we know it would not have arisen without river control. Even now, dams continue to act as bulwarks against catastrophic flood destruction all over the world. River water utilization and river control structures have formed the mainstay of planning policy in decolonized developing countries in the tropics in their quest for self-reliance since the early nineteen forties. Despite these enormous benefits, however, river control has sometimes had disastrous social and environmental consequences. Not surprisingly, the large-scale ecological damage and human suffering associated with river control has been particularly significant in the developing countries where dams have provided maximum benefit.

I was born and brought up in the Ganga Valley of Lower Bengal. The River Ganga was a constant companion in my childhood. When I grew up, the river became a source of inspiration for me. This proximal relation with the river was the true initiator for the creation of this book. I started dreaming of working with the river. I decided to pursue an academic career focusing my interest on understanding the riverine regime and its paradoxes. As a graduate student of Geography, I had been privileged to visit and study the Ganga (Hooghly-Bhagirathi), Damodar, Ajay, Kaliaghai, Kasai and Kangsabati Rivers. With a keen interest I observed everywhere how indigenous technological innovations helped better water resource management and how flooding was accepted by the riparian communities as a positive factor. The disadvantage of floods in one season was converted into an advantage in another.

I was inspired by Manjusri Basu, Reader in Geography of The University of Burdwan. She was instrumental in sparking my interest in the way people interacted with their fluvial environment and responded as a community at both micro and macro levels. This subject haunted me for years and drove me to many places in search of answers. By the beginning of 1990, I was granted a University scholarship and approved for the doctoral program at the same university under the supervision of M. Basu. I selected the Lower Damodar River, a subsystem of the Ganga River as my area of focus. One reason for this choice was the fact that floods have concerned humanity from the dawn of civilization to the present era and this part of the Damodar is notorious for causing flood havoc despite control measures. Also, the Lower Damodar has a flood history dating back to 1665 and is one of the innumerable South Bengal Rivers chained by embankments, the first control measures, predating the British Period. Besides, the Damodar was the first river selected in independent India for a multipurpose river valley development project known as the Damodar Valley Corporation (DVC), a body modeled on the Tennessee Valley Authority (TVA) of the United States. Beginning with the construction of embankments in the eighteenth century and subsequent addition of weirs, barrage and dams, the Lower Damodar River has been transformed into a reserved controlled channel with significant post-dam reduction in regular flow and in monsoon discharge but with the increase of non-monsoon flow with very high variability. The alluvial bars locally known as *Char* or *Mana* that have emerged on the riverbed due to decreased flow are now used as a resource base mostly by Bangladeshi refugees who have matched land use at fine scales to flood experiences applying a concept of flood zoning to the riverbed and effectively assessing short-term risks and long-term benefits. According to M. Basu, "Colonization on the riverbed with semi-permanent alluvial sandbars was actually due to the chance discovery of the fertility of the water-bound landmass". We were fascinated by the complex, sophisticated interrelationships between the riverbed settlers and the natural environment in the presence of floods and dams. As a field researcher, I lived on the sandbars of the Damodar River in order to observe and interview people living in that flood-prone environment. During that time I also collected information on floods, water resources, human perception, adaptation, flood plain zoning, and other topics.

I have since had the opportunity to present the results of my research at different national and international seminars in India and abroad. I also had the opportunity to present papers on the impacts of dams and human perception and adjustment in riverbed sand bars at the Conferences of *International Association of Geomorphologists* held in Singapore in 1995 and in Bologna of Italy in 1997. My presentation in Singapore concluded with a question: should we save our rivers or save the communities? "This is very interesting and fascinating work" – this was the immediate response of M. Gordon (Reds) Wolman one of the most gentle and amiable personalities I have ever encountered. He was genuinely excited and curious about my research. Since 1995 I have been nurtured by his vast encyclopedia of ideas. While writing this preface, I came to know that Prof. Reds Wolman is no more. I have lost a true mentor who was always generous with his time and provided continuous guidance for this book which is based on my PhD dissertation that he examined.

The University of California, Berkeley awarded me a post-doctoral research fellowship in 2002 along with the opportunity to work on the impacts of dams and reservoir sedimentation under the supervision of Matt Kondolf. I had numerous opportunities to visit and study the rivers and reservoirs in California on weekend field trips to further develop my research on the Damodar River where significant silting in the Maithon and Panchet reservoirs and the resulting decrease in flow in the main channel has led to the creation of a series of settled sandbars. This has resulted further in deforestation and anthropogenic degradation of the river itself. Refugees have inhabitated the sandbars despite adverse environmental conditions.

In defiance of economic, social and political limitations, they have persevered in adjusting to the inhospitable surroundings. This hydraulic society poses a challenge to technology as well as to the government in the quest to confront and control flood hazard.

Human impact on the riverine system and the socioeconomic environment has become a matter of great concern in the contemporary world. Geographers, ecologists, planners, engineers and scientists all over the world are paying close attention to the relationship between humans and the environment. M. Gordon (Reds) Wolman, commenting on riverbed settlers in the Damodar River, wrote (personal communication dated April 10, 1996) "is there a set of design flow releases that will at least reduce frequent flooding? Of course, the rare largest floods may be the ones causing the most severe damage to people and property. That may require preventing settlement on the island, a difficult thing to do". We would hesitate to ask river communities to abandon sandbars that have been under cultivation for decades but we would like to propose that agriculture or human interferences be abandoned with the active channel. Our communities must be saved but not at the cost of continuous deterioration of our river ecosystem. The aim should be to optimize the present human uses and to preserve the river as a living system not only for its inherent ecological value but to satisfy future human needs on a sustainable basis. Surely both the river as well as the communities can be saved in this way?

There is a lot of active ongoing research on global climate change. The drastic modification of our river systems has received far less attention. This research attempts to redress the balance by assessing a controlled river in its pre-dam and post-dam periods, reviewing the positive and negative impacts of control structures, reviewing the socio-economic significance of such control measures and human perception and adaptability within the riverbed, and identifying policy options to minimize the negative effects while maximizing the positive ones. This case study of a flood-prone Indian river can be used as a model for planning and managing this and other rivers of similar nature in India and elsewhere. This study may also be used as a good example of how the harnessing of a river and excessive human interference with natural systems alters its fluvial regime. Further, this research would provide an in-depth case study of floods and modification of the hydrological cycle due to human interference, and human adjustment with floods and dams. Therefore, the outcome of the study may be used as a knowledge base for students, researchers, river experts and planners of river valley projects. "We should promote scientific analysis of human impacts on river system and collaborative science-based approaches to river conservation and management. Collaboration is central to ecosystem management," Mike J. Wiley, Roosevelt Professor of Ecosystem Management from the University of Michigan, Ann Arbor, said. He added "I have always found that people really do care and want to manage their water resources more effectively. The difficult part is developing effective lines of communication".

As a researcher, I have assembled extensive data from multiple sources over a period of time and presented it without bias so that this information may be used to make more intelligent decisions in assessing the balance between the benefits and unfavorable downstream effects of dams. Admittedly, the work of a single researcher cannot provide the more complete impact analysis that would be possible through an inter-disciplinary approach taken by a team. Nevertheless, an attempt has been made in this book to focus on that effort by presenting a thorough, data-driven review and analysis of the human-made downstream environment of a controlled tropical river, the Damodar, from an applied geomorphological perspective within a wider geographical framework. The book addresses a topic that is gaining in importance and will remain relevant in the forseeable future. I hope it will make a valuable contribution to research on human environment interactions.

Acknowledgments

This book contains the results of 7-year PhD research project conducted by me under the proficient supervision of Manjusri Basu (Ex-Reader), Department of Geography, The University of Burdwan, India. I hereby express my heartiest sense of gratitude to Ms. M Basu for proving direction, continuous constructive criticism, encouragement and editorial assistance during my research period. This time-bound research project has been funded by The University of Burdwan and due to personal interest the research was carried on, based upon field surveys, over extensive areas for a long period. The author thanks The University of Burdwan and University of California, Berkeley, CA for their financial support for this research. I am grateful to PK Sen (Late Professor, Department of Geography, The University of Burdwan), Late Professor A Biswas, Dr. VC Jha (Department of Geography, Vishva Bharati University), for their valuable suggestions. I would like to thank Mr. D Bandyopadhyay, the then Minister for Agriculture, Government of West Bengal for permitting me to get access of rare and valuable data and Government documents.

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(MRO) office, DVC, Maithon), D Chowdrury (Senior Divisional Engineer, DVC, Hazaribagh), and S Vaddey (Hydraulic Engineer, US Army Corps of Engineers, Portland, OR). I am thankful to them for their valuable ideas.

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Ann Arbor, MI Kumkum Bhattacharyya

Conversion Factors

This book uses metric units of measure. The table below is provided for those who require English units.

To convert from English unit	To metric unit	Multiply English unit by	To convert to English from metric multiply metric unit by
inches (in)	millimeters (mm)	25.4	0.03937
inches (in)	centimeters (cm)	2.54	0.3937
feet (ft)	meters (m)	0.3048	3.2808
yards (yd)	meters (m)	0.9144	1.094
miles (mi)	kilometers (km)	1.6093	0.62139
square feet (ft^2)	square meters (m^2)	0.092903	10.764
square miles (mi^2)	square kilometers (km^2)	2.59	0.3861
cubic feet (ft^3)	cubic meters (m^3)	0.028317	35.315
cubic yards (yd^3)	cubic meters (m^3)	0.76455	1.308
cubic feet per second (ft^3/s)	cubic meters per second (m^3/s)	0.028317	35.315
feet per second (ft/s)	meters per second (m/s)	0.3048	3.2808
feet (ft)	meters (m)	0.3048	3.2808
degree Fahrenheit (°F)	degree Celsius (°C)	(°F–32)/1.8	(1.8 × °C) + 32

Abbreviations

BLRO	Block Level and Revenue Office
CBIP	Central Broad of Irrigation and Power
CPCB	Central Pollution Control Board
cumec, m^3/s	Cubic meter per second
CWC	Central Water Commission
DVC	Damodar Valley Corporation
EL	Elevation
GSI	Geological Survey, India
ha	Hectare
ICAR	Indian Council of Agricultural Research
ICOLD	International Commission on Large Dams
IRS	Indian Remote Sensing
I&W Dept	Irrigation and Waterways Department
km, Km^2	Kilometer, sq kilometer
m	Meter
M.cu.m	Million cubic meters
mm	Millimeter
MRO	Manager Reservoir Operation
N.A.	Not Available
NATMO	National Atlas and Thematic Mapping Organization
NRSA	National Remote Sensing Agency
RBO	River Basin Organization
RR&RD	Refugee Relief & Rehabilitation Department
SOI	Survey of India
TVA	Tennessee Valley Authority
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNICEF	United Nations International Children's Emergency Fund
WB	West Bengal
WCD	World Commission on Dams

Contents

Chapter 1
Purpose and Perspectives

Abstract Floods, once the basis for hydraulic civilizations, are now seen mostly as sources of hazard due to negative interaction between human systems and environmental conditions at particular historical junctures within specific economic and social conditions. The same phenomenon acquires a different dimension if seen rationally as an event with both possibilities as well as perils that one can plan for and guard against. In this study on the Damodar River, physical and human environmental research has been integrated, focusing on river morphology and ecology, human use of river and sandbars or *char* lands as a resource, and policies that shape a river. This leads us to a more holistic understanding of how the forms and ecological status of a river are shaped by the interplay of environmental and anthropological processes. In other words, this research reviews the impacts of control structures in the downstream environment and also provides a detailed study of human role in changing fluvial regime through descriptions of the way in which people, ranging from refugees to local settlers, driven by diverse cultural, economic, religious, and political forces, have transformed the fluvial landscape.

Keywords Anthropogenic · Char/Mana · Control structures · Floods · Fluvial landscape · Human-environmental research · Hazard · Hydraulic civilization · Resource

1.1 Purpose

Floods and control structures, once the basis for riverine civilizations of riparian landscapes, have, despite their enormous benefits, sometimes had disastrous social and environmental consequences at particular historical junctures. Are these consequences unavoidable or is it possible to achieve a judicious balance between the various forces at play so that the benefits of river control can be realized without large-scale ecological damage and human suffering? The answer can only be found in an unbiased and extensive review of data obtained from controlled rivers over a period of time through scientific measurements and intensive field surveys. Though no single study can fill such a need, this research aims at contributing to that effort by

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presenting a thorough, data-driven review and analysis of the human-made downstream environment of a controlled tropical river, the Damodar, from an applied geomorphological perspective within a wider geographical framework. Before getting down to the nitty-gritty details and spelling out the specific objectives of this research, I would like to elaborate a little on the broader purpose and framework of the endeavor. In this context, the following sections provide a brief overview of contemporary and historical water resource management efforts and the environmental, social and economic impact they have had in different parts of the world with particular reference to South Asia.

Major ancient civilizations are hydraulic civilizations and many river basins, even those without optimum combinations of atmospheric, hydrologic and geomorphic inputs, were the sites of these civilizations. These rivers were perennial but flood-prone with fluctuating river regimes. The ancient riparian communities, therefore, were forced to take flood disaster reduction measures on the one hand and implement flood management programs on the other so as to transfer excess floodwater from surplus areas to deficit areas and from surplus seasons to deficit seasons. Artificial levees, canals, dams and many other such artifacts associated with these civilizations were nothing but river control structures and these structures were components of the geomorphic landscape from the dawn of these ancient civilizations (Bhattacharyya 1998).

The first three major civilizations that thrived about 5,000 years ago were those of the Harappans in the Indo-Gangetic Plain, the Egyptians in the Nile Valley, and the Sumerians in Mesopotamia (Easton 1964; Biswas 1970). The Indus Valley Civilization was the largest of the three most ancient civilizations and was in existence between 3000 and 1500 BC (Agarwal and Narain 1997). The Nilotic or the Egyptian civilization prospered in the Lower Nile basin between 3000 and 1750 BC and ended in a catastrophic flood of the River Nile due to tectonic upheavals (Dales 1966). The Mesopotamian civilization flourished in the Tigris-Euphrates basin in Southwest Asia and was in existence between 4000 and 600 BC. The Chinese civilization developed on the banks of the River Hwang Ho in northern China but their contribution to hydrology, especially prior to 600 BC, is not so significant (Biswas 1970). A degree of rudimentary civilization, with some of the social skills and discipline the word entails, was represented by open villages not later than the fifth millennium in the foot-hills of northern Iraq, by Catal Huyuk near Konya in southern Turkey in 7000 BC and by agricultural settlements at Mehrgarh (also about 7000 BC) on the Bolan River in the Indian sub-continent (Mishra 1995). Another recorded practice of irrigated agriculture has been traced to Jericho in the arid Jordan Valley around 7000 BC (Hirsch 1959; Wheeler 1966; Saha 1981). It is the Mesopotamian civilization that flourished in the latter half of the fourth millennium (Wheeler 1966), however, that reached the level of sophistication needed to claim the distinction of being the first real civilization.

Development of the water management systems that allowed these ancient civilizations to flourish necessitated observation of flood behavior, type and nature of silt accretion and collection and maintenance of hydro-geomorphic data for rational use of river water. In Egypt, hydrologic data near Cairo dates back to 622 AD

(Mookerjee 1989), and basin irrigation, which was first introduced in Egypt some 6,000 years ago (Willcocks 1930), is still socio-economically relevant in many tropical countries. In Egypt, the Nile floods served as the basis of successful agricultural irrigation for more than 5,000 years. People have successfully harnessed the river and become accustomed to the natural flood regime. The most important date in the Egyptian calendar was the one on which the annual inundation took place (Ward 1978). An intricate system of basin irrigation involving longitudinal dykes parallel to the main channel of the Nile to regulate flood water, a network of cross dykes and canals to control the flood water into pre-assigned basins, and a diversion channel to the naturally formed Faiyum depression for creating a storage reservoir for excess flood water for later use was developed as early as 3400 BC (Hamdan 1961; Saha 1981). It is also recorded (Payne 1959; Biswas 1970) on the authority of Herodotus that, during the Middle Kingdom (2160–1788 BC), artificial lakes were used to store water and control the high floods of the Nile.

Some scholars believe that the oldest dam was constructed in the desert land of Jawa (Jordan) around 3000 BC. Others believe that dam building began on the Nile. Near Memphis, there are relics of a masonry wall built across the river by King Menes in 4000 BC. The Romans built dams for water storage so well that some of the structures in Jordan are still in working condition today (Reifenberg 1955; Pereira 1973). Though probable, there is little known proof to show that the science of dam construction appeared in a particular place and from there it was taken to others (Agarwal and Narain 1997). About 28.8 km south of Cairo, Egypt in Wadi-el-Garawi, the ruins of Sadd-el-Kafara dam, which was built sometimes between 2950 BC and 2750 BC, are still to be observed (Biswas 1970; Ward 1978; Costa 1988). The Egyptian engineers built another dam in Syria between 1319 and 1304 BC when the first dam failed to serve its purpose. The Egyptians made great advances in water resource development during the Middle Kingdom (2160–1788 BC). Artificial lakes were built to divert high flood flows of the Nile into the historic lake Moeris through canals (Payne 1959). When the inundation came to an end, the stored water of the lake was returned to the Nile and the storage capacity of the lake was made available for the next flood period (Biswas 1967).

The Mesopotamian contemporaries of the Egyptians could not develop a similar system based on one annual inundation whose benefits could be reaped through the growing season. They were obliged to develop perennial irrigation (Brittain 1958). They reclaimed as well as irrigated land long before 3000 BC in marshes in the lowlands near the gulf and along the Lower Euphrates. Traces of these lands can still be seen from airplanes (Sarton 1952). They devised a sophisticated canal system for the twin purposes of irrigation and navigation. The canals built were very often wide enough to reduce bank erosion from rushing water from the off take points of the canals. Silt banks which were created by cleaning canals are now major topographic features (Leopold et al. 1964). The canal banks, therefore, became sites for industrial and commercial centers. Multiple uses of canals were thus one of the characteristics of the agrarian civilization of Mesopotamia (Willcocks 1930).

In the Middle East, where evapotranspiration is a severe problem and channels are lost in sand deposits, a very special system of irrigation referred to as "Quanat" or “Kanat” was developed. In this system, an artificial underground channel or a canal is used to carry water over long distances, either from a spring or from water bearing strata. This system indicates that, faced with water scarcity, the people developed knowledge about water resource engineering (Biswas 1970). The Quanat may be a Persian creation but this human-made underground river is the sole source of water for millions in Iran, the Middle East as well as in Central Asia.

The Indus Valley Civilization (3000–1500 BC) which came to light with the excavation of Harappa and Mohenjodaro in the early 1920s by Rakhaldas Bandyopadhyay, an Indian Historian, covered a vast area, more than seven times the extent of Sumer in Mesopotamia (Easton 1964). The Indus Valley and Mesopotamian civilizations were connected by close trade relations and strongly influenced each other (Garbrecht 1985; Agarwal and Narain 1997). The story of the rise and fall of the Indus valley civilization in a semiarid bio-climatic environment is the story of humans’ struggle to conquer nature and build an integrated coherent society. In this struggle for existence, the Harappans’ response to the challenge of nature, which mainly came from the River Indus, was a positive one. They adopted measures to control annual and abnormal floods. In Sind, for example, there are hundreds of kilometers of single and double lines of embankments (Framji and Garg 1976). Some of the settlements of the Indus Valley Civilization, dating back to 3000–1500 BC, had water harvesting and drainage systems. The most recent to come to light are the settlements at Dholavira, a major site of the Harappan or Indus Valley Civilization, located in the Great Runn of Kutch in Gujarat. The inhabitants of Dholavira fashioned several reservoirs to collect monsoon runoff flowing in the flanking streams of the Manhar and Mansar. These bunds or dams raised across the streams are evocative of the gabarbands of Baluchistan. The purpose of these gabarbands was mostly to collect a “layer of alluvial soil over dry and barren rock, combined with the retention and economic control of distribution of flood water” (E. Hughes-Buller 1906; Agarwal and Narain 1997). Some evidence of irrigation in the Indian subcontinent dates back to the beginning of the third millennium BC when farming communities in Baluchistan impounded rainwater to use in their fields. Dams made of stone rubble have been found in Baluchistan and Kutch. Excellent water supply and sewage disposal systems were well-known features of these cultures. The standard of their hydro-technical infrastructure was not equaled even 2,000 years later by the Romans whose water systems are generally considered outstanding. As in Mesopotamia, protection against annual flooding of the Indus River, irrigation to secure and increase crop yield, and drainage of large alluvial areas were preconditions to the survival of kingdoms in the Indus valley (Agarwal and Narain 1997). According to Leopold et al. (1964), silt accumulation in alluvial areas of the Indus River at Mohenjodaro are of the same order of magnitude (about 33 feet) as that found by archaeological soundings in other alluvial areas during the last 5000 years.

Indian scriptures are rich in examples of human attempts to undertake rational water harvesting measures. The scriptures also refer to the significance of water bodies, natural or artificial, during war. The *Puranas, Mahabharata, Ramayana* and various *Vedic* scriptures make multiple references to canals, tanks, embankments and wells (ICAR 1964). Among the scriptures, the Vedas are the oldest and the Vedic period extends between 2000 and 800 BC (Chattopadhyay 1990). These early Hindu texts, written around 800–600 BC reveal certain knowledge of hydrological relationships. The Vedic hymns, particularly those in the *Rig Veda*, contain many notes on irrigated agriculture, river courses, dykes, water reservoirs, wells, and water lifting structures.

The Rig Veda (2000–1500 BC, an ancient sacred book of wisdom) uses a term *Avata* to signify a well. The dictionary of Nighanta mentions fourteen types of well. At the same time, there are mentions of *Kulya* an artificial river or canal. In another passage, there is a reference to a dried up reservoir. The *Yayuraveda* also refers to canals and dams which were known as Kulya and *Sarasi*. Sarasi, in fact, denotes an artificial reservoir and a natural lake as well. The *Atharva Veda* (III, 13) gives a description of the construction of canals from rivers. A canal is fed by a river or, in other words, a canal takes off from a river. To convey this sense, the Atharva Veda describes a canal as a calf and the feeding river as a cow (Sarava 1954). The Chandogya, one of the principal *Upanishads* (the philosophical reflections of the Vedas, numbering 108 in all), points out (Garbrecht 1985 as cited in Agarwal and Narain 1997, p. 13): "The rivers. . .all discharge their waters into the sea. They lead from sea to sea, the clouds raise them to the sky as vapour and release them in the form of rain. . ..". This is probably the oldest reference to the natural processes within the hydrological cycle. It shows that as early as about 1000 BC attempts were being made to interpret and explain recurrent natural phenomena on the basis of direct knowledge. The linkage between the environment and the water system was understood even at the time of the Greek Philosopher Plato (427–347 BC) who has written a vivid description of erosion he observed at Attica in Greece.

Manu, the first man and the legendary author of an important Sanskrit code of law, the *Manu-Smrti* (second century AD), prescribes a punishment of death for a person causing a breach in a dam. He also writes in his work (VII. 196) that a king, wishing to conquer his enemy, should first destroy all types of dams (tataka) in his territory (Sarava 1954). Bishnugupta Kautilya (third century BC), the prime minister of the King Chandragupta Maurya (321–297 BC), in his Arthasastra or book on polity, gives the same advice i.e., during war the land of the enemy should be flooded by breaking or breaching lakes, dams and embankments (Sarava 1954; Bhattacharyya 1998). The purpose behind such practices was to disrupt the transportation system so that enemies could not move through the flooded terrain. Similar steps used to be taken by the Chinese. During war, enemy lands were flooded by forced breaching of dykes and dams (Schnitter 1994). With a similar purpose, even now, river bridges are destroyed during war. Ramayana, the first Hindu epic (before fifth century BC) describes in detail several advanced engineering works. Valmiki, the author of this epic, gives an account of how King Bhagiratha and his group of engineers diverted the course of the Ganga from the Himalayas towards the present Ganga delta.

The acquisition and protection of state territories, for which Kautilya required finance is the central theme of the Arthasastra and this was Kautilya's major concern. Kautilya, therefore, looked for agriculture as a source of state revenue.