Historical Water Sustainability

Compiled and Edited:

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The Pillars of Sustainability

INTERNATIONAL COMMISSION ON IRRIGATION AND DRAINAGE

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Historical Water Sustainability

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International Commission on Irrigation and Drainage (ICID), established in 1950 is the leading scientific, technical, and not-for-profit Non-Governmental Organization (NGO). ICID, through its network of professionals spread across more than a hundred countries, has facilitated sharing of experiences and transfer of water management technology for over half-a-century. ICID supports capacity development, stimulates research and innovation, and strives to promote policies and programs to enhance sustainable development of irrigated agriculture through a comprehensive water management framework. The mission of ICID is to stimulate and promote the development and application of the arts, sciences and techniques of engineering, agriculture, economics, ecological and social sciences in managing water and land resources for irrigation, drainage, flood management, for achieving sustainable agriculture water management.

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Foreword

The United Nations Sustainable Development Goals (SDGs), adopted in September 2015, assigned targets set to be achieved by 2030. By being, a direct or indirect, part of 7 out of 17 SDGs, water has a cross cutting presence and importance. The SDG #1 clearly states that "By 2030, eradicate extreme poverty for all people everywhere". In this context, ICID Vision 2030 of "A water secure World free of poverty and hunger through sustainable rural development" has been defined and a relevant roadmap has been developed in 2017. The current world population of 7.8 billion is expected to reach 8.6 billion in 2030 and 9.8 billion in 2050, according to Population Reference Bureau (2021). Most of the increase will be in developing countries and we would need to double our food production by 2050 to feed the world. The world has been practicing agricultural water management since early civilizations. However, newer regions being brought under sustainable solutions will have to learn from practices elsewhere which have resulted in a sustainable regions of agricultural water management. A review of water resources and irrigation development scenario in various countries spread across the multiple regions of the world provides insights into success and failures enabling the wider communities to learn from those experiences.

Water heritage is not discrete, but a continuum. In fact, water does not need humans at all. It is the other way around that humans need water for their sustainability or survival. Since the dawn of human civilization, water has been an essential ingredient or enabler of societal development so much so that we started believing "Water is Life," a common phrase in most languages.

Early human settlements emerged around natural water sources and continued to do so for thousands of years. Early Civilizations (Egyptians, Mesopotamians, and others), were developed where the necessary water for agricultural development was readily available, i.e., close to springs, lakes and rivers. During the course of the civilization process, the water bodies became integral parts of human communities and societies and their economic, social, cultural, political, religious, and spiritual activities.

Tracing the history of and understanding the evolution of irrigation in civilizations across the world is necessary to select and collect information on historical irrigation structures from around the world, understand their significant achievements and gather knowledge about the unique features that have sustained the structure for such a long period; to learn the philosophy and wisdom on sustainable irrigation from these structures; and to protect/preserve these historical irrigation structures.

ICID recognized world heritage irrigation structures that represented the state of the art of its time, preserved over hundreds, if not thousands, of years and demonstrated important lessons for water security, food security, and sustainable agricultural water management for generations.

Heritage is not for the sake of only heritage appreciation; on the contrary, it has important sustainability lessons for our future survival and overall continued development. Current civilizations benefited and built on the past heritages. For example, the shaduf and waterwheel for lifting water have led to the evolution of various water-lifting devices through the centuries all the way up to the invention of solar lifting pumps.

Besides modernization, could we not learn lessons from the history to augment and manage our water resources better? What lessons can the history of irrigation bring to the question of why some irrigation systems have long existed for as many as thousands of years, while others failed and got out of use after brief periods?. The evolution of civilisation is closely related to and affected by the origin, development or decline and revival of irrigation. A variety of changes in the irrigation business have taken place, e.g. urbanisation, population increase, groundwater abstraction, building of large dams, economic changes, land use changes, and many other aspects of life have changed and seem sure to continue to change and therefore incessant learning from the history needs to be practiced.

The history is full of sustainable examples to learn from. In Iran, the existence of 37000 Qanats heralds their sustainability. Qanat is a gently sloping subterranean canal. Some Qanats go back to over 1000 years in antiquity and they still exist because they are sustainable. In the Netherlands, drained lakes are polders that have been created by draining areas that were previously permanently under water. Can The Dutch Keep Their Polders Dry? Find this in Chapter 14. Irrigation in Malaysia is generally associated with paddy and paddy planting has been practiced since time immemorial and is still sustained due to successful implementation of management practices under Muda and Kemubu Agriculture Development Authority. More on this in Chapter 07. In Japan (Chapter 08), reconstruction of Tawara weir and canal system in early 17th century and modernization in the late 17th century was undertaken for sustainability. The 'Subak' system in Bali, Indonesia (Chapter 11) is an example of existence of water user association from the past. The local people had been implementing these distinct irrigation based agricultural practices from generation to generation for centuries till present. Thanks to the Grand Canal, now the Cavour, (1863 to 1866) the provinces of Vercelli and Novara are today the major rice producers in Italy (Chapter 10). The Grand Anicut, on river Cauvery in India, is amongst the oldest surviving and standing major irrigation works in the world (Chapter 16). In Hungary (Chapter 17), the comprehensive regulation works of the two major rivers, the Danube and Tisza Rivers are excellent examples for sustainable agricultural water management.

In this way, lessons learned from antiquity may prove effective and efficient for future water use. This publication provides the readers with glimpses of lessons learned and way forward for "Historical water sustainability" in the 21st Century. The readers may also be reminded of ICID publication on "The Indus Basin: History of Irrigation, Drainage and Flood Management" (2004) which provided a historical portrait of the past and present of the Indus Basin covering an area of 1.15 Million Km2. The irrigation system in the Indus basin is perhaps world's largest integrated and physically contiguous system, in a densely populated region. Another ICID publication titled "Danube Valley: History of Irrigation, Drainage and Flood Control" (2004) presents a chronological evolution of the history, art, science and technique of irrigation, drainage and flood management in the riparian countries of Danube River, viz., Austria, Germany, former Czechoslovakia, Hungary, former Yugoslavia, Bulgaria and Romania from the olden times to the period up to 1980.

I am sure this book will be of great benefit to many practitioners around the world.

Happy reading!

Prof. Dr. Ragab Ragab
President, ICID

Preface

This publication on "Historical water sustainability", as an output of the 'Working Group on History of Irrigation, Drainage and Flood Control (WG-HIST)', aims to promote the practices and concepts of historical water sustainability. It is emphasised that sustainable development is related to an evolving process which promotes adaptability to changes and innovation to create opportunities for the future. The evolutionary paths followed in different regions of the world are highly influenced by the prevailing climatic, topographic and agricultural conditions. The adoption of path to sustainability also gets influenced by scientific temper and socio-political and economic conditions. The attempt has been made to compile experiences from a diverse set of countries reflecting a bouquet of conditions. Accordingly, fourteen member countries, namely, China, UK, Thailand, Iran, The Netherlands, Malaysia, Japan, Italy, Indonesia, Central Europe, South Africa, India, Korea and Hungary, contributed their chapters to enrich the contents of this publication. This benchmark publication of its kind is expected to enlighten the professionals engaged in Irrigation and Drainage sector of its uses and opportunities in sustaining agricultural water management thereby enhancing the benefits from the lessons learned from historical irrigation/drainage projects worldwide.

The Chairman of the 'Working Group on History of Irrigation, Drainage and Flood Control (WG-HIST), Dr. Kamran Emami (Iran), was pivotal in pushing the concept of "Historical water sustainability" in ICID. He organized numerous seminars and workshops during ICID Annual Events and eventually providing the leadership in bringing out this publication. My special thanks are due to Vice President Hon. Dr. Kamran Emami. My special appreciation is also due to Er B.A. Chivate (Director – Technical) for reviewing the manuscript. Thanks, are also due to the ICID Central Office team and others for their dedication in bringing out this publication. My profound thanks are also due to Dr. Vijay K Labhsetwar, the then Director at ICID, for providing support in organizing the seminars/workshops and lastly meticulous editing of the final manuscript and brining this publication to its final shape. We hope that this ICID publication becomes an important constituent in your repertoire.

Er. A. B. Pandya
Secretary General, ICID

Introduction

The 21st century would be very distinct from the other centuries in the history of mankind. According to Dr. James Martin (2007), an entrepreneur and founder of the 21st Century School at the University of Oxford in his crowning achievement, “The Meaning of the 21st Century: A Vital Blueprint for Ensuring Our Future”, “We are at an extraordinary crossroad of human history. Our actions, or failure to act, during the next decades will determine the fate of the Earth and human civilization for centuries to come. This is a make-or-break century”.

The latest data from WRI’s Aqueduct Water Risk Atlas (August 2023) show that 25 countries — housing one-quarter of the global population — face extremely high water stress each year, regularly using up almost their entire available water supply. And at least 50% of the world’s population — around 4 billion people — live under highly water-stressed conditions for at least one month of the year.

Without better water management, population growth, economic development and climate change are poised to worsen water stress. Numerous civilizations flourished and vanished over a period of time because of the way they managed their water. According to DIKW pyramid[1], unlike industrial concepts, water wisdom may take decades or centuries to be established. In this context, the proven water wisdom of the past, which was achieved over a period of thousands or hundreds of years, can be regarded as a unique and irreplaceable gift from our ancestors to this generation facing the great challenge of ensuring sustainable development. The synergy of International Working Groups consisting of Multi-Discipline experts presents unique opportunities for drawing universal lessons learned especially in the framework of water sustainability. In this context, WG-HIST has been committed to publishing a book on “Historical Water Sustainability” reflecting the “universal strategies” of ensuring sustainability of various historical water schemes in different countries. As the chairman of WG-HIST, I was entrusted with challenging tasks of reviewing and editing the all chapters and preparing the Executive Summary. I have been involved in this process for the last 2 years. It has been a daunting task but I had an amazing journey: from astounding terraces of China to Marib dam in Yemen, from Qanats of Iran to Roman Aqueducts, from Cavour Canal in Italy to Water tunnels of Bali, from Ambitious dams of Sri Lanka to water tanks of Thailand, from a drained lake in Netherlands to creative levees of Japan, from the evolution of hydraulic engineering in Europe to exceptional high arch dam in Iran, from flood management of Hungarian farms to irrigation schemes of South Africa and …, I have been deeply impressed by the fortitude, courage, determination, wisdom and creativity of the societies involved. I am hopeful that the lessons learned can inspire engineers, scientists, managers and all who are facing the most important water challenges of 21st century.

Kamran Emami (PhD)
Vice President Hon., ICID
and Chair WG-HIST

1 The DIKW pyramid, refers loosely to a class of models for representing purported structural and/or functional relationships between data, information, knowledge, and wisdom. "Typically, information is defined in terms of data, knowledge in terms of information, and wisdom in terms of knowledge"

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Dedication

This publication is dedicated to the people living in extreme poverty with passion, audacity, hope, and fortitude and to all engineers, scientists, researchers, teachers, and artists who, by virtue of their expertise, creativity, and ethics, can take hold of the helm of the ship of the history and changing its course for the benefit of all humanity.

Acknowledgements

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Executive Summary

PRELUDE

Evidence of the earliest hominins, the ancestors of modern humans, has been found in Central and East Africa, and dates back millions of years. Discoveries of early human remains reveal the remarkable ability to adapt to the Earth's changing environment that has been so significant in the evolution of our species. As the glacial period of the Ice Age ended, habitats became warmer and more stable and humans experimented with new ways to feed themselves. By 12000 years ago some groups began to cultivate their own flood sources. Subsequently domestication of plants and animals spread through the continents in the following millennia. Now in early decades of 21st century, in the face of the great challenges of the mankind, we need wise visions, creativity, vigilance and adaptability more than ever.

The 20th century was the century of explosive population growth, resulting in unprecedented impacts. At the start of the 21st century, humankind finds himself on a non-sustainable course – a course that, unless changed, will lead to catastrophes of terrible consequences. We are at an extraordinary crossroad of human history. Our actions or failures to act during the next decades will determine the fate of the human civilization for centuries to come. This is a MAKE-or-BREAK century!

According to a 2020 World Economic Forum (WEF) article, COVID-19 offers an opportunity to "reset and reshape" the world in a way that is more aligned with the United Nations 2030 Sustainable Development Goals (SDG), which necessitated urgent action in respect of climate change, inequality, and poverty. Another post-COVID concern raised by the WEF is food security.

The United Nations Sustainable Development Goals (SDGs), adopted in September 2015, are targets set to be achieved by 2030. Most countries of the world have agreed to work together towards achieving these goals. Water, as the main input for food production, has played the most significant role in the societal evolution over much of the recorded human history. Numerous civilizations flourished and vanished over a period of time because of the way they managed their agricultural water. By being, a direct or indirect, part of 7 out of 17 SDGs, water assumes inclusive dimension both as a natural resource for rural development and an essential input for industrial and human (life-style) consumption. In this context, ICID Vision 2030 of "A water secure World free of poverty and hunger through sustainable rural development" has been defined and a relevant roadmap has been developed in 2017.

In the context of ICID Vision 2030, the proven water wisdom of the past, which was achieved over a period of thousands or hundreds of years, can be regarded as a unique and irreplaceable gift from our ancestors to this generation facing the great challenge of ensuring sustainable development. In this context, WG-HIST has been committed to publishing a book on "Historical Water Sustainability" reflecting the universal strategies of ensuring sustainability of various historical water schemes in different countries. Accordingly, 17 chapters were presented by the members of the Working Group from Netherlands (2), Iran (2), Indonesia, China, Malaysia, Germany, Japan, UK, Thailand, Italy, South Africa, India, Hungary, Korea, and Sweden. The synergy of International Working Groups consisting of Multi-Discipline experts presents unique opportunities for drawing universal lessons learned especially in the framework of water sustainability. As the chairman of WG-HIST, I was entrusted with challenging tasks of reviewing and editing the all chapters and preparing the conclusions chapter. I have been involved in this process for the last 2 years. It has been a daunting task but I had an amazing journey: from astounding terraces of China to Marib dam in

Yemen, from Qanats of Iran to Roman Aqueducts, from Cavour Canal in Italy to Water tunnels of Bali, from Ambitious dams of Sri Lanka to water tanks of Thailand, from a drained lake in Netherlands to creative levees of Japan, from the evolution of hydraulic engineering in Europe to exceptional high arch dam in Iran, from flood management of Hungarian farms to irrigation schemes of South Africa and …, I have been deeply impressed by the fortitude, courage, determination, wisdom and creativity of the societies involved. I am hopeful that the lessons learned can inspire engineers, scientists, managers and all who are facing the most important challenges of 21st century.

The question now is, when we look at a recently constructed irrigation system, how can we estimate the chances that it will still be operating after hundreds of years? What lessons can the history of irrigation bring to the question of why some irrigation systems have long lives of as much as a thousand years, while others fail and go out of use after quite brief periods?

ADAPTABILITY DUE TO UNCERTAINTIES, CHANGING CONDITIONS AND LACK OF KNOWLEDGE IS THE KEY TO SUSTAINABILITY

As presented in all the chapters of this publication, a common trait of historical sustainable water schemes in their life cycle of hundreds of years, is the ability to cope with unforeseen circumstances and uncertainties. The relevant processes are dynamic through time rather than dealing with static goals and variables. In this context, it appears that previous generations were more adaptable than the present generation that is more or less too confident in technically assumed steady state. This is emphasized in Chapter 3:

“The historical evidence about management of irrigation systems is inadequate in many ways, but it does indicate that there have been various threats to sustainability. These threats are not constant. The conditions within which an irrigation system and its users must function will always be liable to changes. External changes, in the political system, or the demands for crop products, or other matters, have often been more significant than the internal behavior of each system’s management. The lesson from this is that management arrangements, such as governance, constitutions, and finance, should be flexible, and able to adapt themselves swiftly to new challenges”.

- **Chapter 3:** “An irrigation system comes under many kinds of stress, due to external factors and internal factors. To be sustainable in the long term, it needs management arrangements that are flexible, and can adjust to cope with changing circumstances.”
- **Chapter 13:** “The country’s irrigation history has shown that South Africa’s farmers are innovative and adaptable to difficult circumstances. The case studies presented here demonstrate that sustainable irrigation is achievable through adoption to changing markets, changes in investment and adjustment in the size of farmers as well as in the size of farms as well as improvements in management”.
- **Chapter 16:** “With the constantly evolving political and economic patterns of India, the administration and financing of irrigation projects has undergone many changes and modifications”.
- **Chapter 17:** The situation changed substantially after the First World War in which Hungary was on the side of the defeated powers. In addition to the substantial loss in human live, the Peace Treaty imposed on Hungary in Trianon significantly re-drew the borders of the country. Most of the country reduced to one third of its size was concentrated in the central part of the Carpathian basin which resulted in significant changes in its water management practices
- **Chapter 14:** Even the Dutch people who are the pioneers of floods management for ten centuries had to change the flood strategies many times: “The Room for the River concept, adopted in 2000 by the Dutch government. This marked a shift from traditional flood risk measures heavily depending on dike strengthening to a much broader approach, aimed at increasing water discharge capacities during extremely high river stages. The latter are expected to materialize more often than in the past, due to climate change. Its aims are a peak flood level reduction of 20 - 30 cm, ecological restoration, and nature development. More than 30 projects have been initiated, such as dike relocation, floodplain excavations, the construction of flood bypasses, the creation of flood storage capacity and, in a few cases, traditional dike strengthening. The Room for the River programme has been developed in a network approach, involving provinces, local governments, and Water Authorities, and in cooperation with a variety of other stakeholders”.
- **The conclusion of chapter 14** is emphasizing the adaptive management approach for flood management: “It will be relatively easy to cope with the impacts of climate change. The big question will be whether our society can and will continue with the careful maintenance and management of the past ten centuries. When we will be able to do this and timely take the appropriate improvement measures, we can continue to live in our low country for many centuries to come”.

- Most of the drastic changes in flood management approaches initiated after devastating event as presented in Chapter 17: “Because forests were cut down over the centuries in the catchment area, flood levels rising relative to previous ones and damage done by them spurred Parliament to take action. In response to the catastrophic icy floods on the Danube in Pest-Buda in 1838 and the devastating damage often done in the river-system of the Tisza, an Act on Regulating the Danube and other rivers was adopted in 1840 and a committee was set up to review the financial and the technical conditions of the task. This was the starting date of the comprehensive regulation works in the Carpathian Basin, before which only isolated activities had changed”.

The basic principle of “Adaptive water resources management” which has been increasingly adopted since early 20th century is as follows:

> *“Characterized with uncertainties, changes, and complexity, the issue of sustainable development is considered as a dynamic process which is evolving through a learning process and not as any kind of optimum or end-state of a system”.*

Finally, is should be pointed out that ICID has established a working group on “Adaptive Flood Management” (WG-AFM) in 2018.

ERADICATE EXTREME POVERTY FOR ALL PEOPLE EVERYWHERE TO ENSURE SUSTAINABILITY

As illustrated by many historical case studies, sustainability and poverty are mutually exclusive. Poverty leads to degradation of the ecosystems through inappropriate use of the resources and prevention of capturing the available potentials, thus depriving vulnerable groups from essential goods, and accelerating both the downwards spiral of poverty and environmental degradation. On the other hand, a sustainable society is the right foundation for eradicating poverty by enhancing social cohesion, capacity building, technology transfer, … and by financing the design, construction, and operation of required substructures. The Brundtland Report stated that critical global environmental problems were primarily the result of the enormous poverty of the South and the non-sustainable patterns of consumption and production in the North. The three main pillars of sustainable development include economic growth, environmental protection, and social equality. The report started from the premise that development and environment were inseparable issues; that it was useless to deal with environmental problems without looking at poverty and international inequality. In this context, it is very appropriate the Goal 1 of UN Sustainable Development Goals is: **End poverty in all its forms everywhere** and ICID vision 2030 is: **Water secure world free of poverty and hunger through sustainable rural development.**

INTERGENERATIONAL EQUITY AND RESPONSIBILITIES

Sustainability refers to the ability to meet the needs of the present without compromising the ability of future generations to meet their own needs. As it involved a strong element of intergenerational equity, the sustainable development must be interpreted as development that creates fairness within and between generations and consequently is based on mutual responsibilities. A journey through the historical evolutions of most of the sustainable projects presented, illustrates the importance of this mutual responsibility. A balance between effective construction and efficient long-term operation is prerequisite of sustainability and can be struck by intergenerational equity and mutual responsibilities.

As an example, chapter 11 presents Subak: “Despite the absence of information about the exact date of the first establishment of Subak as an ancient organization for managing irrigation system in Bali Island, yet, the local people had been implementing this distinct irrigation based agricultural practices from generation to generation for centuries till present”.

Intergenerational interactions, or the interactions between different generations, can play a significant role in achieving sustainable development. Different generations often have different perspectives, needs, and priorities, and working together to address shared challenges can help to build consensus and ensure that the needs of all generations are considered.

There are several ways in which intergenerational interactions can contribute to sustainability:

1. Sharing knowledge and expertise: Different generations may have different knowledge and expertise to offer, and working together can help to create a more comprehensive and nuanced understanding of issues and challenges.
2. Promoting understanding and dialogue: Intergenerational interactions can help to build understanding and dialogue between different generations, fostering mutual respect and cooperation.
3. Ensuring that the needs and interests of all generations are considered: Working together can help to ensure that the needs and interests of all generations are considered in decision-making, promoting a more inclusive and equitable approach to sustainability.
4. Building long-term vision and planning: Intergenerational interactions can help to build a long-term vision for sustainability, ensuring that the needs and interests of future generations are considered in decision-making.

Overall, intergenerational interactions can play a valuable role in promoting sustainable development by bringing together diverse perspectives and ensuring that the needs and interests of all generations are considered.

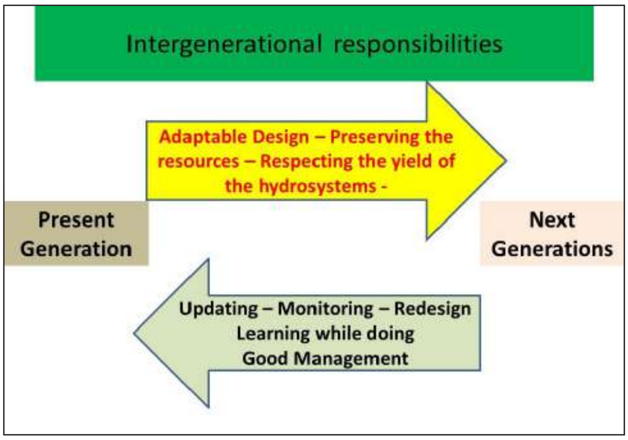


Figure E1. Intergenerational equity and responsibilities

Ethics and Integrity

Many historical sustainable schemes reflect deep rooted ethics in many aspects:

- Ethics towards future generation
- Ethics towards environment
- Ethics towards the society
- Engineering Ethics

In many arid regions of Iran with annual precipitation of less than 100 mm, the societies that have sustained over centuries, have demonstrated strong traits of hardworking, equanimity, contentment with moderated consumption and fortitude for long-term goals. The mentioned traits can be attributed to the accumulated wisdom and ethics of the society (Chapter 5).

Engineering is a bridge over which humankind passes into nature to understand it, control it, and guide it to its own field of interest and service. Sustainability is the balanced pursuit of ecological health, social equity, and economic welfare and consequently "Engineering Ethics" can play a pivotal role in ensuring sustainability. The author has devised a special conceptual formula for the synergy of expertise, creativity, and ethics in engineering of large projects:

- Expertise= 10
- Expertise + Creativity= 100
- Expertise + Creativity + Ethics = 1000

It should be emphasized that sustainable development is related to an evolving process which promotes adaptability to changes and innovation to create opportunities for the future. In this regard, classical science fails to touch the issue due to its fragmentation, relying on the concepts of equilibria and optimality, and dependency on forecasting to deal with uncertainty. In this context, ethics has to be considered in order to develop moral values to deal with humanitarian aspects of sustainability.:

> *'Science can show what probably is done; technology can show what might be done; but ethics can help humankind decide what should be done'.*

According to Max-Neef's hierarchy of science, there are four levels of scientific areas (Max-Neef, 2005). The first or empirical level is associated with the areas such as Physics, Biology and Economics, which would explain What exists in the world. The fields such as engineering, agriculture and commerce, which are situated in the second or pragmatic level, are dealing with What we are capable of doing. In the third or normative level, the areas of science such as law, planning and politics will explain What it is we want to do. Finally, in the fourth or value level, the fields such as philosophy and ethics will deal with What we should do; or, how we should do what we want to do. This implies that sustainability is not fundamentally a scientific or technical issue; it is a political act, an issue of human behavior, and negotiation over preferred futures, under conditions of deep contingency and uncertainty. Consequently, Engineering ethics and sustainability are important components of engineering education that should be addressed by higher education authorities.

It is appropriate to conclude this section by an experience indicating the passions of water engineers for their projects from Chapter 13:

> *"The Loskop Dam comprises a mass concrete gravity wall with an ogee crest spillway. The original dam wall was 45 m high, but was raised in 1979 to 54 m. A note of interest is the fact that the ashes of the original Resident Engineer, Lt Col DF Roberts, are buried in the dam wall (Van Vuuren, 2008)".*

"ENDURING FINANCES"

In the context of water history, "enduring finances" such as stakeholders supports, water rights, voluntary or forced labor, parts of the harvests etc. played a key role in providing required funds for the projects in a the long-term especially when that financing arrangements were fair and equitable. One the other hand, for large projects, the governments' funding for construction were vital:

- **Chapter 10:** The agreement between the Italian government and some English and French financiers for the realization of the canal can be considered as a solid foundation for rapid construction of 82 km long canal in just 3 years. The company committed to finance the sum of 80 million lira for executing the project which was the longest canal in Italy till 1955.
- **Chapter 3:** The desilting of the Ma'rib dam must have been a huge operation. Labour forces of 20,000 had to be assembled at long intervals

to perform the tasks. It is quite possible that part of such a large force would be obtained by capture of men in wars with neighbor states; but it seems sure that a strong state was necessary, and that the task of desilting became more difficult, and probably less frequent, as the state weakened.

- **Chapter 3:** The 12th century kings of Sri Lanka over-stretched the state budget, in their expenditure on reservoirs and other large public projects. This led on to failure and collapse. The kingdom had been able to collect resources that were sufficient for the capital construction of great reservoirs; but keeping those works in good order, with proper maintenance, required further continuous involvement of the state, and this could not be delivered.

- Siraf, an ancient Sassanid (3rd to 7th century) commerce hub, was the largest and the wealthiest port city on the Iranian side of the Persian Gulf during its heyday. It remained a regional trade center until the 16th century, after which it declined in importance. In the adjacent rock mountains, unbelievably extensive rainwater harvesting systems and waterworks (Figure 2#) have been constructed for storing and transferring limited water available to the port. Undoubtedly the affluence of the port was the key to sustained construction and operation of the mentioned waterworks.

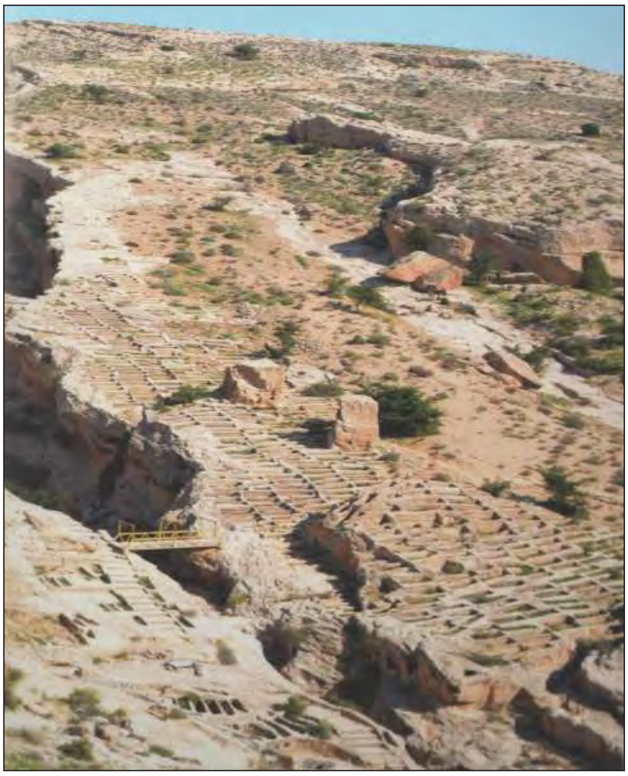


Figure 2#. Extensive rainwater harvesting systems and waterworks

At the first glance "sustainable development" may be considered as paradox and a conflict of environment conservation and economic development, but the resolution of the conflict is not impossible. In the evaluation of the Life Cycle Cost, the present value of the revenues or costs in the 50th years of operation of a water project is less than 1% of the corresponding value in the first year and consequently can be considered as negligible. But in the context of sustainability, they are by no means negligible. This contradiction can be an opportunity for sustainability if the project can be financed by the private or public entities. With reduced official bureaucracy and budget limitations, the project can be designed, constructed, and operated with consideration of all key environmental factors. In the context of a fair agreement, the financer can reap the benefits of the investment in the first years of the operation which is substantial in the context of the present value. Then the project can be handed over to the business-as-usual environment. If properly planed, designed, constructed, and operated, this scheme can prove to be a "sustainable development."

WE CAN ACHIEVE THE UNTHINKABLE!

There are numerous hard and soft historical water schemes and projects that were far ahead of their time. Undoubtedly these can inspire many water engineers, managers, and scientists all over the world:

- **Chapter 2:** A total area of 60,000 mu of terraced fields were distributed in hillsides with the vertical height of 500 m and with more than 1000 terrace levels.

- **Chapter 10:** The 82 km long Cavour Canal in Italy was constructed in just 3 years in 1860s along with 101 bridges, 61 flumes and 201 siphons! The project was constructed by private finance.

- **Chapter 5:** Gonabad qanat is one of the most famous qanats of Iran. According to some archaeological evidences its construction dates back to the Achaemenid era (3rd – 4th century BC), and it has been active for 2400 years. There are 182 shaft wells on the main branch and the total number of qanat shaft well amounts to be 427. The qanat is 11,579 m long (the distance between the mother well and the mouth). The depth of the primary mother well is more than 150 m, though some references suggest a depth of 300 m.

- **Chapter 5:** This article shows that the existence of 37000 qanats in Iran heralds their sustainability. Some qanats go back to over 1000 years in antiquity, and they are still in active use.

- **Chapter 9:** 60 m high Kurit arch dam construct in 14th century in Iran was the highest dam in the world for 550 years till 1904. It is estimated that the dam could have been overtopped more than 1000 times in 650 years and has resisted a devastating earthquake with maximum ground acceleration of 0.75g. These are indicative of the resiliency of the structure which has been introduced in the last decades of 20th century.

- **Chapter 8:** Rice irrigation system has been operated and maintained in Japan over the last 2500 years without suffering from major breakdowns, supporting the food production and livelihood of its population. The preservation of the balance of forests and rice fields in Japan throughout hundreds of years and way before the evolution of the environmental science is astounding.
- **Chapter 2:** In china, mountains regulated by the villages are considered the sacred mountain and deforestation was strictly restricted. Hani generations' rituals are about the Water God worship. Their ritual festivals are arranged at the time for rice planting, flowering, and harvesting. These practices become the genes for terrace culture heritage.
- **Chapter 3:** In Babylon, probably about 1760 BC, the codes of laws given by King Hammurabi were carved on to a great stone (Richardson, 2000). Four of these laws dealt with irrigation. The first of them specified punishment for neglecting maintenance. Such severe treatment of offenders shows that the importance of maintenance, and the dangers of neglecting it, were already well understood, nearly 4,000 years ago.
- **Chapter 3:** The Great Dam of Ma'rib, in Yemen was operational for 1000 years. This dam was one of the largest built in ancient times, and it had a long life. It probably existed from the 5th century BC, and it performed its function of storing water from the wet season, for release to its dependent irrigation systems in the dry season, until the early years of the 7th century. The dam lay on the eastern side of the Yemen plateau, where flows would be variable and could carry large amounts of sediment. A dam in such a position would need frequent maintenance, changes of its spillway and so on, to respond to sedimentation within its reservoir. The desilting of the Ma'rib dam must have been a huge operation. Labour forces of 20,000 had to be assembled (Brunner, 2000), at long intervals, to perform the tasks. Thanks to the excellent operation and maintenance, the dam structure itself, and the irrigation services it delivered, proved to be sustainable, over a period in the order of a thousand years.
- **Chapter 3:** Despite very great changes of the political and religious environments, the irrigation system of Valencia has survived for a duration that may be approaching a thousand years. In the 19th century, when the period of rapid extension of irrigation under state sponsorship was beginning, people came to Valencia from various other countries to seek inspiration from its management techniques.
- **Chapter 4:** In Thailand, the laws and regulations of irrigation are now known as 'Sanya Muang Fai' or muang fai agreement was developed and adjusted to use in the People's Irrigation System in Lanna areas till now.
- **Chapter 14:** One quarter of Netherlands lies below sea level, and over the centuries the Dutch have devised an intricate network of measures to protect against inland flooding and coastal storms. In fact, first water board (waterschappen) was established as far back as 1255 in Leiden as a means to oversee levees developments and maintenance.
- **Chapter 6:** Over the past more than 400 years the Beemster has proved to be sustainable, while the stakeholders have proven to be able and willing to financing and taking care for the water management and flood protection systems.
- **Chapter 8:** To ensure proper and long-term maintenance of Shingen levee and flood protection work in 16th century nearby villagers were relocated in this area to carry out maintenance and rehabilitation works of the constructed system, who were exempted from tax and other duties of the farmers.

We can achieve the unthinkable, but it takes:

- Vision
- Intuition and expertise
- Collective action
- Financial support system
- Good governance (for large schemes)
- Long-term commitments for O&M.
- Audacity
- Fortitude
- Optimal use of local conditions

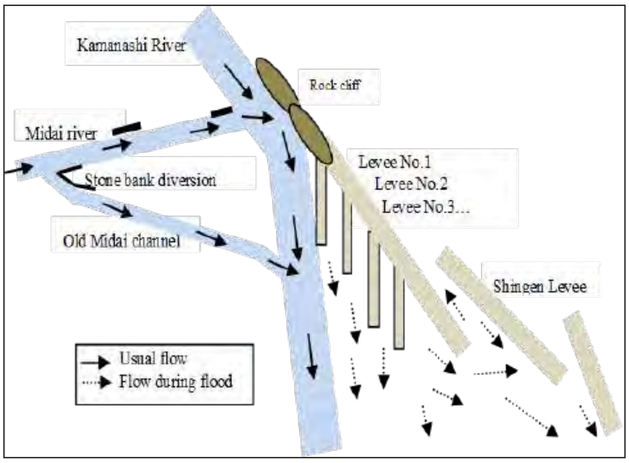


Figure E2. Layout of Shingen levee and flood protection work

THE SYNERGY OF WATER ENGINEERS AND POLITICIANS

In many cases the short-term objectives of the politicians can jeopardize the sustainability of the water scheme in the long-term. As an example, due to high costs of irrigation projects, there has always been a historic tendency to avoid or defer the added cost of installing adequate drainage. Secondly, in state-installed irrigation systems there is often a political dimension to decision-making. In this case, the state chose to deliver water to as large several villages and communities as possible, even though that meant supplying it in quantities that were less than adequate in a technical sense. On the other hand, engineers are committed to long-term safety and functionality of the schemes and thus conflicts with the politicians arise. Still the synergy between politicians and engineers are possible especially when a vigilant and conscious society impose appropriate laws and regulations through democratic representatives. Liberal constitution of Netherland in 1848 limiting the power of the monarchs in design and construction of substructures serves as a vivid example. Finally, it should be pointed out that large capitals of governments can be an opportunity or a threat for sustainability of water projects

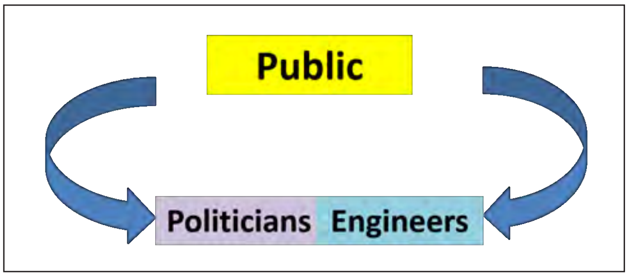


Figure E3. The synergy of public, Politician and engineers in large projects

STRIKING A BALANCE BETWEEN CONSTRUCTION VS. OPERATION

Marib dam and Sri Lanka dams in P12-13

A Common mistake in water engineering is allocating most of the resources in construction and underestimating the financial requirements for proper O&M. From Sri Lanka dams to water tunnel of Bali and from and Ma'rib dam in Yemen to present day mega projects, lack of finance for appropriate O&M is evident:

- **Chapter 3:** The 12th century kings of Sri Lanka over-stretched the budget, spending capital resources on too many big new projects, for which the cost of maintenance would be excessive. De Silva (1981) described 'a conspicuous lack of restraint' by the kings (de Silva, 1981), in their expenditure on reservoirs and other large public projects. This led on to failure and collapse. The kingdom had been able to collect resources that were sufficient for the capital construction of great reservoirs; but keeping those works in good order, with proper maintenance, required further continuous involvement of the state, and this could not be delivered. Another possible explanation of the failure is the spread of malaria through the population around that time and climate change. These explanations are not mutually exclusive, and it seems quite possible that all three of them may have had some role in the abandonment of the reservoirs and their irrigation lands. Indeed, one of the first efforts to resuscitate one of the reservoirs – the setting up of a private company in 1920, to restore and use the 4th-century Minneriya reservoir – failed quickly, due largely to the continuing prevalence of malaria, which could not be combated effectively until another two or three decades had passed.
- **Chapter 3:** In the context of unbalanced costs of construction and operation in recent years, some alarming effects within the irrigation bureaucracies have emerged. The best staff wanted to work in the active fields of design and new construction, where earnings, and the prospects of promotion, were high. The fractions of staff resources that were devoted to operation and maintenance decreased, and those staff tended to be older. Maintenance especially tended to be neglected.
- **Chapter 3:** The failure of the Great Dam of Ma'rib, in Yemen, in the 7th century, was a great and dramatic event (Wolfrum and Wolfrum, 2001). The dam lay on the eastern side of the Yemen plateau, where flows would be variable and could carry large amounts of sediment. A dam in such a position would need frequent maintenance, changes of its spillway and so on, to respond to sedimentation within its reservoir. The desilting of the Ma'rib dam must have been a huge operation. Labour forces of 20,000 had to be assembled (Brunner, 2000), at long intervals, to perform the tasks. It is quite possible that part of such a large force would be obtained by capture of men in wars with neighbour states; but it seems sure that a strong state was necessary, and that the task of desilting became more difficult, and probably less frequent, as the state weakened, until at last it was insufficiently done, and the irrigation system was overwhelmed in a high flow. So, this seems to be a case where sustainability persisted while the state was wealthy, but was lost in a time of economic weakness.
- **Chapter 3:** When the state weakens, its capacity for dealing with the complexity of irrigation management is reduced. Cases as far apart as Polonnaruwa in Sri Lanka and Ma'rib in Yemen provide evidence of this.

- **Chapter 11:** In Indonesia, since the economic depression in 1997, the capacity of the government to finance the O&M of water resources infrastructures became decreasing. This was due to the increasing number of community-based irrigation infrastructures that are becoming the government burden. The problem has been apparent when the government intervention to rehabilitate and improve the O&M, by virtue of centralistic decision-making approach, with was substantially increasing the government burden. This approach had apparently been increasing the dependency attitude of the water users on O&M, including dependency attitude on the financial responsibility.

MONITORING AND ADAPTATIONS FOR SUSTAINABILITY

The profession of hydraulic engineering is quite ancient and most of the early civilizations are inconceivable without the advances it had made possible. For thousands of years, the skills that went into hydraulic engineering were a precise observation of nature, experience, and intuition. Our ancestors did not have the present sophisticated technologies for monitoring the hydro systems. Still, they were much closer to the Mother Nature compared to the modern engineers and they were much more adaptable to unforeseen changes. Through centuries the resulted learning process evolved to water wisdom that can even assist the modern engineers and managers. On the other hand, good management, and fair distribution of water in all historical schemes required some kind of measuring mechanism:

- **Chapter 15:** Rainfall measurement is one of the most important factors in irrigation. In 1441, cylindrical rain gauge was invented for the first time in the world, and measurements were made at several places in the country for the next 100 years. But measurements discontinued and records destroyed due to invasions from neighboring countries in 1592 and 1636. The measurements restarted in 1770 and continued until 1907 for 137 years and its records kept well.
- **Chapter 5:** The qanat of arch has a perfect system of water-rights measurement and ownership. The cycle of irrigation of this qanat is once every 15 days, in other words, each farmer can use his water right every 15 days. These cycles amount to 24 rounds per year. Each round is 140 joreh and each joreh is broken down to 6 dongs or shares. So, the 15 day's cycle of water consists of 12,600 shares or 2,100 joreh. It is worth nothing that some of the stakeholders of the qanat rent out their water rights to farmers. Sometimes the irrigated lands exceed the water right and farmers are forced to rent some water under the supervision of the qanat manager.

Floods were a great threat to many historical water schemes and consequently farms closely monitored them and stayed vigilant before and during large floods:

- **Chapter 14:** Even in 18th century, the Dutch had very sophisticated schemes for monitoring and strengthening the dike during high floods and warning and evacuation procedures were highly organized and developed.
- **Chapter 17:** The main strategies of Hungarian farmer for coping with floods are as follows:
  - Traditional farming in the flood area
  - Farming above the flood level
  - Rational farming in the areas protected from floods and in the areas free from floods

Undoubtedly implementing above mentioned strategies required close monitoring, measurements and flood mapping.

- **Chapter 4:** In the reign of King Phra Nang Klao or King Rama III, due to frequently occurred flood in the Central Plain, the King gave a royal initiative to install a stone water level gauge in front of the Tham Mikkarat Temple in Ayutthaya Province in B.E. 2374 (1831) (Figure 11). The measured level was recorded as official

Table E1. Yearly rainfall in Seoul

Year	Yearly rainfall (mm)	Reservoir const.	Rain gauge
1791	1,787	–	
1792	1,517	–	
1793	934	–	
1794	1,206	–	
1795	882	Mansekgeo	
1796	1,425	–	
1797	948	–	
1798	1,156	Mannyeonje	
1799	967	Chukmanje	

messages and used to forecast the economic situation of the country. The stone become has the first water level gauging station of Thailand and still in use for over 170 years.

FOUR LEVELS OF MANAGEMENT

An irrigation system comes under many kinds of stress, due to external factors and internal factors. To be sustainable in the long term, it needs management arrangements that are flexible, and can adjust to cope with changing circumstances.

An irrigation system is sustained by good management. It needs the proper performance of a set of processes that we call governance, organization, operation and maintenance. We can think of these processes as four levels of management which, together, ensure that the physical system performs its expected functions, and remains fit to continue doing so In brief:

- governance means setting strategies, selecting leaders and decision-makers, making decisions about necessary changes, assembling resources of labor and finance, and setting out common rules of behavior as well as procedures for dealing with breaking of such rules;
- organization means forming and controlling teams of people who will execute the tasks of operation and maintenance, and monitoring their outcomes;
- operation means the daily adjustments of water-control equipment to send water through the system from its source and distribute it to its users;
- maintenance means activities that keep all the physical facilities in suitable condition for fulfilling their functions.

Moreover, every one of these four management activities requires an input of resources – labour, finance, equipment. These resources have to be found, continuously, throughout the life of the irrigation system, and the ways by which they are found and used has direct effects on the quality of the management functions.

The synergy of expertise, creativity, and intuition for coping with diverse conditions

Based on the success stories presented in this publication, the pillars of sustainability can be presented as follows:

- People
- Government
- Natural Resources
- Financial Resources
- Laws, Rules and Regulations
- Expertise

Expertise refers to design, construction and operation of water schemes. Undoubtedly expertise is far more important than its relative weight and costs compared to the other pillars. Here is an example related to rapid construction Canal Cavour in just 3 years in 1860s (Chapter 10):

> *'The astonishing speed with which the canal was realized was due above all to the careful planning by state engineer Carlo Noè, extending to the smallest construction details, and also to the skill of the engineers directing the works, and their great experience in the realization of large longitudinal works such as the railways.*

The profession of hydraulic engineering is quite ancient and most of the early civilisations are inconceivable without the advances it had made possible. For thousands of years, the skills that went into hydraulic engineering were a precise observation of nature, experience and intuition.

Reviewing the history of science and technology, it can be concluded that theory often follows invention, and not the other way around. A few illustrating examples are presented in Figure E4. This is the same story in water engineering: "Good practice can be achieved before the development of the relevant theory." For a vivid case study let us turn back the clock 4600 years ago. Sadd-el-Kafara in Egypt was probably built around 2600 BC (Figure E5). It stood about 14 m high and 113 m across and was able to dam between 465,000 to 6,200,000 m^3 of water. The edifice was destroyed by a flood shortly before its scheduled completion and was never rebuilt. For the following 800 years, no other dam projects are known to have been attempted in Egypt (Grabrecht, 1995). As shown in the figure 5, similar to modern earthfill and rockfill dams, Sadd-el-Kafara was provided with core and shell elements. Furthermore, encasing the dam were upstream and downstream walls created from limestone ashlars. The ashlars were set but not mortared in stepped rows resembling stepped spillways in modern dams.

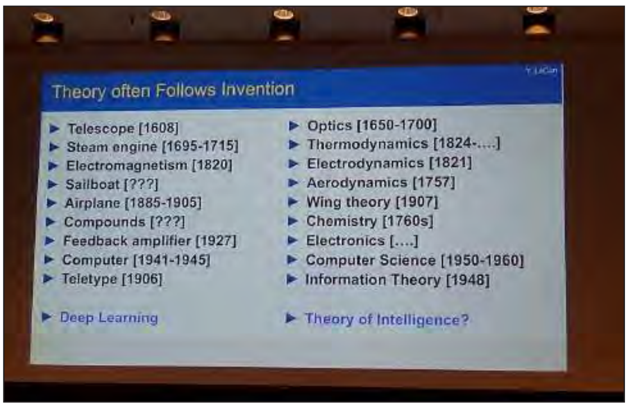


Figure E4. Some examples on precedence of inventions before theory

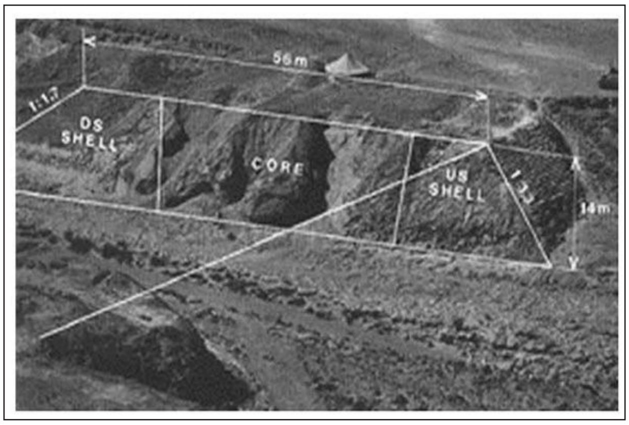


Figure E5. 4600 years old Sadd-el-Kafara resembling a modern earth fill dams

Although the word 'engineer' is derived from the Latin 'ingenium' (talent, ability), the Romans did not have engineers as we know them. The description 'solving challenging technological tasks and the terms 'technical progress' and 'innovation' are often used interchangeably, with 'innovation' certainly being the most comprehensive as it also includes areas outside the technology. Chapter 12 presents the evolution of expertise from intuitive solutions of hydraulic engineering problems to solutions supported by calculations and experimental models. What the engineers of historical schemes lacked in modern science and technologies, they made up for by intuition and creativity:

- **Chapter 5:** The invention of Qanat was the main pillar of sustainability in arid regions of Iran.
- **Chapter 8:** Shingen levee and flood protection work is vivid example of optimum using the local conditions to achieve the main functions.
- **Chapter 2:** The differences of regional topographies, climatic conditions, and water resources are the driven force for invention and creativity of the Chinese traditional irrigation engineering
- **Chapter 5:** The ancient Iranian constructed the earliest underground dams in the world in some qanats near Isfahan and Kashan. The largest of these underground dams is 9 m high and can store about 270000 m^3 in winter for subsequent use in dry season.
- **Chapter 6:** The creation and sustainability of the Beemster drained Lake that already proved to be sustainable for more than 400 years go back to the beginning of the 17th century when a start was made with placing the windmills in a series.
- **Chapter 9:** To avert construction of diversion tunnel, Iranian used to construct the historical dams on a brick arch in narrow canyons. The lower part the dam would be constructed during a dry season. At Abbasi dam site, the lower part was not constructed so during floods the outflow from the dam was automatically regulated. Abbasi retarding dam symbolize creativity and sustainability and can be regarded as a technical jump. Through creativity and persistence, the visionary builders of the structure succeeded in construction of an effective, safe, low cost and sustainable dam that has successfully achieved the main function of the project for the last 600 years. It is likely that the dam would attenuate the floods of Nahrain River for many centuries to come.

The turn of the 20th century also marked an end to predominantly intuitive practice of engineering based on practical experience. Intuition and experience were increasingly complemented and sometimes eventually replaced by calculations, where the intuition needed to be confirmed by the relevant expertise and intensive observation of nature. Since the formulas used in calculations always describe only a part of the natural process, negative consequences of unreflective, practical application are inevitable. Based on numerous case studies the modern water engineers should utilize the synergy of intuition, creativity and modern technologies:

- **Chapter 9:** The successful use of flood retarding scheme of Abbasi dam in the MuKo river in solving the conflicts of flood management and environmental values can demonstrate the need for intuition and creativity in many modern water projects.
- The creative historical scheme of construction of a dam on a bridge was used in 143 m high Kosar dam in South-West of Iran. The scheme reduced the construction time considerably. The main function of the dam is regulating domestic water for cities along the Persian Gulf.

While a strong grasp of science and math is essential to success in engineering, those who truly excel in this field are known for their innovation as much as they are for their technical expertise. Civil engineering requires creativity and versatility. Based on modern experiences, creativity is one of the most important soft skills for an Engineer. Engineers must always think of creative ways to come up with a solution, and they need to use their creativity to envision future innovations. Like any skill, creativity can be trained and improved. In this context, Value Engineers studies have proved to be an efficient and effective methodology for promoting creativity in large projects by saving hundreds of Billions of dollars in developed countries and ICID has established a working group for promoting VE in irrigation, drainage, and flood projects.

Finally, in construction and operation of most of the historical water schemes there was little competition for most talented and experienced engineers and experts but after the industrial revolution, and especially in IT era many gifted persons are choosing professions with better financial prospects rather than water engineering:

- **Chapter 17:** It was typical for the era that while engineers for railroad construction were sought all over the country, engineers with plans for irrigation had to hunt for the customers.

Resiliency is the key for coping with Uncertain risks

To ensure sustainability of a project in the long-term, it should successfully cope with different types of extreme event such as floods, droughts, wars, earthquake, etc. The case studies presented in this publication demonstrate the inherent uncertainties associated with these extreme events. Due to the limited resources and lack the modern science and technologies, the historical water structures could not be constructed to accommodate large extreme events. In this context, resiliency is an important characteristic of most of the historical sustainable structures. The 60 m high Kurit dam which was the highest dam in the world for 550 years is an illustrating example:

- **Chapter 9:** The dam builders of 650 years ago could neither foresee the extreme floods probable during the life of the structure nor excavate a spillway in the rock. Accordingly, they selected the arch configuration which is highly overtopping resistant considering the erosion resistance of the lime masonry. Evidently the dam must have been overtopped frequently as the reservoir volume was much lower than mean annual flow of the river. Old residents of nearby Chirook village say they have seen years with more than 10 overtopping but never a year without overtopping. Accordingly, it is estimated that the Kurit dam has resisted more than 1000 overtoppings in 650 years! On the other hand, although the dam is relative thin with the crest thickness of just 1.2 m, the Kurit dam and Abassi dam have withstood extreme Tabas earthquake with a maximum ground acceleration of 0.75g without destruction.
- **Chapter 14:** When the inhabitants of the lower parts of Netherland increasingly faced floods they started to live on artificial mounds, while during floods the surrounding land was under water. These mounds were gradually raised.
- **Chapter 2:** The key project of Mulan Pei consisted of the dam, spillway weir, flushing gates, and diversion components on the right and left banks of the river. The dam is 111.13 m long and 7.25 m high, along which there are 32 gates. the storage capacity of Mulan Pei is 30 million m^3 with irrigation areas of 13,000 ha. So far, the project has been operational for about 1000 years. There is basically no sedimentation in front of the dam and two inlets are still in the normal use

Even in the 21st century, in view of the effects of the climate change on extreme floods, many dams are designed to adapt to extreme events far larger than design parameters and remain inherently safe:

- Starting in 1980, RCC has been used to hydraulically upgrade more than 60 existing embankment dams (to provide for overtopping) This method has proven both effective and economical (Mclean et al, 1993) (Hansen and Randall, 1999).

The resiliency of water schemes is not limited to structural. Social, operational, economic and ecological resiliencies are also important prerequisite of sustainable development:

- **Chapter 3:** While famous large dams of Sri Lanka face huge sustainability challenges, between 300 BC and 1300, about 15,000 small reservoirs were built in the country (Panabokke et al., 2002). Moreover, it is estimated that about half of these reservoirs are still functioning. Panabokke et al. (2002) describe the contrast between the large, state-governed systems and the smaller, locally-managed systems, like this: "While there was a decline and decay of the major irrigation systems of the dry zone from 1200 AD onwards, these small tank systems continued in varying degrees of utilization and operation, on their own internal organizational strengths".
- The Asian Financial Crisis that occurred in 1997 affected Malaysia severely. Investments in irrigation were severely cut back. Nonetheless irrigation persevered and with continuous 'soft' programs in the form of capacity building and performance assessments.
- **Chapter 14:** In the context of the safety of the extensive and crucial dikes of Netherland in the 21^{st} century, the big question will be whether the society can and will continue with the careful maintenance and management of the past ten centuries. When they will be able to do this and timely take the appropriate improvement measures the can continue to live in the low country for many centuries to come.

Renewable Energy is one of the most important pillars of sustainability

In many chapters of this publications case studies of sustainable water schemes that utilize renewable energy have been presented and it appears that relying on renewable energy have increased the resiliency of the schemes:

- **Chapter 5:** Qanat is a rather sustainable technique to tap groundwater without inflicting any damage on the aquifer. Qanat system works only with the force of gravity and does not consume any kind of fuel unlike pumped wells.
- **Chapter 6:** Historically, windmills in Holland served many purposes. The most important probably was pumping water out of the

lowlands and back into the rivers beyond the dikes so that the land could be farmed. In the fourteenth century, hollow-post mills were used to drive scoop wheels to drain the wetlands. The Dutch windmills originate from the 11th century. The Netherlands used to have 10.000 windmills, nowadays over a 1.000 are still standing and most of them still work. In The Beemster Drained Lake that already proved to be sustainable for more than 400 years, In the middle of the 19th century the paddle wheels were replaced by open Archimedes screws. All in all, for about three centuries windmills have taken care for the water management of the Beemster.

- **Chapter 5:** Qanats not only supply water to the cultivated lands, but also, they have some other economic functions like breeding fish, providing energy for watermills, supplying water to the icehouses, etc.
- **Chapter 2:** In the North China Plain without sufficient surface water, the rainfed agriculture history relying on field irrigation works is at least 3,000 years. China is one of the world's oldest countries to build terraces. The northern rainfed terraces might appear in the 2nd century BC. After the 9th century, the south region of the Yangtze River was gradually developed. With the population increase, lands in hill and mountain regions were gradual reclaimed and terraces for growing rice appeared. Terraces were built from the bottom up and rainfed fields gradually evolved to rice terraces.
- Historical diversions projects utilized in most of the counties relied on renewable energy and many on the were operational for hundreds of years.
- In Yazd, Iran, wind catchers or wind towers were traditional architectural element used to create cross ventilation and passive cooling in buildings. Many of these wind towers are still achieving their main functions hundreds of years after their construction. The wind has been the sole source of energy for these wind towers.

The importance of technology transfer

In the context of role of technology transfer in water sustainability, rice cultivation in Japan serves as an illustrating example. Rice irrigation system has been operated and maintained in Japan over the last 2500 years without suffering from major breakdowns, supporting the food production and livelihood of its population (Chapter 8).

- Rice cultivation started in Japan about 2500 years ago, applying the cultivation technology imported directly from China or via Korea.
- The major technological breakthrough was realized in the 7th century through the application of sophisticated survey and construction techniques and the mobilization of large amount of labor and tools. Systematic application of imported technology through the migrants from Korea, based on the grand design of integrating traditional small irrigation schemes, enabled the technological leap of the ancient period. Such major intervention was only possible with the initiative of a state, which was formed in the central part of Japan at the beginning of the 7th century. Since then, these technology and cultivation practices have been adopted to the local conditions of Japan.
- In the 16th century, water resources development in small and medium sized rivers had almost been completed, and the technologies to develop major rivers and deltaic plains were not available. With the accumulation of knowledge and technology in mining and castle building as well as administering people during the civil war period in the 14th to 16th century, flood control works and development of deltaic plains of major rivers were implemented, which largely expanded the rice cultivation area and production capacity after the 17th century as it is shown in Figure E6.
- The major technological breakthrough was realized in the 7th century through the application of sophisticated survey and construction techniques and the mobilization of large amount of labour and tools. Systematic application of imported technology through the migrants from Korea, based on the grand design of integrating traditional small irrigation schemes, enabled the technological leap of the ancient period. Such major intervention was only possible with the initiative of a state, which was formed in the central part of Japan at the beginning of the 7th century. The process of technology transfer in Japan is illustrated in Table E1. The importance of adaptation and localization of imported technology should not be overlooked.

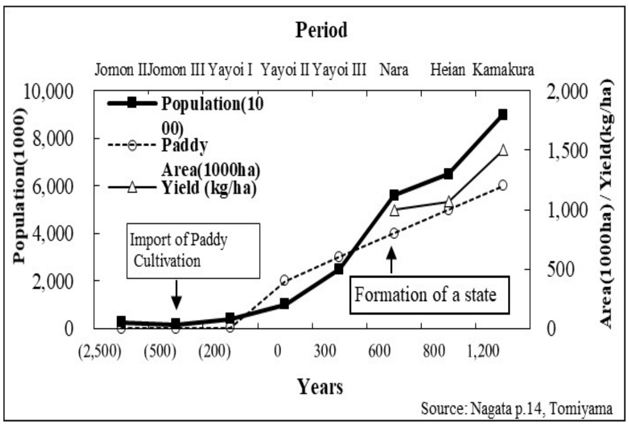


Figure E6. Historical development of paddy fields and population

Table E2. The process of technology transfer in Japan			
	Technology import	**Local adaptation/ internalization**	**Extension to wider groups**
Stake-holders	Immigrants, Priests, scholars	Bureaucrats, Resident warriors, Upper class farmers	Local farmer leaders, farmer groups
Process/ cause	Immigration Official envoy	National isolation, Closure of a country	Involve-ment farmers, Spread of education

- **Chapter 9:** The successful use of flood retarding scheme of Abbasi retardimg dam (Iran) in the MuKo river dam (Japan) indicates that even historical intuition and creativity can be transferred for solving the conflicts of flood management and environmental values.
- **Chapter 9:** The creative historical scheme of construction of a dam on a bridge was used in 143 m high Kosar dam in South-West of Iran. The scheme was initially devised and applied by Iranian dam builders but for Kosar dam, the scheme was proposed by Russian engineers. The scheme reduced the construction time considerably. The main function of the dam is regulating domestic water for cities along the Persian Gulf.

NON -STRUCTURAL ASPECTS (SOFTWARE INSTITUTIONS)

As indicated nearly in all the chapters of this publication, sustainable use of water resources requires not only hardware facilities but also appropriate software institutions in terms of people's groups stakeholders and organizations and regimes and rules as essential components.

The existence of Specific name for the system in many countries indicates the importance of the systems such as:

- Mounfai in Thailand
- Samakumu and Colmatage in Cambodia
- Nawan in Laos
- Komira in Bangladesh
- Torisu in Nepal
- Warabandei in India and Pakistan,
- Kanna in Sri Lanka.
- Waterschappen/Hoogheemraadschappen (water boards) in the Netherlands

In Chapter 11 the merits 'Pranatamangsa' as the ancient practice of Javanese Heritage on Irrigated Agriculture are discussed. It has long been discovered that 'Pranatamangsa' has been strong evidence of the sustainable basis of ancient irrigated agriculture and still adapted now with some adjustment with the most recent implementation condition. Despite the fact no exact evidence about the history of the Pranatamangsa has ever been discovered, this traditional agricultural calendar was known to have been practiced by ancient Javanese farmers long before the Hindu Era in the Indonesian Archipelago. Aartsen (1953) believes that the lowland agricultural pattern for paddy has been practiced in Indonesia for over 2,000 years, and yet it is still comprehended by many rural traditional Javanese farmers today. The basic techniques of the Pranatamangsa are incorporated with the 'simplicity' principles. Simple that every farmer can easily adopt the technique without involving sophisticated learning process.

In this context, the World Water System Heritage (WWaSH) program as a global initiative for the protection of water management systems encompassing people's groups, organizations, regimes, rules, and practices considered as outstanding values to humanity was proposed by Board of Governors (BoG) of the 52nd World Water Council (WWC) in Mexico City.

The proposal of initiating a collaborative program called the World Water System Heritage (WWaSH) as a means for sharing knowledge, based on historical expertise for sustainable water management across all sectors and geographical areas was first brought up by Prof. Yamaoka from Japan.

In reference to the communications on developing WwaSH criteria and guidelines, WG-HIST of ICID has reviewed the available documents and criteria. In the process, considering the non-structural nature of heritage systems, a pointing system based on 10 criteria and relevant indices has been developed for evaluating the candidates (Table E3). The following guidelines are prepared to help the panel evaluate the criteria proposed.

LAWS AND REGULATIONS

The Hammurabi code of laws, a collection of 282 rules, established standards for commercial interactions and set fines and punishments to meet the requirements of justice. Hammurabi's Code was carved onto a massive, finger-shaped black stone stele (pillar) that was looted by invaders and finally rediscovered in 1901. The stele was rediscovered in 1901 at the site of Susa in present-day Iran, where it had been taken as plunder six hundred years after its creation. The text itself was copied and studied by Mesopotamian scribes for over a millennium. The stele now resides in the Louvre Museum.

Hammurabi's Code is a reminder that society's need for law is eternal. The ancient tablet is one of the earliest known written records of laws that give order and shape to human society, and it is by far the most complex.

Four of these laws dealt with irrigation. The first of them specified punishment for neglecting maintenance.

Table E3. The tentative pointing System for Evaluation processes of (WwASH) Program			
Sl. No.	**Criterion**	**Index**	**Points**
1	Sustainability	Years in Operation	20
2	Representing collective Wisdom	Panel Judgment on Ingenuity, Evolution, Innovation, Adaptation and collective effort	10
3	Active stakeholder's Participation	Panel Judgment	10
4	Historical Background	No. of Historical papers on the system and No. of Historical books and/or historical documentaries presenting the system	10
5	Resilience in Adverse conditions	Panel Judgment and review of system response during social, environmental and economic crises	10
6	Specific name in the native language for the system	Name (s)	5
7	Adaptability to local conditions	Panel Judgment	5
8	Universal value to humanity	Panel Judgment, No. of English or French Books and Paper on the system	10
9	Contribution to socio-economic development of the region	Panel Judgment	10
10	Organizational Structure of the system and Documentation processes	Panel Judgment Judgment on the documents available and documentation process	10

Such severe treatment of offenders shows that the importance of maintenance, and the dangers of neglecting it, were already well understood, nearly 4,000 years ago. There are numerous references to the key role of laws and regulation in sustainability of many historical water scheme:

- **Chapter 2:** Mizube style' has become the China's first irrigation law.
- **Chapter 4:** 'When a weir is constructed, it is necessary to have law and regulations under which the management will be effective. Because of this reason, Mangrai Sart or Phya Mangrai's Laws include the regulations on the matter in great details. No matter how good the irrigation is, confusion and dispute can rise if it lacks laws and regulation to control.' Those laws and regulations are now known as 'Sanya Muang Fai' or muang fai agreement. It was developed and adjusted to use in the People's Irrigation System in Lanna areas till now.
- **Chapter 5:** The third secret of qanat sustainability is its effective management and the precise regulations ruling over it.
- **Chapter 8:** At the beginning of Edo period, competition for forest areas/resource became very intense. In the process of resolving competition and confrontation, the custom of using forest as a common was established and prevailed nationwide. However, landlords set the forest regulation of clarifying the border between the forest of the lord and of the community. Regulations were laid down that specified detailed use right where the product can be harvested, number and day or class of people entering the forest, or the size of equipment to harvest the log.
- **Chapter 15:** Government organization for reservoirs and irrigation, Reservoir Administration Unit (RAU) was established in the Joseon Government in AD 15th century. It was responsible for reservoir and irrigation related works; inspection, statistics, preparation of regulations, reporting to the king etc. The total number of reservoirs and ponds in Joseon kingdom was 3,527 in 1728; 3,378 in 1781 and 3,685 in year 1808.

PEACE AS A MAJOR BUTTRESS OF SUSTAINABILITY

The Sistan basin is in south-east Iran and south-west of Afghanistan. For more than 5,000 years the Sistan basin has been inhabited by sophisticated cultures and thus contains some key archaeological sites. The Shahr-i Sokhta, or "Burnt City", in Iran, built in 3100 B.C. near a currently dried-up branch of the Helmand River, was abandoned one thousand years later, most likely due the altered river course. Kang and Zaranj in Afghanistan were major medieval cultural hubs, now covered by sand. Here, signs of historical irrigation systems, including canals, are still visible in the Dasht-e-Margo and Chakhansur areas while elsewhere canals are filled with silt and agricultural fields buried by shifting sand. Today the area is sparsely populated. Till late 14th century, the Sistan delta fed by Helamnd river was a prosperous agricultural hub. After the invasion by Timūr Gurkānī, a brutal Turco-Mongol conqueror who destroyed many water substructures of the region such as Rustam masonry dam, the region never regained the prosperity and importance it enjoyed before the war.

There are numerous similar historical experiences illustrating that peace is an essential foundation for sustainable development, as conflict and violence can disrupt economic and social development and have negative impacts on the environment. Overall, peace and sustainability are closely interconnected, and addressing the root causes of conflict is essential for achieving long-term peace and stability, as well as sustainable development.

As mentioned earlier, in the arid and semi-arid regions of Iran that lack surface water such as Yazd province in Iran, qanats made life possible. As the result of the limited water resources, people had to supplement their income by other vocations such as trade. From the early times the people of the "qanat axis" of Iran understood that in their fragile environments, war and sustainability are mutually exclusive. These developments resulted in peace wisdom and no major military campaign initiated in the region for hundreds of years. Even today the regions are known for their peace and conservative culture.

The developments of Water schemes in Hungary in 18th and 19th centuries serve as another illustrating example (Chapter 17):

- After getting rid of Turkish rule in the 17th century, not only political but natural conditions began to be pacified. German, Slovak, and Serbian settlers were moved to the depopulated areas and the forthcoming more peaceful period that lasted for almost a century saw the beginning of water control works that laid the foundation for economic growth. Flood and river control operations that took place in isolation and hence turned out to be often unsuccessful were given true impetus in the 1840s, with flood control operations along the Tisza River spanning almost half century.

METICULOUS DOCUMENTATIONS OF THE EXPERIENCES, PROCESSES, AND PROCEDURES

As mentioned earlier, in view of the inherent uncertainties of hydro systems, learning and adaptation has been the key to sustenance of many historical schemes. In this context, based on the chapters received Japan, Korea and Netherlands appears to have more robust and meticulous documentations:

- **Chapter 8:** As shown in Figure E7 (Historical development of paddy fields and population), the area of the rice fields and the country population has been estimated for 2000 years!

- **Chapter 15:** In four tables the key information on major reservoirs constructed in Korea as early as the third century AC are presented. The information includes the irrigation area (ha) of the reservoirs to the last digit!

- The Dutch have a worldwide reputation for effective and efficient management of the dikes that protects vast lowlands of their country. Figure E8 illustrating the exact location of dike breaches along the Waal and Meuse in the Betuwe regions, between 1750 and 1820, is indicative of the meticulous documentation of their water projects.

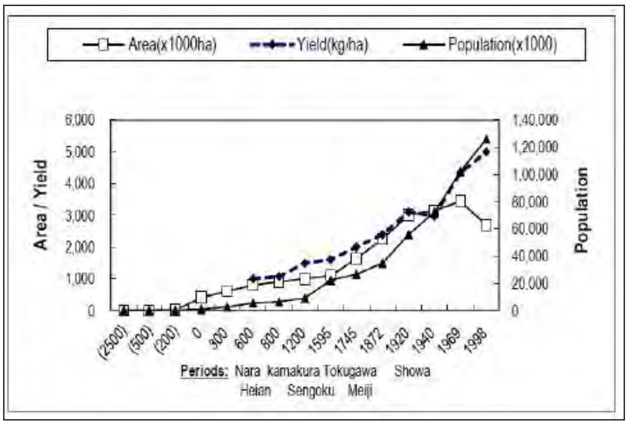


Figure E7. Historical development of paddy area, yield, and population (Sources: Tomiyama, 1993; Nagata, 1994; Yamazaki, 1996)

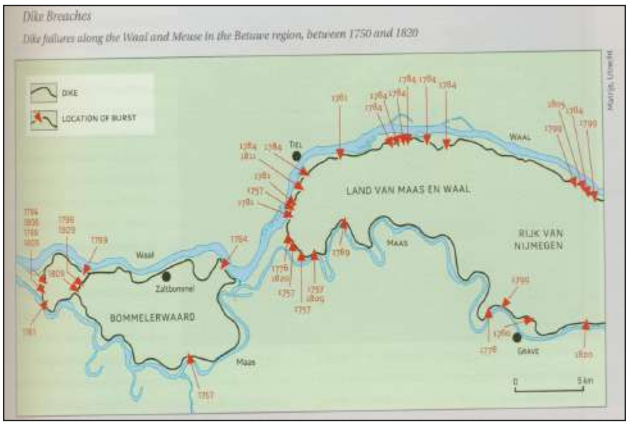


Figure E8. Dike Breaches along the Waal and Meuse between 1750 and 1820

WATER WISDOM AND SUSTAINABILITY

In knowledge management literature it is often pointed out that it is important to distinguish between data, information, knowledge, and wisdom. The generally accepted view sees data as simple facts that become information as data is combined into meaningful structures, which subsequently become knowledge as meaningful information is put into a context and when it can be used to make predictions. This view sees data as a prerequisite for information, information as a prerequisite for knowledge and knowledge as a prerequisite for wisdom. Data are assumed to be simple isolated facts. When such facts are put into a context, and combined within a structure, information emerges. When information is given meaning by interpreting it, information becomes knowledge. At this point, facts exist within a mental structure that consciousness can process, for example, to predict future consequences, or to make inferences. As the human mind uses this knowledge to choose between alternatives, behavior becomes intelligent. Finally, when values and commitment guide intelligent behavior, behavior may be said to be based on wisdom.

With today's sophistication, the time step for a typical data to wisdom process may be a day or a week or a month in industrial cases. But in the context of water engineering, the time step may be a year or a decade or a century. A heritage system is the outcome of collective data to wisdom procedures described and this precious water wisdom can play a key role in enhancing the modern projects. Water wisdom is the understanding and appreciation of the value and importance of water, as well as the knowledge and skills needed to manage water resources in a sustainable manner.

As demonstrated in different chapters of this publication, the effectiveness of the acquired water wisdom has been repeatedly verified in forest conservation in Japan, in land reclamation in Korea and Netherlands, in construction of higher historical dams in Iran, Japan, Korea, China, Sri Lanka, India, and Thailand, and in flood management in Hungary, Netherland, Japan, Iran, and other countries. In this context, even today the water wisdom acquired over centuries should be considered in design, construction, and operation of water schemes:

Chapter 9: Nearly all historical dams of Iran are masonry. Through ages, they have learned that with the hydrological conditions of the country, earth fill dams were vulnerable to large floods in the long-term and the dams should be constructed to resisted overtopping (resiliency). One the other hand, in the past 3 decades, 7 cofferdams of modern dams have failed due to overtopping in the country. Now many clients insist on overtopping resistant cofferdams (a modern water wisdom). If the water wisdom of historical builders had been used in designing the failed cofferdams, much delays and damages could have been prevented.

MULTI-DISCIPLINARY APPROACH AND SYNERGY TO WATER ENGINEERING

The genesis of qanat technology in Iran reiterates the importance of multi-disciplinary approach and synergy to water engineering. During the early first millennium before Christ, for the first time some small tribal groups gradually began immigrating to the Iranian plateau where there was less precipitation than in the territories they came from. They came from somewhere with many surface streams, so their agricultural techniques required more water than was available in the Iranian plateau. In their pursuit of water, they noticed some permanent runoff flowing through the tunnels excavated by the Acadian miners who were in search of copper. These farmers established a relationship with the miners and asked them to dig more tunnels in order to supply more water. The miners accepted to do that, because there was no "technical difficulty" for them in constructing more canals. In this manner, the ancient Iranians made use of the water that the miners wished to get rid of it, and founded a basic system named qanat to supply the required water to their farm lands. Undoubtedly qanat technology could not have thrived without the skills of surveyors, geologist (intuitive), tool makers, diggers, dredgers, construction workers, managers, and operators. The same pattern exits in nearly all the case studies presented in this publication. This look at the history of the engineering profession shows just how closely technological progress and the engineering profession are intertwined and what challenges it has overcome in the past:

- **Chapter 14:** The existential flooding challenges in Netherland induced two major innovation processes: better sluice building technology, developed since about 1300, and more effective polder drainage technology, epitomized in the use of windmills. Windmills geared for the pumping of water, probably introduced in 1408, became scattered over the polder lands and by 1500, 208 windmills were being used. They remained a crucial drainage tool until the mid-19th century, as the steam power pumping stations gradually took over. In the beginning of the 20th century diesel and electric pumping stations took over the job.
- **Chapter 6:** In the beginning of the 16th century this became possible by the invention of the windmill with a revolving cap. Initially several small shallow lakes were drained and reclaimed. At the beginning of the 17th century a start was made with placing the windmills in a series.
- **Chapter 6:** Malaysian Government initial intervention assisted in opening of new lands and gradual intensification of irrigation and drainage channels using mechanical dredgers. The systematic applications of science and engineering in irrigation planning and design with consideration on aspects of hydrology and floods as well construction of permanent structures using concrete were introduced. This approach significantly improved the irrigation development and management sustainability.
- **Chapter 17:** Based on a review on history of irrigation in Hungary, it was concluded that "...it was a fundamental truth that the excellence of technical implementation does not guarantee success for irrigation in itself; it also necessitates knowledge of factors including agro chemistry, crop production, transport, finance and sales as well as their successful application which turns the apparently simple task into a complex one."

LARGE VERSUS SMALL PROJECTS

Based on the historical schemes presented it is observed that in the long-term, communal water use and management system of small projects exhibit more sustainability:

- **Chapter 3:** Throughout these times, while the famous large dams of Sri Lanka were being constructed and used, small-scale construction continued in the island. Panabokke, Sakthivadivel and Weerasinghe have estimated that, between 300 BC and 1300, about 15,000 small reservoirs were built. Moreover, they estimate that about half of these are still functioning.

- **Chapter 3:** Panabokke describe the contrast between the large, state-governed systems and the smaller, locally-managed systems, like this: "While there was a decline and decay of the major irrigation systems of the dry zone from 1200 AD onwards, these small tank systems continued in varying degrees of utilization and operation, on their own internal organizational strengths".

- **Chapter 3:** The investment of village labour in the successful innovation and construction of these village tanks resulted in the development of a strong sense of common property that ensured the maintenance and stability of these small village tanks over hundreds of years. Through this, they also developed a high degree of resilience to various stresses compared to the larger tanks, which were managed by a central bureaucracy, which easily succumbed to the stress's consequent to the collapse of the central governments of the medieval kingdoms.'

- **Chapter 3:** There were places where the dependence of the city on the production of lands nearby was recognized and through mutual co-operation strong degree of sustainability was achieve. Perhaps the most celebrated case of this kind is at Valencia, in Spain. Despite very great changes of the political and religious environments, it has survived for a duration that may be approaching a thousand years.

- **Chapter 5:** One of the most efficient traditional management systems has been utilized in O&M of qanats. The system has always relied on the local potentials and its owners' contribution. The managerial and financial systems have evolved in compliance with the environmental and social conditions over hundreds of years, and any careless manipulation can put all the human ecology of the region including the qanats at risk. Government in its nature does not have a systematic relationship with qanats and this can be considered an advantage for Qanat civilization.

- **Chapter 5:** The qanats of Bam have a distinction that they provide most the water needs of the province. The mentioned qanats are still active water carriers and have retained not only their architectural and technological structures but also their function. They continue to provide the essential resource water sustaining Iranian settlements and gardens and remain maintained and managed through traditional communal management systems. These management systems have remained intact and have been transferred from the distant past thanks to the collaboration of people and users. The discharge of one these qanats, is 360 l/s which is equivalent to the domestic demands of city with a population of 200,000. The qanat suffered a collapse in the spring of 2022 as the result of construction activities of a modern project. As the result of the intense effort of traditional communal management system, the qanat was restored in very short time.

In general, for any specific project, fair and long-term interaction of stake holders and government in financing the construction, operation and maintenance should be worked out.

CONFLICT RESOLUTIONS AND ENSURING SOCIAL COHESIONS TRANSPARENCY AND ON RULE OBSERVANCE

A major way of ensuring social cohesion within an irrigation system is to develop institutions and procedures for the swift resolution of conflicts among its users. Such institutions work well if they are understood and respected by all users. The cases of Valencia and other systems along the south-east coast of Spain have given long-term evidence of the role of such transparent, user-based institutions for sustainability

- **Chapter 3:** As illustrated by the success story of Valencia irrigation systems, transparency and on rule observance was a key element in people participation and sustainability of the water schemes for more 1000 years.

- **Chapter 3:** Greek ambassador to the court of Chandragupta Maurya records in his account 'Indica' that state officers measure the land and inspect the sluices by which is let out from the main canals into their branches, so that everyone have an equal supply of it.

- **Chapter 8:** The feudal lord and the Shogun in those days prohibited the fighting between and among villages over water and ordered people to resolve the conflict by court decision.

If fighting resulted, those who were involved in fighting were severely punished, in many cases by death penalty. The feudal government in 1776 stipulated on the resolution of water conflict as: ‘When the consensus is difficult to get, local governor or government official will be dispatched to inspect the site and countermeasure will be formulated. The countermeasure will be on trial for certain period of 3-5years, during which period water could be abundant or scarce, and make a final judgment by learning from this trial period’ (Watanabe, 2014).

RESPECTING THE YIELD OF THE HYDOSYSTEMS

The core concept of qanat is as follows: ‘humans adjust themselves to the water available not the other way around’. This concept can be the key to the sustainability on a very large scale in water engineering and food security. The history of older irrigation systems shows very clearly the importance of developing sets of rules for water use, with accompanying procedures for open allocation of penalties to any users who try to break the rules. For sustainability, these lessons will have to be learned and applied in the modern use of groundwater

- **Chapter 3:** The role of groundwater in developing-country irrigation (other than the shallow groundwater that could be accessed with animal power) is relatively recent. Since the 1960s, as small pump equipment became cheaper and especially as rural electrification schemes expanded, the use of groundwater, both by individuals and by organised groups, has been increasing rapidly. This is posing numerous new problems, in water governance as well as in irrigation governance. There are many basins (Punjab is a prominent example) where groundwater levels have fallen with remarkable speed in recent decades. This is clearly not a sustainable trend. Ancient water-delivery tunnels, such as the qanats of Iran or the Karez of Xinjiang, are failing, as the water-tables from which they draw their supply are depleted.

- **Chapter 5:** The water users in the arid regions of Iran known as “qanat civilization” are known for their saving of the water. This is the direct result of the water scarcity in the regions. Unfortunately, it appears that recent water transfer schemes have adversely affected the valuable culture of wise water consumption.

In the context of respecting the yield of the Mother Nature, the success story of Japan in striking a balance between rice production and forest preservation for the last 600 years is very encouraging:

- **Chapter 8:** Struggling to survive in mountainous country like Japan, people started to learn about the impacts of forest degradation and the importance of forest conservation. After logging for capital and temple construction at the beginning of the state formation, prohibition of forest clearing had been issued many times at about 800. Over the years, the importance of maintaining forest for fostering water resources, preventing flood, and preserving natural environment was recognized among local leaders and shared by farmers. To sustain the paddy field production without heavy external inputs, it was understood that forest area of about 5-10 times as large as the cultivated field was required to obtain the supply of green manure from the forest and secure necessary amount of water for cultivating the paddy field. The system of communal forest started to emerge in the medieval period (14-16th century), which allowed to use the resources in the forest or grass as a common.

Fast forward to the 21st century, the individual responsibility in Sustainable Consumption and Production (known as SCP) can make a real difference for the next generation and it is emphasized by Goal 12 of SDG of UN. Sustainable Consumption and Production is about doing more and better with less. It is also about decoupling economic growth from environmental degradation, increasing resource efficiency, and promoting sustainable lifestyles. It appears that water history can be used as a medium for encouraging the people to adopt SCP.

HARMONY WITH FLOODWATERS

Floodplains are usually very fertile agricultural areas. Floods carry nutrient-rich silt and sediment, and distribute it across a wide area. floodplains are flat and often have relatively few boulders or other large obstacles that may prevent farming. The historical irrigation schemes on floodplains had the advantage of proximity to the river as the main water resources. Consequently, harmony with floodwaters has always played a key role in sustenance of many water schemes, from Netherlands to Japan, from Malaysia to India, from Sri Lanka to Thailand as presented in almost all the chapters of this publication. An illustrating example of harmony with floodwaters has been demonstrated in Hungary in 18th and 19th centuries by classification of land use by flood zoning:

Chapter 17:

- Traditional farming in the flood area: Here the primary emphasis was on free-range animal husbandry where pastures were irrigated by nature (floods). Characteristic features included ability to support small populations’ only, diverse types of farming, but sets of farms isolated from one another.

- Farming above the flood level – Farming based on crops requiring less water (grain and maize), irrigation used only occasionally, farming with a minimum of machinery but with plenty of water, both free-range and indoor livestock farming were pursued. Characteristic features included ability to support larger populations, the danger of exploiting soils, requiring relatively little knowledge about farming, and there were possibilities for extensive development.
- Rational farming in the areas protected from floods and in the areas free from floods – Grain production on arable land combined with irrigation, increase of the land area under irrigated crops (vegetables and fruits), and replacement of the producing capacity of the soil with the help of indoor livestock farming was practiced. Characteristic features included ability to support large populations, production of cash crops embedded with market conditions, investments requiring significant capital and substantial farming culture was required.

Large floods occur every few decades and continuous financing of the flood protection schemes has always been challenging. The success story of the Dutch in “keeping their polders dry” has been directly linked to financial support of the stakeholders:

- **Chapter 6:** Over the past more than 400 years the Beemster has proved to be sustainable, while the stakeholders have proven to be able and willing to take care for the water management and flood protection systems.
- **Chapter 14:** It will be relatively easy to cope with the impacts of climate change. The big question will be whether our society can and will continue with the careful maintenance and management of the past ten centuries. When we will be able to do this and timely take the appropriate improvement measures, we can continue to live in our low country for many centuries to come.

MULTIPURPOSE IRRIGATION SYSTEMS

By developing diverse revenues for the water users, their resiliencies and consequently the chance of sustainability of the water schemes are enhanced as demonstrated by many case studies:

- **Chapter 4:** During Thon Buri Period, the reign of King Taksin the Great development of water resources in the lower delta had begun. However, the style of development was not different from the Ayutthaya Period that is excavation of canals for multi purposes, transportation, commerce, and security control besides for cultivation purpose. This was the first time that people were moved to settlements along the canals to promote agriculture.
- **Chapter 5:** Qanats not only supply water to the cultivated lands, but also, they have some other economic functions like breeding fish, providing energy for watermills, supplying water to the icehouses, etc. Therefore, the revenue of a typical qanat has not been limited to agricultural productions. The multiple economic profits of qanat gave it a better chance to survive in the course of history. In the face of many natural and human-induced disasters in the past two thousand years, qanat could have stayed at the hub of local economy in Iran.

GOOD GOVERNANCE AND SUSTAINABILITY

In large historical water schemes the long-term vision and wise decisions of kings and rulers have had great influence on sustainability of the system. Many case studies on the role of good governance have been presented in chapters 3, 4, 8 10, 15, 16 and 17. Good governance is essential for achieving sustainability, as it helps to ensure that decisions and actions are taken in a responsible, accountable, and transparent manner. Good governance can help to create an enabling environment that supports the implementation of sustainable development policies and practices.

There are several key elements of good governance that are particularly important for sustainability:

- **Accountability:** Good governance requires that those in positions of power and responsibility are held accountable for their actions, which can help to ensure that sustainability efforts are effective and responsive to the needs and concerns of stakeholders.
- **Transparency:** Good governance requires transparency in decision-making and the use of resources, which can help to build trust and confidence in sustainability efforts.
- **Participation:** Good governance involves engaging a wide range of stakeholders in decision-making processes, which can help to ensure that the needs and interests of all stakeholders are considered and that solutions are inclusive and equitable.
- **Rule of law:** Good governance requires adherence to the rule of law, which helps to ensure that decisions and actions are taken in a fair and consistent manner.

CAPACITY BUILDING

The importance local communities in managing the water schemes has been emphasized in previous sections. There are several case studies that indicate capacity building was highly prized in many early communities. Japanese achievement in capacity building in historical water schemes may be considered exceptional:

- **Chapter 8:** Many lords in this period followed the suit, and the technology spread widely in the country. At the beginning, planning, design, and implementation were the job of engineering bureaucrats of a state or lords. But in the latter period, resident warriors and upper-class farmers mastered the technology and implemented irrigation and flood control as well as reclamation works. By involving farmers in the construction and rehabilitation works, the capacity of farmers to manage the system improved and the applied technology became more locally adapted.

- **Chapter 8:** Throughout the development and management of resources in Japan, elite engineers or government technocrats did not monopolize technology. Rather it was extended to local people and adapted to local environments, which in turn induced innovations and allowed establishing long-term sustainability and local management of resources.

- **Chapter 11:** The basic techniques of the Pranatamangsa (indigenous irrigated agricultural calendar in Java) are incorporated with the 'simplicity' principles. Simple that every farmer can easily adopt the technique without involving sophisticated learning process. The complexity of the technique becomes obvious if it is comprehended from the implications of school of thoughts of what today are called agricultural environment, cosmography, bioclimatology, socio-cultural circumstances, and others.

- **Chapter 8:** Human capital development in the form of education supported the technological innovation from a wider sector of society. Sharing the knowledge and knowhow led to the engagement of development works by priest, warriors or even farmers themselves. Temple schools or 'Terakoya', started in the early 16th century, taught primary literacy and calculation to common people, including merchant and farmers. Terakoya spread widely in the early 18th century all over Japan, and numbered 16,000 in mid-18th century.

- **Chapter 8:** Such capacity building and education among farmers induced the development of grass-root techniques and knowhow, leading to the publication of books on farming technology by progressive and innovative farmers. These books were used for accumulating and extending techniques, know-how and experiences to a wider population. One of the most famous is a book called Nogyo Zensho (Comprehensive guidebook of agriculture) by Miyazaki Yasusada as early as 1697. Figure E9 illustrates the role of capacity building in the context of the Interactions of three factors for sustainable development.

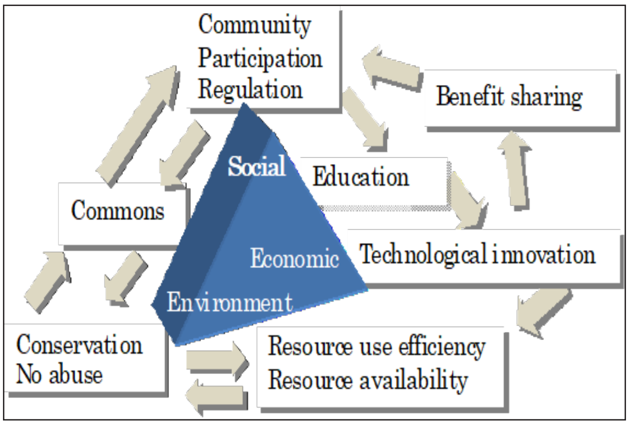


Figure E9. Capacity building in the context of the Interactions of three factors for sustainable development

BENEFIT SHARING AND COMMUNITY RISK-TAKING

In comparison to the present generation's combination of client, consultant, and contractor for project management, it appears that previous generations have exhibited more risk-taking tendencies. The intuition-based approaches utilized in historical projects relied on trial, error and observation and the communities' accepted failures as steps required for eventual success. Furthermore, the whole community participated in risk-taking and eventual benefits or costs. In this context, local comminutes were meticulous and vigilant for any type of possible saving because of the benefit sharing. By focusing financial consequences on the clients (usually governmental bodies) and the risks on the consultants or the contractors, many recent projects have been adopting very conservative criteria for design and construction.

Overall, promoting harmony with floodwaters involves finding ways to manage and adapt to flooding in a sustainable manner, which can be achieved through strategies such as flood risk management, land use planning, green infrastructure, community engagement, and education and awareness.

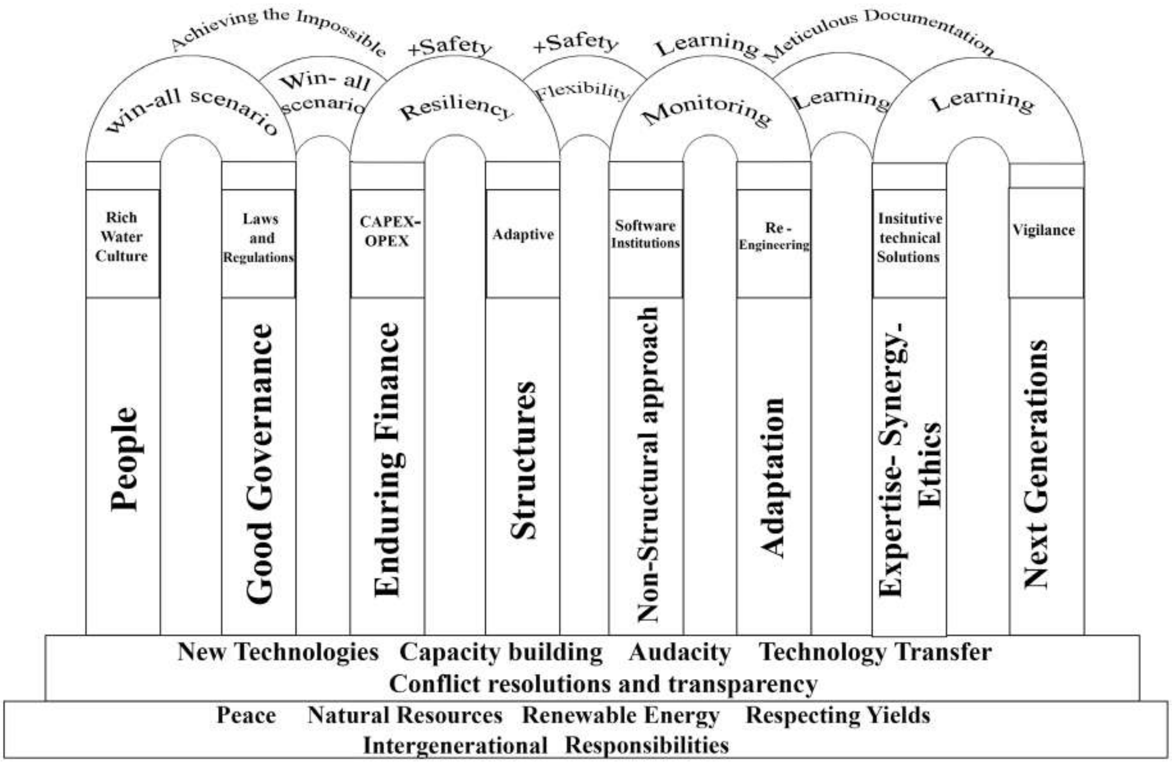
A RICH WATER CULTURE IS PREREQUISITE FOR SUSTAINABILITY

A rich water culture refers to a society or community that has a strong and deep understanding of, and connection to, water and its importance in their lives. A study of sustainable historical water projects illustrates that a rich water culture can be an important foundation for sustainability, as it can help to foster a sense of stewardship and a commitment to the sustainable management of water resources. In this context, it is not surprising that those involved in construction and operation of historical water projects in arid regions had special social status and they were held in high regard by the societies.

There are several ways in which a rich water culture can support sustainability:

1. Valuing water: A rich water culture can help to raise awareness about the value of water and the importance of managing it sustainably.
2. Promoting conservation: A rich water culture can encourage individuals and communities to adopt practices that conserve water and reduce demand on water resources.
3. Supporting water management practices: A rich water culture can help to build support for water management practices that are designed to protect and preserve water resources.

The Pillars of Water Sustainability



CHAPTER – 1

Sustainable Development and Water Resources

Ali Bagheri [a] and Peder Hjorth [b]

Water plays a crucial role in the process of sustainable development. Dealing with the issue of sustainable development, water requires principles to be fostered in order to fulfil the normative level of the society – known as morality – as well as the natural rules – identified as God given causal relations. Thus, it is argued that in order to be able to practice the concept of sustainability in the field of water resources, we need to respect the basic principles of sustainable development, a concept that is tightly linked to the Brundtland Commission and Agenda 21 and must not be subject to arbitrary interpretations. Therefore, inthis chapter, the sustainable development is considered as a dynamic process and its suggested principles are grounded in the physical relations of nature, which are formulated in terms of the laws of thermodynamics, as well as moral values to treat both environmental and humanitarian aspects of the issue, respectively. The idea of *Viability Loops* has been adopted to give a practical definition of sustainable development in accordance with developing the capability of perceiving and adapting to changes and creating a variety of opportunities in the future.

INTRODUCTION

An increasing awareness of the environmental damages caused by traditional economic development programmes throughout the world aroused universal objections in the 1960s and 1970s. This led to two environmental resolutions that made many people change their perception of development. The first one, which can be traced to the publication of *Silent Spring* (1962) by Rachel Carson, happened in the 1960s and aroused debates related to the environment against the economic growth. These debates resulted in the UN Conference on the Human Environment and Development in Stockholm (1972), which focused on international cooperation for and on the environment. The Stockholm conference resulted in the establishment of environmental ministries and agencies in over 100 countries and led to the creation of the United Nations Environment Programme (UNEP) in 1974 in Nairobi, Kenya, with responsibilities to focus on environmental policies, guidelines, and actions (Hens and Nath, 2003). The Stockholm effort to bring together the issues of environmental protection and development was continued in the World Conservation Strategy (WCS) in 1980s, a study commissioned by UNEP and executed by the International Union for the Conservation of Nature and Natural Resources (IUCN). The document established a framework for national and sub-national conservation, and priorities for international actions. It laid stress on the complete compatibility of conservation and development; its objective was to integrate conservation and development in order for the later to be sustainable. Development was deemed necessary but should be based on the principles of conservation. The key concept in the WCS was sustainability (Adams, 1990). However, the focus was too much on the conservation of nature, and the concept of sustainable development did not really catch on.

Ten years after the Stockholm Conference, the Stockholm +10 Conference was held in Nairobi, Kenya. Indeed, it was at the Nairobi Conference that the social and economic drivers of environmental problems were recognised leading to the establishment of the World Commission on Environment and Development (WCED) in 1983 which was the initiation of the second environmental revolution. That revolution was triggered

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by publication of the Brundtland report (Our common future; WCED, 1987) under the leadership of the former Prime Minister of Norway, Gro Harlem Brundtland. Calling for a 'holistic approach' for most of the basic concepts related to 'sustainable development', the Commission argued that the time had come to integrate economy and ecology, so that the wider community would take responsibility for both, the causes and consequences of environmental damages.

The report (WCED, 1987) defined sustainable development as '*meeting the needs of the present generation without compromising the ability of future generations to meet their own needs*'. It, therefore, involved a strong element of intergenerational ethics. The report started from the premise that development and environment were inseparable issues; that it was useless to deal with environmental problems without looking at poverty and international inequality. As it involved a strong element of intergenerational equity, the kind of sustainable development advocated by the report, must be interpreted as development that creates fairness within and between generations.

Poverty was seen as both a major cause and a result of environmental degradation. Thus, adding to the WCS strategy, the Brundtland Report placed a heavy emphasis on economic growth, which was seen as essential for eradicating poverty, and for generation of a surplus to enable countries to tackle environmental problems. Expansion of the global economy through rapid growth in both the North and the South, more free trade, increased aid, greater transfer of efficient technology were all part of the Bruntland scenario for sustainable development. The Brundtland Report was primarily concerned with securing a global equity, advocating redistribution of resources towards poorer nations and encouraging their economic growth.

However, the report also mistakenly, according to our understanding, suggested that equity, economic growth, and environmental maintenance were simultaneously possible and that each country is capable of achieving its full economic potential whilst at the same time enhancing its resource base. The report also recognised that achieving equity and sustainable development would require both technological and social changes.

Having become the 'official' philosophy of development of developing nations and of international aid agencies including the World Bank, it resulted in the UN Conference on Environment and Development (UNCED) in Rio de Janeiro in 1992, which focused more on a holistic approach to the social, economic and environmental dimensions. Thus, the final outcomes of the conference, the Rio Declaration and Agenda 21, emphasized issues concerning social aspects and human rights in development programmes. In addition, a new environmental body called the Global Environmental Facility (GEF) was created and placed under the control of the World Bank.

The Agenda 21 definition of sustainable development was refined at the Social Summit in 1995 and at the Habitat Conference in 1996. Since then, there have been no improvements. The change of attitudes was clearly exposed at the Rio+5 Summit in 1997. Thereafter, the concept of sustainable development has been even more eroded and undermined.

Attempting to reverse this trend and to set out strategies for greater and more effective implementation of Agenda 21, the World Summit on Sustainable Development (WSSD) was held in Johannesburg, South Africa in 2002. However, this Rio+10 Summit was as disappointing as the Rio+5. The road to Johannesburg took another four conferences where the concept was watered down (Buenos Aires, 1998; Bonn, 1999; The Hague, 2000; and Marrakech, 2001) to prevent any establishment of an efficient action plan for sustainable development.

It is, therefore, suggested that the concept of sustainable development has to be tied to Agenda 21. If we allow everyone to provide his or her definition of sustainable development, the concept becomes meaningless. Thus, it is emphasised that sustainable development is related to an evolving process which promotes adaptability to changes and innovation to create opportunities for the future. In this regard, classical science fails to touch the issue due to its fragmentation, relying on the concepts of equilibria and optimality, and dependency on forecasting to deal with uncertainties. Furthermore, ethics has to be considered in order to develop moral values to deal with humanitarian aspects of sustainability. Finally, based on physical laws of nature as well as ethics, the principles for the sustainable development in water resources systems are suggested in this chapter.

SUSTAINABLE DEVELOPMENT

The ideal of sustainability

Even two decades after the Brundtland report, the concept of sustainable development is not well understood. Due to many facets of sustainable development, the main challenge during these two decades had been to find ways to implement the concept in the everyday life in operational terms (Veeman and Politylo, 2003)[1].

Based on the traditional linear thinking, scientists tend to assume that society and social institutions have an 'end-state', a fixed target towards which they are evolving. Contrary to such ideas,it is suggested that the sustainability is neither a state of the system to be increased or decreased, nor a static goal or target to be achieved. It is an *'ideal'* of development efforts in a system. Ideals come from the ethics and values and

1 For a trans-disciplinary and conceptual overview of the sustainable development literature, see Pezzoli (1997a, b) and Mebratu (1998).

they are indeed non-quantifiable. Mitroff and Linstone (1993) stated that:

- 'Although far from recognizing and admitting it, every philosophical system contains Ideals. Indeed, by definition, every system must contain them. Each philosophical system posts certain fundamental entities or desired end states of nature or humankind that are unachievable within any finite time period.
- Ideals are fundamentally different in principle from goals or objectives. Goals and objectives are desired end conditions that one either achieves, or does not, within some finite time period.
- … the fundamental purpose of Ideals is to urge humankind on in quest of a better end state.
- *Ideals thus serve as critical benchmarks. They are desired ends that one, it is hoped, approaches indefinitely even if one can never achieve them completely*'.

This concept makes sustainability a moving target that is continuously getting enhanced as we understand more about our socio-environmental system.

As stated above, we insist that the concept of sustainable development has to be linked to Agenda 21. Efforts on behalf of various scholars to redefine sustainable development as anything that fits with their current lines of research have to be discarded as counterproductive.

Sustainable development as a process

Let us recall the Chinese proverb from Lao Zi, the founder of the Taoism, who says '*Give a man a fish and you feed him for a day. Teach a man to fish and you feed him for a lifetime*'. This proverb reminds us that going through processes is crucial for a lifetime, or sustainable living. Processes are dynamic through time rather than dealing with static goals and variables. Characterised with uncertainties, changes, and complexity, the issue of sustainable development is considered as a dynamic process which is evolving through a learning process and not as any kind of optimum or end-state of a system. Neither is it adoptable to strategies based on command nor control, fixed goals and predictability (Holling and Meffe, 1996; Rammel, Hinterberger and Bechtold, 2004).

Weak and strong sustainability

At least two distinct conceptions of sustainability have been developed. Strong sustainability (SS) asserts that it is 'natural capital' that should be sustained while weak sustainability (WS) is centred on man's well-being (Beckerman, 1994; Holland, 1996; Jamieson, 1998). WS, which is more likely than SS to be embraced by conventional economists, can be characterized as a state in which 'well-being does not decline through time' (Pearce, 1993).

Jamieson (1998) argues that the idea of WS fails to capture the concept of sustainable development because it makes no essential reference to environmental goods. Within the WS paradigm, there is little reason to object to declines in well-being as long as they are on the optimal path (whichever way optimality may be defined). However, we posit that it is mistaken to characterize sustainability in terms of welfare rather than resources. As Daly states:

- *"…the welfare of future generations is beyond our control and fundamentally none of our business…our obligation, therefore, is not to guarantee their welfare but their capacity to produce, in the form of a minimum level of natural capital…*'' (Daly, 1995)."

SS is more in the spirit of environmentalism than WS; however, Jamieson (1998) argues that since SS is defined in terms of the maintenance of the stock of natural capital, natural capital must be defined and distinguished from human-produced capital. Furthermore, some account must be given of what exactly it means to maintain natural capital.

Read in the strongest way, any reduction in the stock of Earth's natural resources would violate SS. Read in the way that we endorse; natural capital would be maintained as long as there were no reductions in the services provided by the natural environment, even if the stocks of any particular species were radically reduced.

Adapting to changes, creating new opportunities

Grounded in the concept of ecological resilience, Holling (2001 and 2004) proposed the theory of '*panarchy*' based on the idea of both creative actions and conserving ones. He clarified the meaning of 'sustainable development' using the interactions between cycles in a panarchy, which combines learning with continuity. As he asserts '*sustainability is the capacity to create, test, and maintain adaptive capability. Development is the process of creating, testing, and maintaining opportunities. The phrase that combines the two, sustainable development, therefore refers to the goal of fostering adaptive capabilities while simultaneously creating opportunities*' (Holling, 2004). While others are worried about the sustainability of the world due to vanishing of natural resources, we agree with Leisinger (1998) that '*there is not only natural capital in the sense of natural resources, biodiversity and other nature-given, but also other kinds of capital, for example:*

- human capital, resulting from investments in education, health and nutrition of individuals, as the enabling factor for innovation;

- social capital, in the sense of the institutional and cultural basis for a society to function as well as good governance.

Evolutionary development

Recalling evolutionary concepts in terms of development, we believe that a sustainable society should be flexible enough to understand changes and to learn how to adapt to changes in terms of innovations and creating new opportunities (Rammel, 2003). The evolutionary paradigm has to be oriented towards processes and structural changes, which is related to innovations in a social evolutionary perspective, rather than equilibria or defined states of the environment (Ring, 1997). As Cary (1998) states:

- '*Sustainability is not a fixed ideal, but an evolutionary process of improving the management of systems, through improved understanding and knowledge. Analogous to Darwin's species evolution, the process is non-deterministic with the end point not known in advance*'.

In an evolutionary system associated with continual development, there cannot be any best state, or a stable equilibrium, or an optimal path of development. The economic neoclassical approach to innovation is largely based on the ideas of predictability, optimality and equilibria, which, as a complete contradiction to an evolutionary understanding, prevents any comprehensive approach to sustainable development (Rammel, 2003). The neoclassical equilibrium growth theory, assumes all the agents to be identical, with the same rationality, and following the same paths to optimise their utilities.

Furthermore, to create new opportunities and innovations, we have to learn how to do it? In this sense, the basic requirement is '*adaptive flexibility'*, which is the ability to address changing conditions through a process of continuous adaptive learning and the possibility to initiate new development trajectories (Rammel, 2003). Ackoff (1997) argues that:

- 'We *talk about the accumulation of information, but we fail to distinguish between data, information, knowledge, understanding, and wisdom. … we have focused mainly on data and information, a little bit on knowledge, nothing on understanding, and virtually less than nothing on wisdom*'.

It is essential that public pedagogy be the foundation of sustainable development models; thus, the distribution of knowledge would have an important and crucial role (Robèrt, Daly, Hawken and Holmberg, 1997).

Our culture is being shaped by our social memory and knowledge. These bytes of knowledge and information, which Dawkins (1976) called *Memes*[2], evolve and are transmitted through generations. They will define the value system in a society based on which the ideals including sustainability are developed. To promote innovation and creation of opportunities in our social system, it is crucial to encourage evolving ideals.

We agree with Keiner (2004) that, the idea of '*evolutionary development*' is important and we believe that the concept of sustainability should be tied to the concept of evolution ability. Keiner (2004) defines the concept of '*evolutional development*' as the development that '*meets the needs of the present generation and enhances the ability of future generations to achieve well-being by meeting their needs free of inherited burden*'. This implies that sustainability has to enable strategies to deal with uncertainties, unpredictable and non-optimizing changes, and evolving properties as well as with a continuous process of adapting economic development to altered social and ecological conditions (Rammel and van den Bergh, 2003).

Our descendants are entitled to inherit good heritage *i.e.* we should leave less burden than we inherited ourselves; so, the today's generation should transform its heritage from burden to gain which can be in the form of opportunities to offer new resources and to find substitutes for those resources that are non-renewable (Keiner, 2004).

In addition to creating new opportunities, next generations anticipate us to foresee the impacts of our technology and policies, and to enact appropriate remedies while the time is available to act effectively (Partridge, 2003).

Sustainable development in the literature

The literature is full of various attempts to define sustainable development and sustainability. The concept has been broadly discussed since it was brought to public attention by the Brundtland Report (WCED, 1987) and it has since been developed into a blueprint for reconciling economic and ecological necessities (Krotscheck and Narodoslawsky, 1996). However, as the concept of sustainable development is at odds with mainstream science, most of what has been written on sustainable development is more confusing than clarifying.

Solow defines sustainability as preserving the production capacity for a long future (Solow, 1992). Pearce, Barbier and Markandya (1990) consider development as a vector of desired social goals, which the society tries to maximize by working on its components. The components of the vector are: increase in real per capita income, improvement

2 In the 'Selfish gene' Richard Dawkins says that he had originated the term '*meme*', a cultural equivalent of '*gene*', by shortening '*mimeme*' which he says he derived from the Greek '*mimeisthai*', to imitate (Laurent, 1999).

in hygiene and nutrition, educational successes, accessing resources, equitable distribution of wealth, increase in liberty, etc. Sustainable development is then a condition in which the vector of development does not decrease. Fuwa (1995) defines biophysical sustainability as preserving or improving the integrity of the life supporting systems on the earth.

Klauer (1999) considers the common concept in different definitions of sustainability as preserving a condition, for instance in Solow's definition as preserving the production capacity, in Pearce *et al.*'s definition as preserving the characteristics of a social system, and in Fuwa's definition as preserving the life supporting system on the earth. In Brundtland's definition sustainability has also been defined as preserving the ability of humans to meet their needs.

Among others Brown, Hansen, Liveman and Merideth (1988), Turner (1988), Svedin (1992), and Daly (1991) contributed to make this concept scientifically acceptable, so that, it is possible to take it as a yard-stick for strategic planning.

In recent decades, the human rights issue has come to the forefront in discussions about developmental processes. The foundations of the globally accepted framework for universal goals, norms and standards consist of the United Nations Charter (1945) and the Universal Declaration of Human Rights (1947). The framework was followed by the United Nations Declaration on the Right to Development (1986) and the Rio Declaration on Environment and Development (1992). These latter declarations define the concept of development as processes that are economically viable, socially equitable, and environmentally sustainable. In fact, the UNDP Human Development Report 2000 declares human rights to be the most important factor in human development (UNDP, 2000).

THE CHALLENGE TO CLASSICAL SCIENCE

Classical science – let's say Physics, Biology, Economics, etc. – is inadequate to address the issue of sustainable development. This inadequacy originates from intrinsic attitudes and limitations associated with the conventional science. According to the Indo-European Root Etymology, the word *science* is a derivative of the word *skei*, which means to cut or to split. This is a clear indication that traditional science is based on fragmentation and, thus, is totally inadequate to deal with a holistic concept such as sustainable development.

We agree with Nath (2003) that while science and technology can offer economically viable solutions to small-scale environmental problems, such as those for treating municipal wastewater or restoring relatively small areas of contaminated land, they cannot be applied to solve large-scale or global problems. Indeed, an examination will show that science and technology are almost exclusively concerned with treating the 'symptoms' and not the 'cause' (Nath, 2003).

We argue that the approach of the conventional science will not lead in a sustainable development due to the following considerations.

First, classical science is dominated by the concepts of equilibrium and optimality and fails to perceive and treat changes easily. The Newtonian vision of the world implies that the elements making up the variables are reduced to a 'machine' by a mathematical model that represents the system in terms of a set of differential equations governing its variables. The simplistic assumption that there would be only one solution of those differential equations leads to the idea of 'equilibrium'. But, that is not valid for open systems, even in physical systems, when they get open to flows of matter and energy, there is not necessarily a unique final state identified as 'optimal'. This is why we cannot imagine a predictable future for open systems. To cope with such situations, we have to come up with a new understanding of science. Conventional mathematical systems; which are capable of functioning, but not evolving, do not contain the capacity for structural change in open systems (Clark, Perez-Trejo and Allen, 1995).

Thinking about sustainable development requires a break with traditional thinking and practice. It forces us to go from static, equilibrium oriented approaches to dynamic, evolutionary ones (van den Bergh and Gowdy, 2000). Evolution implies a focus on complementary rather than substitution. Evolution and change are concepts that science has traditionally been unable to deal with satisfactorily. As Clark *et al.* (1995) assert, that it is related to the choice of 'mathematics' as its preferred language of expression where equations express equivalency of the left and right hand sides. They express that:

- '*change is not just an occasional and rare phenomenon, but instead, change and more importantly the capacity to change, plays a much greater role than previously believed in explaining the diversity we observe around us*'.

There is no equilibrium state since the environment is continually in a state of flux and change (*ibid*).

Classical science assumes all systems are isolated or closed; so, no new matter or energy can flow in, and hence, the systems are moving towards thermodynamic equilibrium. But, in fact, systems such as ecology and economics are always open and only attain thermodynamic equilibrium with death (Clark *et al.*, 1995). It is believed that:

- '*Living [or organic] systems are in constant dialogue (not equilibrium) with their environment, and even when not visibly evolving, maintain the capacity to evolve and change which is related to their underlying diversity*'(Clark *et al.*, 1995).

Second, the fragmentation in science leaves some of the issues – mostly related to complex and organic systems – lie on the white borders and not dealt with. To deal with organic systems and complex problems, we have to move from a mono-disciplinary and even from multidisciplinary and pluri-disciplinary paradigms to inter- or even trans-disciplinary approaches (Max-Neef, 2005; Hjorth and Bagheri, 2006).

Humankind now needs to move from the age of reductionist science to an age of synthesis or integrative science (Cairns, 2003). As Max-Neef (2005) defines our times, '*we know quite a bit, but understand very little*'. What is needed is a form of trans-disciplinary thinking that focuses on the connections among fields as well as sectors and interests; that involves the development of new concepts, methods and tools that are integrative and synthetic, not disciplinary and analytic; and that actively creates synergy, not just summation (Robinson, 2004).

Third, the way classical science treats uncertainty is through forecasting. However, when dealing with sustainability, we cannot look into the future with any degree of certainty. Every forecast is related to probabilities and is doomed not to come true; instead, we have to go through assumptions based upon possibilities to get prepared for future.

Finally, science and technology need to be supported by moral values that are dealt with as ethics. As Cairns (2003) asserts, '*Science can show what probably is done; technology can show what might be done; but ethics can help humankind decide what should be done*'.

SUSTAINABLE DEVELOPMENT FROM A SYSTEM DYNAMICS PERSPECTIVE: THE IDEA OF VIABILITY LOOPS

We adopt the System Dynamics (SD) approach to come up with a practical definition of sustainable development. SD is one branch of systems thinking which combines the theory, methods, and philosophy needed to analyse the behaviour of systems not only in management, but also in other fields. It is based on the dynamic feedback structures of systems, which goes through a circular causation of events. This attribute of SD - along with its stock and flow structures, time delays, and nonlinearities - determine the dynamics of a system (Sterman, 2000).

In any complex system, some kind of self-organising mechanisms are working to keep the system in balance according to the stocks of resources and carrying capacity of the system. In terms of the system dynamics approach, the critical balancing or negative feedback loops in a system need to self-correct the system by adjusting, reinforcing or positive feedback loops. The key elements in those critical balancing mechanisms, which Hjorth and Bagheri (2006) called *Viability Loops,* are the development and the flow of information/knowledge and/or matter/energy to keep the system in balance (Bagheri and Hjorth, 2006).

Viability loops can provide actors in a system with effective information of the system status to influence their policy and decision making strategies in order to enhance the sustainable development of the system. Furthermore, they can promote the establishment of mechanisms to recover matter and/or energy stocks as well as sinks for wastes. For instance, in Figure, it is seen that the reinforcing loop of population growth will be checked by means of a balancing loop due to the limitation of resources. The balancing loop in this example is acting as a viability loop that helps the system to be kept in balance.

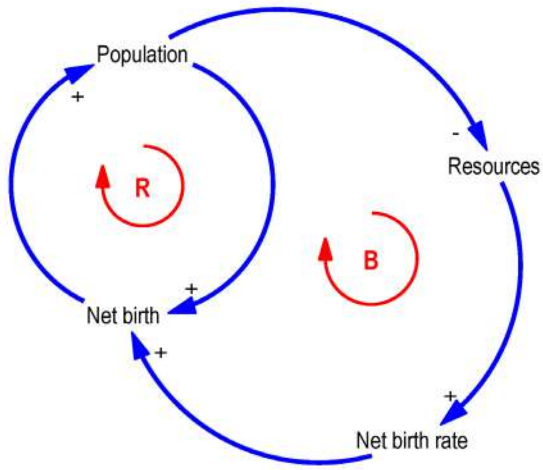

Figure. An example of Reinforcing (R) and Balancing (B) loops. The balancing loop here acts as a viability loop

In contrary to looking at sustainable development as a static state which implies that its goals may conflict (see *e.g.* Lamberton, 2005; and Munda, 2005), we rely on the idea of *Viability Loops* (Hjorth and Bagheri, 2006; Bagheri and Hjorth, 2006) to define sustainable development as a process in which the viability loops in a dynamic system are functioning to check the reinforcing mechanisms. This process will lead to keeping the system in balance through both perceiving and adapting to changes and creating new resources and opportunities by redirecting the flows of capital, energy, information, and knowledge to innovate and to deal with new challenges.

Planning for sustainable development is, hence, to identify the viability loops and to keep them functional (Hjorth and Bagheri, 2006). To this end, we need to improve the system capacity to understand changes, to find ways to adapt to changes, and to promote innovations to create new opportunities and resources for the next generation.

PRINCIPLES OF SUSTAINABLE DEVELOPMENT

The conventional picture of development treats science, values, and resources as exogenous inputs into a system of technological and social organisation; nevertheless, values and knowledge, as well as social organisation and technology, would be seen as subsystems co-evolving with, and influencing each other (Jenkins, 1998).

According to Max-Neef's hierarchy of science, there are four levels of scientific areas (Max-Neef, 2005). The first or *empirical* level is associated with the areas such as Physics, Biology and Economics, which would explain *what exists* in the world. The fields such as engineering, agriculture and commerce, which are situated in the second or *pragmatic* level, are dealing with *what are we capable of doing*. In the third or *normative* level, the areas of science such as law, planning and politics will explain *what it is we want to do*. Finally, in the fourth or *value* level, the fields such as philosophy and ethics will deal with *what we should do*; or, *how we should do what we want to do*.

When talking about sustainable development, we are standing in the normative level to plan our systems to work in accordance with sustainability. However, it is required to follow governing laws of nature as well as social ideals coming from *empirical* and *value* levels, respectively. To evolve, we have to improve the *value* level in our society while we discover new facts in the *empirical* level. The *value* level may evolve via learning processes within both intra- and inter-generations. The human dimension of sustainability requires the development of methods of deliberation and decision making that actively engage the relevant interests and communities in thinking through and deciding upon the kind of future they want to try and create (Robinson, 2004).

Values and opportunities

The ethical orientations of people and administration in a society determine their attitudes and behaviours specifically in relation to nature. Neil Brady (2003) draws three categories for ethical orientations and associates each of them to universals and particulars. The categories are *deontology* which deals with duties, principles, wills, norms, obligations, laws, and rules; *teleology* which is related to purposes, interests, goals, means-ends, consequences, and hopes; and *axiology* which is associated with values, feelings, cares, affections and preferences.

For instance, a universal deontology acknowledges principles such as accountability, responsibility and prudence as the chief values for public administrators, while, freedom, honour, benevolence, justice and efficiency are regarded as ideals of a public service from a universal teleology perspective. Finally, universal axiology is regarded as an ethic of shared values that appreciate water supplies, waste disposal, etc. because they are universally valued.

Normally, ethical virtues get legitimate through a universal acknowledgment; however, religious principles also inspire moral values. Values begin with a spouse, a child, a family (Neil Brady, 2003) and then go beyond to a society as a social attitude and culture.

The differences in views about the meaning and value of sustainability are rooted partly in different philosophical and moral conceptions of the appropriate way to conceive of the relationship between humanity and nature (Robinson, 2004). This implies that sustainability is not fundamentally a scientific or technical issue; it is a political act, an issue of human behaviour, and negotiation over preferred future, under conditions of deep contingency and uncertainty (*ibid*).

How we treat the environment is fundamentally determined by our attitudes to nature, which in turn is shaped by our worldview and moral values (Nath, 2003). To promote sustainable development, a renaissance in our moral values is needed.

According to Aristotle, nature has no intrinsic value. It is of value only if it benefits humans (Nath, 2003). This utilitarian attitude was reinforced in the 17th century by the writings of Francis Bacon (1561-1626) and René Descartes (1596-1650) indicating that nature and everything within it was for the sole benefit, well-being and pleasure of humans (Anderson, 1948 and Clarke, 1982 in Nath, 2003).

Based on reductionist economic thinking, this worldview leads to the school of 'economic growth', which is supported by the simplistic principle that man has power over the Earth and is entitled to use and exploit it to his own benefit. (Decleris, 2000).

Partridge (2003) states that,

- '*The classical economic approach to values is thoroughly theological, embracing (usually uncritically) the ethical theory of preference utilitarianism. This is a 'consequentialist' theory, which holds that the value of an act or policy is to be determined by the results thereof, and that the 'right' course of action is that which maximizes 'the good' (in this case, aggregated human want satisfaction). In contrast, normative values may be defended by 'deontological' theories, which hold that a course of action that maximizes the good might, nevertheless, not be the morally 'right' thing to do*'.

The Platonic worldview, on the other hand, acknowledges the intrinsic value of nature, and of all things within it, for its own sake (Lesser, Dodds and Zerbe, 1997). This philosophy is in line with the school of 'deep ecology', which indicates a return to simple ways of managing nature. At the focus of attention and interest of this school are evolution, ecosystems, and in particular the conservation of species, without placing any special weight on man. From that standpoint they highlight the disastrous impact of industrial civilization on nature and recommend us to abandon it. They argue that any kind of traditional development will inevitably lead to depletion of natural resources, and leave the problems of the environment unsolved (Decleris, 2000).

In this school, to which we do not subscribe, it is believed that it is not man alone who has rights but animals too, plants, and even nature's inorganic elements. They are right to say that man's survival is highly dependent on the environment and nature; however, they underestimate man's particular characteristics and especially the role of technological development in man's evolution. They have also extended the scope of ethics. For that reason their value consists not in their extreme conclusions that they advocate, but in highlighting the vitally important role played by ecosystems as the irreplaceable basis for man-made systems.

The schools of economic growth and deep ecology are extreme because they are one-sided. Thus, both suffer from deficient logical method. The first, which is purely analytical, isolates man from his environment and examines his economic action in its own right and over a relatively short time scale (4 to 30 years). The second is indeed holistic, but is in reality pseudo-systemic because while it focuses on ecosystems, it cuts short the hierarchy of systems and completely ignores the unique qualities which distinguish mankind from all other living systems (Decleris, 2000).

Yet, that is the main problem since man is different from other living systems and man-made systems have special characteristics and potentialities that must be taken into account. That vital perception gave birth to the school of *sustainable development.* The school of 'sustainable development' represents the most efficient approach to the fundamental problem of relations between man-made systems and ecosystems, not because it is between two extremes, but because it is based on integral systemic logic. The rules of sustainable development also constitute a learning curve: man must learn to coexist and co-evolve with ecosystems. (Decleris, 2000).

A review on the development of the principles of sustainable development

The Brundtland Commission offered what has become one of the most widely used definitions of sustainable development. We think that The Brundtland Commission's definition of sustainability has helped to provide a consistent definition to a word – *sustainability* – that has been difficult for many to grasp in theory or practice. In addition, it is more concentrated on man's wellbeing within and between generations, and merely offers a very broad vision or goal but no set of approaches to get there.

The United Nations Conference on Environment and Development, held in Rio de Janeiro (1992), refined and developed the ideas from the Brundtland Commission and resulted in a declaration constituting 27 principles of sustainable development. Although emphasising nature, the principles are primarily based on anthropocentric normative values. The principles were refined and developed at the Social Summit in 1995 and at the Habitat Conference in 1996. Since then, there has been continuous erosion and undermining of the concept of sustainable development. This was evident at the Rio+5 assessment in 1997, where most governments backed down from their previous commitments.

The Millennium Development Goals is another example. International aid organisations are simply not set up to work in the way required to implement Agenda 21. Thus, the aid industry had to take action. The result was the Millennium Development Goals, which have little relevance to sustainable development, but are phrased in terms that the aid industry can manage.

Rather than the technical and financial focus of the Millennium Development Goals, we need adequate social and political process indicators to monitor the development towards, or away from, sustainable development.

The *Bellagio Principles* (Hardi and Zdan, 1997) could be developed into performance indicators, to serve as an assessment tool of whether a system progresses towards sustainable development or not. Unfortunately, there is a lack of focus, which means that too many indicators will be needed to measure the performance. We find the principles worked out by the Natural Step Foundation to be more promising.

The Natural Step principles of sustainable development

The Natural Step (TNS) is a set of non-prescriptive and ideal oriented principles developed to guide human decision-making and design. These principles, reached by the consensus of numerous Swedish scientists, identify the basic system principles necessary for life. TNS was founded in 1989 by the Swedish oncologist Karl-Henrik Robèrt. Taking the moral principle that '*destroying the future capacity of the Earth to support life is wrong*' as given, Robèrt and his colleagues finally reached an agreement on the following four principles necessary for a sustainable society based on the laws of thermodynamics (Holmberg, Robèrt and Eriksson, 1996; Azar, Holmberg and Lindgren, 1996; Robèrt *et al*., 1997; Robèrt, 2000):

- ***'Principle 1 (Stored deposits). Substances from earth's crust must not systematically increase in nature.*** In the sustainable society, fossil fuels, metals and other minerals must not be extracted at a faster rate than their slow redeposit and reintegration into the earth's crust;

- ***Principle 2 (Synthetic compounds and other societally produced material).*** *Substances produced by society must not systematically increase in nature.* In the sustainable society, substances must not be produced at a faster pace than they can be broken down and be integrated into the cycles of nature or be deposited into the earth's crust;
- ***Principle 3 (Ecosystem manipulation).*** *The physical basis (air, soil, water, sunlight, organisms) for productivity (growth and reproduction) and diversity (biodiversity) of nature must not be systematically deteriorated.* In a sustainable society, we cannot harvest or manipulate the ecosystem in such a way that productive capacity and diversity systematically deteriorate;
- ***Principle 4 (Socio-economic considerations).*** *Fair and efficient use of resources with respect to meeting human needs.* Humanity must prosper with a resource metabolism meeting system conditions 1- 3. This condition is necessary in order to get social stability and cooperation for making changes in due time. In practical terms, in today's situation, it implies increased technical and organisational efficiency throughout the whole world, including a more resource-efficient lifestyle particularly in the wealthy sectors of society. Furthermore, it implies improved means of dealing with population growth.'

To derive the above principles, it is assumed that matter and energy cannot be created or destroyed (according to the first law of thermodynamics and the principle of matter and energy conservation), matter and energy tend to disperse (according to the second law of thermodynamics), material quality can be characterised by the concentration and structure of matter (what we consume are the qualities of matter and energy – the concentration, purity, and structure of matter, and the ability of energy to perform work. We never consume energy or matter because it is neither created nor destroyed, and the net increase in material quality on earth is produced by sun-driven processes. Photosynthesis is the only large-scale producer of material quality (Holmberg, 1995).

TNS is unusual in its provision of the Earth system principles and boundaries, which can serve as a scientifically based set of guidelines for any human activity. The above principles serve as reasonable guidelines, providing different ways of framing human-environment interactions and helping actors to take responsibility for their ecological and social impacts. TNS is helpful because it provides a big-picture understanding of natural principles and boundaries that decision-makers can use to make better-informed choices. However, it intentionally does not prescribe a methodology for making design decisions. Instead, actors are required to familiarise themselves with the basic system conditions and principles of TNS and to discuss and reflect on adequate ways to apply them to their own activities.

Systems orientors serving as the principles of sustainable development

Being grounded in ethics, the system orientors suggested by Bossel follow a similar methodology as the principles of TNS; except that the latter are grounded in the natural laws but the former go back to ethics. Bossel's ethics reads: '*All people should have their needs satisfied so they can live in dignity, in healthy communities, while ensuring the minimum adverse impact on natural systems, now and in the future*' (Peet and Bossel, 2000). Bossel defined the following characteristics as the basic orientors of the systems (Bossel, 1996, 1999): existence related to the *normal environmental state*, effectiveness related to the *scarcity of resources,* freedom of action and *security* related to the *environmental variety*, *adaptability* related to the *environmental change*, *coexistence* related to the interests (orientors) of *others* (actor), and psychological needs for human systems.

SUSTAINABLE DEVELOPMENT AND WATER RESOURCES SYSTEMS

Sustainability has also been regarded to exist in water related areas as well, *e.g.* Falkenmark (1988) defined sustainability based on the role that water plays in the development. She suggested various conditions for sustainability. Soil permeability and water retention capacity have to be secured to allow rainfall to infiltrate and to be used in the production of biomass on a large enough scale for self-sufficiency. Drinkable water has to be available. There has to be enough water to permit general hygiene. Fish and other aquatic biomass have to be preserved and remain edible.

Goodland, Daly and El Serafy (1991) consider sustainable water resources management as a balance between changing human economic systems and larger, but normally slower changing, ecological systems. Therefore, human life can continue indefinitely to flourish, if the supporting ecosystem and environmental quality can be maintained and improved. Sustainable development is, therefore, an improvement in the quality of life without necessarily causing an increase in the quantity of resources consumed. Thus, the idea of sustainable growth, *i.e.* the ability to get quantitatively bigger continually and to use more water, is dubious, to say the least. Sustainable development is interpreted as an effort to improve qualitatively and continually, on the other hand, may be possible.

In addition to the efforts to give a definition for sustainability in water resources, it has been tried to be practiced in water related issues as well; *e.g.*

Kandiah (1990) examined the issues of effective water-quality management and their relations to sustainable agricultural development. Niu and Harris (1996) studied the relationships between economic development and environmental protection, where issues of system sustainability were analyzed. Simonovic (1996a,b) developed a decision support system for sustainable management of water resources. Xia and Hu (1997) studied water-related environmental problems and their relations to the sustainability of water resources systems with the provision of a case-study for the Sanhua Region, China. Plate (1993) and Suzuki (1998) discussed the challenges to science and engineering in terms of sustainable development for water resources systems. Additional reports of research in this area can be found in Haimes (1992), Falkenmark (1997), Loucks (1997, 2000), Gutierrez-Martin and Dahab (1998), and Huang and Xia (2001).

The value of 'water'

Since the International Conference on Water and the Environment in Dublin in 1992, the notion of '*water as an economic good*' has been widely accepted among water resources managers. That is based on the principle that people are 'economic men' who respond rationally to financial incentives and disincentives (Grimble, 1999). The concept implies two schools of thought, one maintains that water should be priced at its economic value and the other one interprets the concept to mean that decisions on the allocation and use of water should be based on a multi-sectorial, multi-interest and multi-objective analysis in a broad societal context, involving social, economic, environmental, and ethic considerations (Savenije, 2002).

However, there are still some debates on the topic. It is argued whether allocation can be reasonably left to free market forces, or whether the market fails to meet social objectives related to water (Liu, Savenije and Xu, 2003). Savenije (2002) states since water is essential, scarce, fugitive, a system, bulky, non-substitutable, not freely tradable, complex, a public good, location bounded, inherent with high mobilization costs, non-homogeneously marketed, prone to market failure, and valued with various merits in addition to economic characteristics such as health and aesthetics, it is really different from any other good. It is urban drinking water bias which leads people to believe that water is just another economic good; however, except for bottled water and virtual water, water markets are not useful beyond the much localised scale of a micro-catchment, an aquifer or an irrigation system (*ibid*).

Water has an economic value; however, it is not an ordinary economic good. When human thirst and basic needs have been satisfied, water can be considered an economic good; on the other extreme, where water is abundant, it ceases to be an economic good. But the question is what kind of economic good is water?

Water serves a number of purposes ranging from domestic water demand, agricultural and industrial water demands through aesthetic, recreational, and environmental water uses, to waste disposal. This multiplicity of water uses lead to it being considered as both a private and a public good according to its excludability – the degree to which users can be excluded – and subtractability – the degree to which consumption by one user reduces the possibility for consumption by others (Liu *et al.*, 2003). As they indicate, for instance, if water is used for recreation in a lake it would be regarded as a public good due to its low excludability and subtractability; while, if the water in the lake is allocated to supply water for a region, it would turn to be a more private good due to its increase in excludability.

Seyam, Hoekstra and Savenije (2003) argued that most efforts to evaluate water values have focused on measuring the value of water in certain water using sectors, so that only the part of the water cycle nearest to the end user is recognized as an economic good. They suggest that the value of a water particle in a certain place and at a certain point in time be equal to its value in situ plus its contribution to downstream benefits generated in later stages. It is based on the hypothesis that the full value of a water particle depends on the path it follows within the hydrological cycle and the values generated along this path (Seyam, Hoekstra and Savenije, 2002). However, their method is still based on calculating water values in terms of economic benefits.

Rogers, Silva and Bhatia (2002) advocate water pricing to cover not only costs of supply but also opportunity costs as well as externality costs. In contrary to the conventional belief that raising water prices will reduce equity, they argue that increasing prices can improve equity due to making it affordable for utilities to extend services to those currently not served.

On the other hand, international law, international agreements and evidences from the practice of States strongly and broadly support the '*human right*' to a basic water requirement (Gleick, 1998). Although in the most popular covenants and international declarations, the right to water is not explicitly mentioned, it is implied implicitly due to the principle of protection of human rights to life, to the enjoyment of a standard of living adequate for health and well-being, of protection from disease and to adequate food. However, the right to access to water for basic needs was explicitly recognised by the statement of the United Nations Water Conference in Mar del Plata in 1977 (United Nations, 1977 in Gleick, 1998). That statement was supported then by the Declaration on the Right to Development (DRD) (United Nations, 1986 in Gleick, 1998) and the Convention of the Right of the Child (CRC) (United Nations, 1989 in Gleick, 1998). However, the amount of water required to meet human basic needs is debated to vary from 3-5 to 50 litres per capita per day.

We believe that mechanisms and policies related to water services can mobilize other mechanisms and influence the process of sustainable development. Water has an essential and unique role to integrate different sectors of society, economy and environment. Not only does it have an economic role, but also it can play a social role as it initiates population migrations, political conflicts, and civilization settlements as well as its crucial role in ecological systems. So, here we come to proclaim that *water is a means of sustainable development*.

However, it is argued that economic tools should be applied to keep market mechanisms active to make technology to innovate and man to adapt to changes in the real world.

The principles of sustainable development adapted for water resources systems

Sustainability in development is not actually a goal as in the traditional meaning, but it is an ideal towards which we should strive during the process of development. It is not a fixed goal to be achieved, rather, it is an evolutionary value which evolves as our worldviews and understandings of the real world evolve.

In addition to moral values, ideals must follow the physical rules which are governing the environment. In this regard, our knowledge of the real world which is formulated in terms of scientific basic laws will be influencing the way our ideals are shaped. It is also an evolving process that as we discover more about our surroundings, we will try to improve the ideals accordingly.

Since sustainable development is dealing with humans as well as environment, we apply both Bossel's systems orientors originated from ethics - as the principles associated with the *value* level - and the principles of TNS - as those associated with the natural physical laws in the *empirical* level - to initiate principles of sustainable development. In this way, the principles of sustainable development in a water resources system are derived by customizing those basic principles as below:

EXPLOITATION OF WATER RESOURCES IN A BASIN MUST NOT VIOLATE ITS NATURAL HYDROLOGICAL BALANCE

Withdrawal from local water resources in a basin as well as water transfer from/to other basins must be carried out in accordance with the natural regime of hydrology in the region.

1. *Waste disposal into nature – due to either water or energy consumption - must not exceed the environment carrying capacity.* The environment carrying capacity must be concerned so as not to let wastes be accumulated in the ecosystem in terms of contaminants;
2. *Persistent damages to the ecosystem due to water services must be prevented.* Regarding water resources systems, manipulations in the ecosystem must not result in persistent impacts which will be carried on to the next generation as a burden.
3. *The system must be capable of adapting to changes to equitably distribute and efficiently use water.* It is crucial to understand changes and learn how to adapt to changes effectively.
4. *There must be various opportunities for human to be able to meet his water needs.* It is not our responsibility to meet the needs of the next generation; rather, we must leave a variety of options for them to be capable of meeting their own needs by themselves.

We can resort to the above principles in order to implement sustainability in the development efforts associated with water resources systems. Furthermore, rather than focusing on a topic-by-topic research agenda, we need to identify the overarching principles, and recognize the limitations of discipline-based perspectives and acknowledge the need to integrate across physical, chemical, biological, and social sciences when dealing with water problems of relevance to society.

CONCLUSIONS

In contrast to some other views that see sustainability as an end-state for systems, which should be grasped, this contribution argued that sustainability is a value which is continuously evolving. It is not a goal in its traditional sense, but it is an ideal towards which we strive to move; however, it is not fully achievable.

The ideal of sustainability is underpinned by both physical rules which govern nature and moral values which are initiated from the normative level of our society. So, as we learn more about the real world and as our ethical values evolve, the ideal of sustainability will evolve too. That makes it a dynamic moving target.

Hence, sustainable development is a process that helps us perceive and adapt to changes in our environment and provide a variety of options and opportunities that will enable our descendants to meet their own needs.

To give a practical meaning to sustainable development, we adopt the idea of viability loops to indicate that sustainable development is a process in which the viability loops in a dynamic system remain healthy and functional. The dynamisms captured by viability loops aim to keep the system in balance through adaptation to changes and creation of new opportunities.

To address the issue of sustainable development, we have to move beyond classical science to more integrated inter-disciplinary areas and rely upon possible assumptions, instead of probable forecasts, to get prepared for the future. To develop our worldviews we need to improve our understanding of the real world as well as the value system of our society.

Although economic values are not adequate to address the issue of sustainable development, we argue that economic policies could be regarded as effective tools to promote societies to navigate towards sustainability.

To give a framework to practice sustainable development, we need to define principles of sustainable development. The principles should be grounded in the physical relations of nature as well as being originated from the value level of a society.

In this contribution, we adopted the principles of The Natural Step which are grounded in the laws of thermodynamics – as the physical part – and the system orientors suggested by Bossel – as the principles addressing moral values – and customised them to assert principles of sustainable development adapted for water resources systems.

Although water has economic attitudes and it is also considered as one of the essential human needs and/ or human rights, we argue that water is a means of sustainable development.

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CHAPTER – 2

Sustainability of Chinese Civilisation and Historical Irrigation Projects

Tan Xuming [a]

INTRODUCTION

The history of China's irrigation has lasted more than 5000 years. The evolution of civilisation is closely related to and affected by the origin, development or decline, and revival of irrigation. Irrigation practices are also subject to the natural environment, and different regional technology and scales. This is attributable to the different geographical latitudes, topographies, and climate conditions in the different regions of China. Among the various natural and geographical conditions, the terrain and climate conditions directly impacted on ancient irrigation projects.

TOPOGRAPHY, CLIMATE CHARACTERISTICS AND IRRIGATION TYPES

The topography of China is characterised by high terrain in the northwest and low terrain in the southeast. The mountains account for about 33% of the total area, the plateaus about 26%, hills about 10%, and plains and basins about 31%. Most of rivers flow from the west to the east along with the topography. The downstream areas of the seven large rivers in China (i.e., Yangtze River, Yellow River, Huaihe River, Haihe River, Pearl River, Songhua River, and Liaohe River) and the southeast coastal plains account for 8% of the total land area. Over 40% of the population, 35% of the arable land and 60% of industrial and agricultural output values are found in these regions. Historically these regions were also the wealthy areas of China.

China has a typical East Asian monsoon climate. Most of the regions have the advantage of the same periods of rainfall and heat that are suitable for plant growth. In the mainland from the southeast coast to the northwest, the annual precipitation decreased from 1600 mm to less than 200 mm. The amount of precipitation in the eastern region is large, and 60% to 80% of the annual precipitation is concentrated in June to September and the largest monthly rainfall may reach 30% to 50% of the total annual precipitation. Therefore, rainstorm floods often occur in eastern China, while droughts occur throughout the country, including Guangdong and Guangxi regions with abundant rainfall and the southeast coastal areas. The differences of regional topographies, climatic conditions, and water resources are the driving force for invention and creativity of the Chinese traditional irrigation engineering. For example, in the arid region of the Turpan Basin in Xinjiang in western China, Karez wells were developed for irrigation. The Yellow River flows through Ningxia and Inner Mongolia Plains. Therefore, complete irrigation system there was built in the region 2,000 years ago. In the North China Plain without adequate surface water, the rainfed agriculture historically relied on field irrigation works developed at least 3,000 years ago. In the humid southeast coastal region, the rice has been grown with traditional irrigation practices since 7,000 years ago. Most of water diversion projects, distributed in the plains and barrage ponds for water storage in hilly areas have history of more than 300 years and, are still utilized today.

THE PROCESS OF CIVILIZATION AND IRRIGATION DEVELOPMENT

In the 5,000 years of Chinese history, agriculture has always been the major political and economic support. The rise and fall of a dynasty was closely related to

a Professor, Water Resources History, IWHR, Chair of China Water Resources History Research Association. Interesting Research on China Water Resources History, Protection of Water Heritage. Website: http://sls.iwhr.com/history/engineer/A3603index_1.htm.

Figure 1. Rivers, lakes and irrigation belts in China

food. Under the specific natural environment of China, irrigation and technology often represent the degree of agriculture development and also reflect political, cultural and economic fundamentals in different historical periods.

The origin of water with civilization (about 4000 BC to the 200 BC)

The first page of recorded Chinese history was about water management by Dayu. Around 4,000 years ago, Chinese people living in the Yellow River and Huaihe River basins began the change from mountain hunting and livestock to agricultural practices. Devastating floods lasting 10 years landed the tribal people into impasse. Under the leadership of tribal chief Dayu, the Chinese diverted the floods, moved out of the plight of disaster, and rebuilt their homes. After the success of flood management, the first Chinese dynasty, the Xia Dynasty, was established. In the 7th century BC, China entered the spring and Autumn Period with the most active thoughts. The feudal system in the Zhou Dynasty formed several relatively independent vassal states with numerous political and economic exchanges. Agriculture in the vassal states began to get wide attention.

The birth of irrigation and irrigation engineering

Irrigated agriculture is the symbol of the origin of Chinese civilization. Without any written record, it is difficult to know the exact time of the occurrence. Chinese irrigation can be traced from Zhejiang Hemudu ruins dating back 7,000 years ago. Archaeological discoveries included ancient paddy/rice and well remains, showing the presence of irrigation in the rice civilization. From archaeological studies, an irrigation system dating back 3,600 years ago was also found near the Shang capital. From the channel remains of 245 m, significant differences among main, lateral, and field irrigation channels were clearly observed. Stone dike for water diversion was found at the intersection of the main and lateral canals. Changes of channel cross-sections indicated the places to separate field channels from a lateral canal. A field was divided into several rectangles by the criss-crossing channels. There were significant elevation differences among canals and among fields.

Figure 2. Schematics of Quebei project (drawn in the 19th century). This water storage project was built in 605 BC. With land reclamation, the water area nowadays is only 30% of that 2,000 years ago

The Western Zhou Dynasty (11th century BC to 476) had well developed agriculture. The economic centre at that time was located in the downstream of Yellow River, i.e., Shandong and Henan areas of today. In the Western Zhou Dynasty, an irrigation system was regarded as a 'divine kingship' system, i.e., 'Ida irrigation canals'. With the system, a piece of land was divided in '井'shape, i.e., 9 smaller pieces. A storage well was located in the central piece and the remaining eight pieces were of arable land surround by canals. The first collection of poems in China, 'The Book of Songs', depicted the scene that farmers near the Western Zhou Dynasty's capital, Gao Jing (now southwest of Xi'an) took water from Biao Pond to irrigate rice. Biao Pond was a water storage pond, which was connected with rice fields by channels (Figure 3). Around 400 BC, the literature on 'Zhou Li' (i.e., the Zhou ritual system) was documented and officials for the irrigation management were designated, such as 'Rice Men', whose main responsibility was to manage water storage ponds and channels.

Around 1000 BC, China was in the heyday of the spring and Autumn Period ruled by the Zhou Dynasty. The Chu vassal state located in the Jianghuai plain was the most prosperous kingdoms. In 605 BC, Sun Shuao of the Chu built Quebei project (Figure 2) in the Huaihe River tributary of Shi River and built Qisibei project in another tributary of Guan River. These two water storage projects provided a strong support for the agriculture development of the Chu vassal state. Since 2000 years, these two projects have been continuously managed. Water storage capacity is now more than 100 Million m^3 and irrigation areas are 12 Million mu (1mu =1/15ha).

Figure 3. Lifting water with shadoof (palace Farming and Weaving figure in the 18th century)

Wells and irrigation

The beginning to utilization of wells was an important landmark event of civilization, which indicated that human settlements could prosper far away from rivers to seek wider spaces for survival and development. In the spring and Autumn Period, in today's Hebei, Shaanxi, Shanxi, Henan, Shandong, and other northern arid or semi-arid areas, wells became general sources of water for irrigation and life, which showed that the agricultural production in these regions had been developed to a certain level.

According to a legend, the follower of Dayu, Boyi, was the inventor of wells. Well water was first used for living beings. Well water used for irrigation was attributable to the invention of a water lifting tool, shadoof. Well irrigation might originate in aristocratic gardens in the Warring States (4th century BC). During this period, fields with canals and wells were considered to be ideal field system under the royal rule. In the 1st century BC, well water had become a source of irrigation water with supporting irrigation canals. Around the 3rd century, windlass began to be used to take water from deep wells for irrigation. Deep well water was often stored in open ponds to increase temperature, then allowed to flow into farmlands through canals. Wells, equipment to take water from the wells, and canals constituted the well irrigation system. However, well water irrigation was not widely used in the fields and only for small-scale manors, courtyard gardens, or landscape. Until the 14th century (during the Ming and Qing Dynasties), the Chinese population increased to 100 Million. After wheat began to occupy large areas of China, the central and local governments allocated funds to support farmers in the northern semi-arid plains to develop upland well irrigation. Since then, well irrigation had been widely applied in the fields.

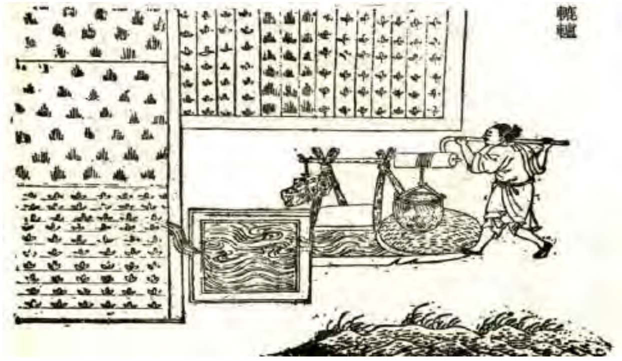

Figure 4. Windlass used for taking water from well: well irrigation (drawn in the 13th century). During the 1st to 5th centuries, well irrigation was commonly used in gardens. The invention of windlass made it easier to take water from deep wells. After the 13th century, wells became main water source for irrigation in farmlands of the North China plain

Irrigation project in the Qin and Han Dynasties (the 3rd century BC to the mid of 3rd century)

From the 3rd century BC to the 1st century, during the formation of the Qin Empire, the first climax to build large water diversion projects appeared in China. In 422 BC, the Wei State built twelve canals of Zhangshui in the Haihe River basin. In 256 BC, the Qin State built Dujiangyan in Minjiang River of Sichuan. In 246 BC, the Qin State constructed the Zhengguo Canal in Jing Rive, a third tributary of the Yellow River. These projects provide stable water sources for the valley and alluvial plains, which benefited agriculture as well as the development of water transportation. The earliest urban and rural areas were developed in these regions.

Dujiangyan

Dujiangyan was a water conservancy project constructed after the ambitious Qin State conquered the other six states to complete reunification. Dujiangyan is located in the upstream of the Minjiang River and northwest of Chengdu, where the Minjiang River enters into the Chengdu Plain. The terrain here created a good condition for natural water diversion. To introduce water of Minjiang River into Chengdu, the first was to cut a water inlet. Baopingkou was the permanent inlet cut at the end of the Minshan mountain and also the earliest key project of Dujiangyan. The successful construction of Baopingkou opened up broad prospects for the development of Dujiangyan. Dujiangyan has undergone continuous improvement and development processes. No later than the Tang

Dynasty, the headwork already had the present scale (Figure 6). The key water control works consisted of the water division project (i.e., fish head), water diversion project (i.e., baizhang dike and 人shaped dike), water regulation project (i.e., Feisha weir) and, water inlet (i.e., Baopingkou).

Ancient Dujiangyan irrigation region almost covered the whole of Chengdu Plain. The irrigation areas were 200,000 qing (1 qing = 100 mu =100/15=6.667 ha). Navigable waterways crossed the different directions of the Chengdu Plain, which were also the main flood channel of the plain (Figure 6). After the main canal entered into Chengdu, the canal system continued to be improved, which formed the urban landscape water system of Chengdu. The advantages of irrigation and water transportation made Chengdu to be one of the important commercial cities with national economic prosperity since the Han Dynasty. The Chengdu Plain was known as the 'Land of Abundance'. The engineering technologies of Dujiangyan produced wide and long-term effects. Similar diversion dam types, canal planning, and architectural style could be found in the southern China, Japan, and Korea. Even the names of hydraulic and river components in these areas, such as bamboo cages and Macha were similar.

Figure 5. The statue of Dujiangyan creator, Li Bing. In 168, the official of Dujiangyan management, 'Dushui Yuan' constructed the statue, which was a symbol of Dujiangyan regulatory agencies in the Han Dynasty.

Zhengguo Canal

Zhengguo Canal was built in the 1st year of Qin Dynasty (246 BC), which was a landmark project for the evolution from the vassal states with the feudal system to the centralized dynasty. Zhengguo Canal was named with the name of its planner and developer, 'Zhengguo', who was China's first hydraulic engineer on record. Zhengguo Canal was built with sound planning and design. Taken from Jing River, water flowed along the main canal of Zhengguo and entered Lo River. The main canal was 150 Km long and flowed from west to east along highest line of the second terraces on Weibei plain. The areas in the south of main canal were with gravity irrigation. Water from Jing River with high sediment and organic matter content was used as the irrigation water, which made saline fields and infertile Weibei plain become fertile fields.

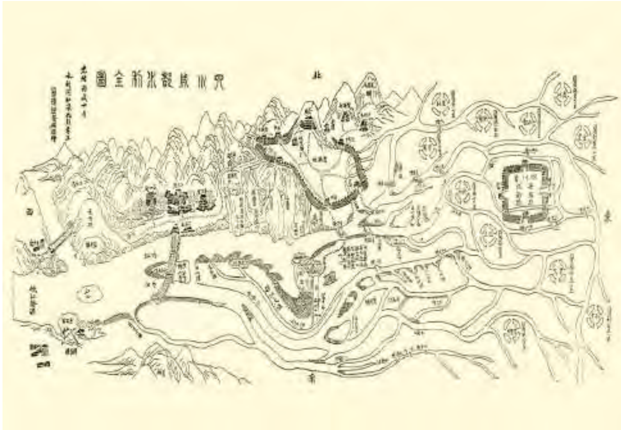

Figure 6. Dujiangyan and the canals on Chengdu Plain (drawn in 1886). Since the 2nd century Dujiangyan irrigation system has been distributed in the plain.

The successful project planning of Zhengguo Canal laid the foundation for the expansion of irrigation areas later. In the Western Han Dynasty (140 BC – 135 BC), a new canal (Bai Canal) was constructed along the Zhengguo Canal southward.Bai Canal was named with the surname of a person, who proposed to construct this canal. Thus, Zhengguo Canal was renamed as 'Zheng Bai Canal' later. Zheng Bai Canal benefited areas, including counties of Jingyang, Sanyuan, and Gaoling of Shaanxi, with irrigated areas over 180,000 qing (1 qing = 100 mu =100/15=6.667 ha). In the Tang Dynasty (618-907), Zheng Bai Canal continued to be expanded. About the 8th century, imperial relatives and dignitaries in the capital Chang'an purchased land and operated manors in the irrigation region of Zheng Bai Canal, and operated water mills on the main canal, resulting in decrease of irrigated areas by 6200 qing (1 qing = 100 mu =100/15=6.667 ha). The Tang government had to promulgate the 'Mizube style' to stop these actions to protect the irrigation areas. 'Mizube style' has become the China's first irrigation law.

In the Song Dynasty (960-1127), because of riverbed gullies of Jing River, it was difficult to get water from the diversion head works of Zhengguo Canal. Emperor Shenzong allocated government relief funds to reconstruct the Zhengguo Canal head works in Xining 5th year (1072 AC). The reconstruction project was not completed because of severe drought in Guanzhong. After 36 years, the renovation project was completed and the main canal constructed and extended for two kilometers upstream. From the 12th to 15th century, the head works was moved upstream for several times. Finally Zhengguo Canal could not completely obtain water from the river and spring water along the canal was used for irrigation. the irrigation areas were only over 1300 qing (1 qing = 100 mu =100/15=6.667 ha) in the last year of the Qing Dynasty (1911 AC). In 1930s, a project to take water from Jing River (i.e., Jinghui Canal) was built. In the upstream of the Zhengguo head works built in the Song Dynasty, an overflow dam was constructed with a length of 68 m and a height of 9.2 m. On the right bank a three hole intake was set up. Below the head works, ancient channels were utilized and finally irrigation was partially restored. After the 1950s, the dam of Jinghui Canal was heightened several times, the channels continued to be improved, and the modern irrigation areas increased to 80,000 qing (1 qing = 100 mu =100/15=6.667 ha).

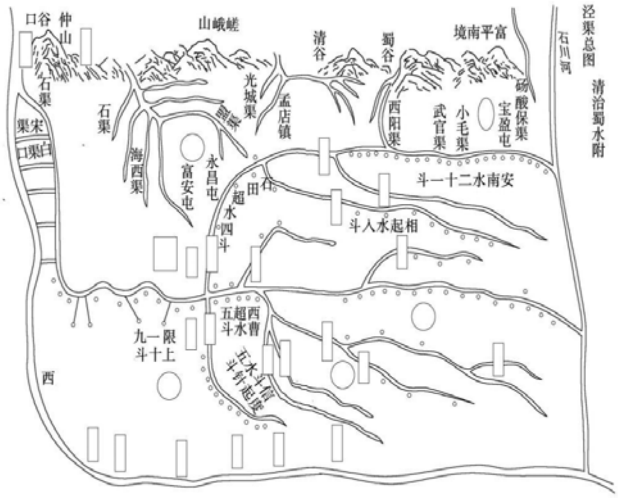

Figure 7. Zhenguo Canal and the related system (13th century). The figure shows the changes of inlets from the 3rd century BC to the 11th century. Jing River irrigation project maintained the sustainable development of agriculture in the Guanzhong Plain for more than 2,000 years

The period for continued irrigation progress and irrigation machinery invention (from the 3rd to 13th century)

In the 3rd century, the powerful centralized rule in the Han Dynasty gradually declined. China has entered an era, during which local separatist regimes fought each other. In the 4th to 5th century, not only frequent wars happened among the separatist regimes in the north, but also the Western Turks, Huns, and other ethnic groups invaded China. The Southern and Northern Dynasties experienced the most turbulent time in the Chinese history, during which the centralized control was temporarily lost. Therefore, this was an active period to be full of ideas and culture and also a period of inventions for irrigation and water application machinery.

After the 3rd century, without the central control, powerful families with huge land had the opportunity to quickly develop. Thus, the manor agriculture in the north became prosperous. Decline of the population and prosperity of the manor economy led to the demand for machinery. In this particular period, water mills and other hydraulic machinery for food processing, and cylinder cars and small equipment for irrigation and drainage began to be used in potential royal manors. Some nobles or imperial officials used these machines to show off their status and wealth.

After the 5th century, the agricultural economic centre shifted to the south. With the rapid development of south-eastern coastal areas, a great number of weir dams were built. Tasha weir in Yin county of Zhejiang and Mulan Pei in Putian of Fujian were the representative works in this period. In the shorter rivers of the south eastern coastal areas, weirs and dams were used to block tides and to store water from upstream. These projects were used not only for irrigation, but also as an urban or rural drinking water sources.

Hydraulic power application and irrigation machinery invention

Main inventions of hydraulic machinery included cylinder cars used for irrigation or drainage (Figure 8), and water pestles, water mills, and water spinning wheels used for industry processing. In the Tang and Song Dynasties, thriving business and developed agriculture promoted the wide applications of the hydraulic machinery and water power lifting irrigation. The hydraulic machinery was used by ordinary people and even in distant regions and remote mountainous areas. After the 13th century, the hydraulic spinning wheel and hydraulic blower gradually disappeared.

In the 13th century, Wang Zhen wrote the first book 'Agricultural Book' to record developments in agriculture and irrigation. In the book, the author systematically recorded irrigation machinery used at that time or already lost, and the lost ancient water irrigation and hydraulic machinery for food processing.

Figure 8. Hydraulic lifting water: the cylinder cars in working (drawn in the 19th century). The diameter of cylinder car or water wheel is generally 2-3 m, which determines the height to lift water. Cylinder car was commonly used as urban and rural water utilities before the 20th century

Figure 9. Hydraulic machinery used for pottery (drawn in the16th century). Pestle driven by water wheel was used to mix clay, which greatly reduced labour

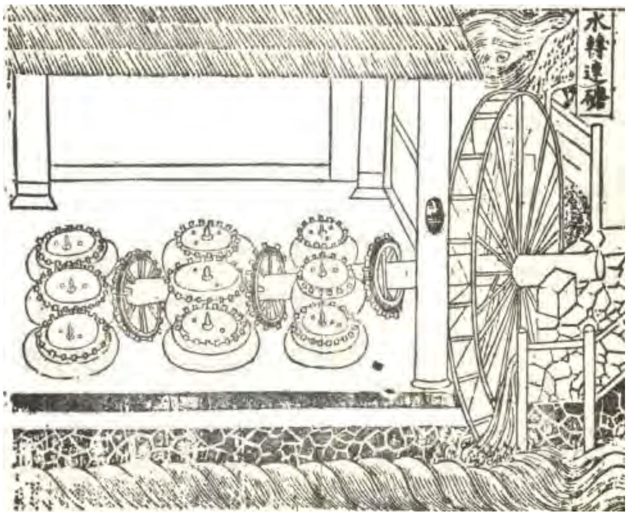

Figure 10 Multiple water mill (drawn in the 13th century). This was an ancient water mill set for grain processing. A water wheel could drive multiple water mills

Tuoshan weir

Tuoshan weir was built on the Yin river of Ningbo, which was an integrated hydraulic project for salty water blockage, fresh water storage, irrigation, water supply, and drainage (Figure 11). In the 7th year of the Tang Dynasty (833 AC), the magistrate of Yin county, Wang Yuanwei, was in charge of the construction of Tuoshan at the location 75 Km from the southwest of Ningbo today. The main body of Tuoshan weir was a spillway dam with a length of 130 m and a height of 8-9 m, which crossed Yin river to block salty water and to store fresh water. In the downstream of the main stream, three sluices, i.e., Wujin, Jiddu, and Xingchun, were built. During the flood season, flood water was introduced to Yongjiang river. At high tides, the three sluices were opened to introduce the fresh water pushed by tides into irrigation canals, which played the role to block salty water and to store fresh water. Tuoshan weir provided the main water source for the ancient Ningbo city. Water introduced by the main canal was stored in 'Ri' (day) and 'Yue' (month) lakes in the city and water supply canals were distributed along the streets.

Figure 11. Tuoshan weir and the related canal project

Mulan Pei

Mulan Pei was located on Mulanqi 4 Km of southwest of Putian in Fujian and built in the Northern Song Yuanfeng 6th year (1083 AC). Until today the project is still working to irrigate over 10,000 ha of farmland in Putian plain. Mulan Pei was built at the tide traced end so that it can stop tides, prevent farmlands from salty water, and store fresh water from the mountain streams in the dam upstream. The key project of Mulan Pei consisted of the dam, spillway weir, flushing gates, and diversion components on the right and left banks of the river. The dam is 111.13 m long and 7.25 m high, along which there are 32 gates. So far, the project has been working for about 1000 years. There is basically no sedimentation in the dam and two inlets are still in the normal use. The irrigation region of Mulanqi was divided into Nanyang and Beiyang, which were controlled by the main canals on the left and right banks, respectively. Drainage water enters into the sea at Sanjiangkou of Putian. Now the storage capacity of Mulan Pei is 30 Million m^3 with irrigation areas of 13,000 ha.

Figure 12. Mulan Pei in Putian of Fujian (photo was taken in 2013)

The culmination of irrigation development (from 14th to 19th century)

In 1270s, the Mongol army commanded by Kublai Khan matched long way from the northern grasslands to the south and established a unified regime in China: The Yuan Dynasty. In order to transport grains from the south to Beijing, the Beijing-Hangzhou Grand Canal of 1700 Km was constructed. Rice produced in the south was continuously shipped to Beijing through the canal, which stimulated the agricultural development in the south. Food production in the midstream and downstream of the Yangtze River supported the China's economic lifeline.

In the Ming and Qing Dynasties (1368-1911), China's population was more than 100 Million, increasing the pressure for food supply. With the increase in population, food production areas were also rapidly expanded. Even in the arid northwest and cold northeast, lands began to be reclaimed. On Hetao Plain (i.e., Ningxia and Inner Mongolia) in the upstream of Yellow River, irrigation project development in this period was much faster than any previous historical period. In Fujian, Hainan, and Taiwan of the southeast, and Yunnan, Guizhou, Sichuan of the south-western, various irrigation engineering patterns were developed under the different local conditions and natural environment conditions.

Before the 11th century, China's major agricultural crops were rice in the south and millet grain in the north. With wheat, corn, and sweet potato incoming from abroad to China since the 2nd century, rainfed agriculture began to develop in alpine and sub-alpine areas, where originally only tribal peoples lived. In the 14th century, rice agriculture, originally form the south, was developed in the hilly regions. Terraces with irrigation system resolved the problem of rain-fed irrigation. Rice fields with high yields also appeared in some areas with poor natural conditions.

In the mountain areas with slope greater than 45° C, the rice terrace system is a homogeneous system composed by vegetation, irrigation and drainage systems and terraces. The system helps achieve the objective of soil conservation leading to agricultural benefits, and more importantly, it maintains the natural environment of the region.

Irrigation projects in arid Xinjiang

In the Qing Dynasty, Chinese territory extended to the northwest. In the Kangxi and Yongzheng periods, farming lands began to be reclaimed in the northern region of Xinjiang and irrigation projects were also developed. In the 18th century, Sibo soldiers stationed in the Ili region constructed Chabuchaer Canal (Chabuchaer in Xibo language means granary), which introduced water from Ili River for rice fields. This was the only rice growing area in Xinjiang. In the 19th century, Huangque Canal was built on the Ili River tributary of Kashgar river. Thus irrigated areas in the Ili plain reached 200 Million mu (1mu =1/15ha), which became a granary in the northern Xinjiang. With the continuous irrigation benefit, the area is still the most prosperous agricultural region of Xinjiang today. In Turpan and Hami Basins in Xinjiang connected with Tianshan in the north, water from snowmelt infiltrates into the ground through the gravel soil. Before the 19th century, the local Uighur landowners began to build Karez wells to irrigate vineyards. After the 19th century, the construction of Karez wells was supported by the government funding. After the 1980s, motor-pumped wells were commonly used while the Karez wells were on the edge of disappearing. The use of water resources with Karez wells is beneficial to maintaining ecological oasis. Therefore, protection of Karez should be of great value from the ecological and cultural aspects.

Figure 13. Diversion project of Yili River in Xinjiang: Chabuchaer canal headworks (built in the 17th century, water diversion without dam)

Figure 14. Xinjiang Karez (the junction section of culvert and open channel)

Subalpine rice terraces and irrigation systems

China is one of the world's oldest countries to build terraces. The northern rainfed terraces may have appeared in the 2nd century BC. After the 9th century, the south region of the Yangtze River was gradually developed. With the population increase, lands in hill and mountain regions were gradually developed and terraces for growing rice were constructed. Terraces were built from the bottom up and rainfed fields gradually evolved into rice terraces. Terraces are widely distributed in southern China, among which Yuanyang Hani terraced fields in Yunnan, Ziquejie terraces in Xinhua County of Hunan, and Longji terraces in Longsheng County of Guangxi are most famous:

(1) *Ziquejie terraces in Xinhua County of Hunan.* Ziquejie terraces (Figure 15) were located in Xuefeng Mountain of the west of Xinhua County of Loudi. A total area of 60,000 mu (1mu =1/15ha) of terraced fields were distributed in hillsides with the vertical height of 500 m and with more than 1000 terrace levels. With annual rainfall of 1200 mm, it is a rain-fed agricultural area in the southern China.

Ziquejie terraces are located at the most northern end of China's subalpine rice terraces. Ziquejie terraces were constructed in the 11th century with a history of 1000 years. In Xinhua region, the earliest aboriginal ethnic groups were Miao, Yao, and Dong. In the 9th century, Han's entrance brought farming civilization from the Central Plains. Most likely, this was the birthplace of subalpine rice terraces in China. In the Ming Dynasty, the agricultural practices reached the neighbouring Guangxi, Guizhou , and Yunnan, and were accepted by different ethnic groups.

The Ziquejie mountainous areas had thick red loam soil layer with high water holding capacity in the soil. Terraces were distributed along the contours. The rich rainfall in the region guaranteed the basic need for rice growing. In spring and during early rice seedling stage, small amounts of supplemental water was needed for irrigation. Spring water seepage was an important source of irrigation water in the spring and during drought years. Water was diverted to each terrace through field ditches and streams. In each terrace, there was a small irrigation system that included soil pores, rock fissures, and mini ditches. Over the hillsides, slopes, sizes, lengths, widths, and heights of cascading terraces were different, which were beneficial for the stability of slopes, minimizing erosion.

(2) *Hani terraces in Yuanyang of Yunnan.* Hani terraced fields (Figure 16) were in the south of Ailao mountain in Yuanyang County of Hani and Yi Autonomous Prefecture in Yunnan Province. Terraces with different shapes were connected with each other, where the largest rice field could be of more than 1000 mu (1mu =1/15ha). Terraces distributed on cliffs were with slopes of 15 to 75 degrees. At the most, over 3000 levels of terraces were constructed in one side of a hill. Terraces extended from the river valley to the mountains over 2000 m above sea level, reaching the highest limit of rice growing.

Around the 6th century, Hani ethnic group lived in the Ailao mountains and began to grow rice about the 16th century. With the 198,000 mu (1mu =1/15ha) of terraced fields in Yuanyang County as the center, the terraces extended to several surrounding counties, with a total area of 1.05 Million mu (1mu =1/15ha). Hani people believe in natural ecological concept. Mountains regulated by the villages were considered as sacred mountains and deforestation was strictly prohibited. Hani generations' rituals were about the Water God worship. Their ritual during festivals were arranged at the time for rice planting, flowering, and harvesting. These practices became the genes for terrace cultural heritage.

Figure 15. Ziquejie terraces in Xinhua of Hunan

Figure 16. Hani terraces in Yuanyang of Yunnan

(3) *Longji terraces in Longsheng of Guangxi.* Longji terraces (Figure 17) were located in Longji mountain (Ping'an village) in Guangxi. Longji mountain had an altitude of nearly l000 m and, slope mostly in the range of 26 ~ 35º, and the maximum gradient of 50º. Terraces were distributed at altitudes of 300-1000 m and the total area of Longji terraces was about 66 Km^2. Longji terraces were started to build in the 13th century and completed in the 17th century, with a history over 650 years and a total area of terraced rice fields of 99,000 mu (1mu =1/15ha). The mountains were steep and the area of many

terraces was smaller less than 1 mu (1mu =1/15ha). The local people said: 'One frog hop can cross three terraces.' In the deep mountain regions, forests, terraces, and villages distribute along the mountains as follows: forest were on the top of mountains for water conservation, villages were in the middle, and terraces were around the villages and extend to the foothills. Longji terraced fields distributed along the contours formed a convenient gravity irrigation system, which meet the demand for rice irrigation and also avoid soil erosion in mountainous areas. The construction of Longji terraces provided a valuable experience in achieving food self-sufficiency and maintaining good regional ecological environment.

Figure 17. Longji terraces in Longsheng of Guangxi

CONCLUSIONS

The unique natural and geographical conditions make irrigation an important component in civilization building in China. The origin and development of irrigation engineering was of historical significance in the evolution and spread of civilization in the regions. In China, there are many irrigation projects with history of more than several centuries or even millennia. The continuation of irrigation projects implied the continuation of its management and cultural accretion, which reflected the wisdom of ancient people to deal with the relationships between human and water, and their values for water. Irrigation project management and administration promoted the close links between water and the societies as well as the culture, which merged with the regional folk customs, religious, and architectural culture.

Traditional irrigation projects, with the different styles of water conservancy engineering, ecologically valuable engineering structures and hydraulic components, or valuable literature and archives, formed the precious cultural heritage. Since the 20th century, with the rapid development of modern technology, we have lost the necessary attention to the ancient water conservancy projects and thus, many ancient irrigation works were devastated in the so-called modernization process. Motivations for quick success and short-sighted behaviours drove people, in some regions, to obtain financial benefits from conversion or demolition of ancient water conservancy projects. To learn historical wisdom and preserve irrigation civilization, it is necessary to protect the ancient irrigation heritage to start with, which may be the best illustration of sustainable development.

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High Angle Shot Merwede Canal Surrounded by Grassy Fields Captured, The Netherlands

CHAPTER – 3

The Roles of Management in Sustainability of Irrigation Systems

Charles L. Abernethy [a]

INTRODUCTION

The areas of land equipped with irrigation facilities increased greatly during the past half-century. In the same period there was also a great need for repair and rehabilitation, not only of ancient irrigation systems, but also of some that were quite recent. There has also been much loss of formerly irrigated lands. Some lands have been abandoned by its users and some others have been absorbed into growing cities.

Yet it is not hard to find irrigation systems, operating today, that have been in existence for a century or more. The question now is, when we look at a recently constructed irrigation system, how can we estimate the chances that it will still be operating after such a long time? What lessons can the history of irrigation bring to the question of why some irrigation systems have long lived, as much as a thousand years, while others failed and went out of use after quite brief periods?

Irrigation systems may fail in various ways. Failures may occur suddenly, or they may be gradual. Sudden failures are most likely in systems that depend on dams, which may be breached or overtopped. Sudden failures are dramatic, and can cause great hardship to communities, because they may mean loss of all local capacity for food production, for some extended period. Therefore, we are more likely to know about those in historic accounts. That does not mean that they are necessarily more common. An irrigation system may fail slowly, rather than suddenly. Quite possibly, gradual failures are more numerous than sudden ones; and they may happen through long-term deterioration, over many years or even decades.

An irrigation system is sustained by good management. It needs the proper performance of a set of processes that we call governance, organisation, operation and maintenance. We can think of these processes as four levels of management which, together, ensure that the physical system performs its expected functions, and remains fit to continue doing so. In brief:

- Governance means setting strategies, selecting leaders and decision-makers, making decisions about necessary changes, assembling resources of labour and finance, and setting out common rules of behaviour as well as procedures for dealing with breaking of such rules;
- Organisation means forming and controlling teams of people who will execute the tasks of operation and maintenance, and monitoring their outcomes;
- Operation means the daily adjustments of water-control equipment to send water through the
- system from its source and distribute it to the users;
- Maintenance means activities that keep all the physical facilities in suitable condition for fulfilling their functions.

Sustainability of the irrigation system cannot be expected, unless all above four management functions are performed well. However, we must not suppose that a system of management which seems to be successful at one point in time will continue to be successful far into the future. An irrigation system comes under many kinds of stress, due to external and internal factors. To be sustainable in the long term, it needs management arrangements that are flexible, and can adjust to cope with changing circumstances. Moreover, every one of these four management activities require an input of resources – labour,

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finance and equipment etc. These resources have to be found, continuously, throughout the life of the irrigation system, and the ways by which they are found and used has direct impact on the quality of the management functions.

Throughout the history of irrigation, we can discern two contrasting styles of management, which have probably been present almost from the early period of irrigation, some thousands of years ago, and which continue to the present time. We may call these two classes external and internal management; or we may call them state-management and self-management.

An internally managed system is one where most of the management decisions and functions are done by the people who are using that irrigation system. An externally managed system is one where decisions and management functions are done by people who are mostly not users: today, that usually means that these managers are officials of a state bureaucracy. The principles of sustainability seem to be different, between these two styles.

A third category is management by companies. Such enterprises are comparatively recent, though they began to appear in the 19th century, and have been increasing significantly in recent times. Often, they are focussed on the production of a specific crop – sugar cane, for example, or high-value fruits – and often the investment in establishing them and operating them is linked to the management of a processing factory in the same region.

If an irrigation system is internally managed, it must still be able to deal with many external participants. Government officials, traders, and landlords, providers of finance, and people who use the same water source for other purposes, or who depend on other water-related natural resources such as fish or timber: all of these groups of people can affect the viability and sustainability of an irrigation system.

Before we proceed to look at some specific examples, we should note the remarkable complexity of irrigation management, because this is important in any consideration of principles of sustainability, and the roles of management in achieving it. When we consider these, we should not think of management as some separate, external activity. The users of an irrigation system have to do many things themselves, and must co-operate, if it is to work well.

Irrigation systems are sometimes regarded (by people who are not involved in them) as rather simple rural enterprises. In reality, they are among the most complex and challenging joint activities. They usually have large numbers of participants, and many objectives. The life of an irrigation system may extend through centuries, and goes through many phases – construction, operation, renewal, extension, technological innovation and product changes. The demands on its management arrangements are different in each of these phases.

The scale of irrigation systems varies enormously. There are tiny systems of a few hectares, where perhaps a few families have come together to grow vegetables using a shared well or pump; and from there the management units range upward to the Gezira scheme in Sudan, which could irrigate 800,000 ha from a single source. The numbers of users, and the extent of each user's land, also vary greatly. Management principles in, for example, Vietnam cannot be the same as in Australia or the United States, where the number of farm families per square kilometre may be several hundred times fewer.

The water that is applied to the fields of an irrigation system may originate in a lake, river or aquifer, and must go through a series of processes – capture, storage, conveyance, distribution and application – before it reaches the plants/fields. Every user is interested in the performance of all those processes, but the users' interests are not all the same. For example, an irrigation user whose land lies near to the water source will be much less interested in the good performance of the functions of conveyance and distribution, but for the 'tail-end' users, these are of high importance.

The nature of the water source itself is significant for the viability and sustainability of an irrigation system. The Nile is perhaps the greatest example of a source that could deliver a high level of natural sustainability: its natural flow is highly regular; its single annual rise is unusually predictable, its sediment content is moderate and relatively fine, so it delivers a little increment of soil to the land on its flood plain, each year. Rivers with higher ranges of flow, greater amounts of coarse sediment, and so on, require much more interventions, if irrigation systems dependent on them are to be sustained.

Thus, the sustainability of an irrigation system is related to many sorts of factors. They may be classified, broadly, as the system's natural environment, economics, social co-operation, and management. If we want to assess whether a new irrigation system, or any other new engineering installation, will be sustainable, we must try to predict the future. We cannot really know how the conditions within which it operates will change. The same is true, even more, for organisations and institutions. Politics, economics, social values, and many other external factors will vary and change and the stresses under which the system has to function will become different.

All the factors of complexity that have been discussed above exists today, and had been present throughout the history of irrigation. Yet irrigation, although it is obviously difficult to manage, is one of the oldest of communally organised human activities. It may have begun in the region that is now south-eastern Turkey, near the upper reaches of the Tigris River, perhaps in the 7th millennium BC. But it seems that it was invented separately in many other parts of the world. When we come to the 2nd and 1st millennia BC, there were irrigation systems in what is now Vietnam, in North China, in Mexico, in the Tigris and Euphrates basins, in Egypt, in the Indus basin, in southern Italy, and some of these seem to have been in existence since a long time before.

But, when we try to identify the early period of irrigation, we do not have written records, and we can learn nothing practical about the earliest modes of management. It seems reasonable to assume that the earliest systems would be small, and would be built and operated by their own users. However, by the time that historical information about management starts to appear, such information tends to be about larger systems in which the state had some role. That does not mean that self-management did not exist: most probably, state-management and self-management have both always been present, but state-managed systems are more likely to leave documentary data.

One of the first indications that we have shown the significance of maintenance and operation was well understood. In Babylon, probably about 1760 BC, the codes of laws given by King Hammurabi were carved on to a great stone (Richardson, 2000). Four of these laws dealt with irrigation. The first of them specified punishment for neglecting maintenance:

> *'If a man has been careless regarding the maintenance of his field dyke and he has not maintained the ditch and a breach has occurred in the dyke which destroyed the cultivable area, the man in whose dyke the breach occurred shall restore any grain that may have been lost.'*

The next law says that, if the guilty farmer who neglected maintenance of these field bunds was unable to hand over sufficient grain to the affected neighbour, then he should be sold as a slave:

> *'If he is not able to recompense with grain, they shall exchange him and his property for silver, and the men in the cultivable area whose grain the water destroyed shall share it'.*

Such severe treatment of offenders shows that the importance of maintenance, and the dangers of neglecting it, were already well understood, nearly 4,000 years ago.

The problems of clumsy operation were also recognised, in the ensuing two laws, which specified penalties for opening water-delivery systems in a way that would inundate or damage a neighbour's land.

The relationship between state authorities and the users of irrigation systems is frequently mentioned in early references to irrigation. Many such comments indicate the need for irrigation systems to have some kind of external arbitration, which might be provided by the state. For example, in the 3rd century BC, a Greek ambassador, Megasthenes, having visited the court of the north Indian emperor Chandragupta Maurya, described the role of a district officer:

> *'The district officer measures the land and inspects the sluices by which water is distributed into branch canals (watercourses), so that everyone may enjoy his fair share of benefit.'* (Framji et al., 1984)

Comments of this sort show awareness that the users of an irrigation system do not co-operate easily or automatically. There is an inherent rivalry among the users, especially in places where the water is scarce, or where it varies seasonally. Some kind of external mediator is often needed. This mediation service is important for the sustainability of the system, and there are examples where it has been provided by the state, or by the priests, or by some nearby city that is dependent on the products of that irrigation system.

The failure of the Great Dam of Ma'rib, in Yemen, in the 7th century, was a great and dramatic event (Wolfrum and Wolfrum, 2001). It illustrates a different aspect of sustainability:

This dam was one of the largest dams built in ancient times, and it had a long life. It probably existed from the 5th century BC, and it performed its function of storing water from the wet season, for release to its dependent irrigation systems in the dry season, until the early years of the 7th century. The dam lay on the eastern side of the Yemen plateau, where flows would be variable and could carry large amounts of sediment. A dam in such a position would need frequent maintenance/ de-siltation, changes of its spillway and so on, to respond to sedimentation within its reservoir. It seems clear that the dam structure itself, and the irrigation services it delivered, proved to be sustainable, over a period in the order of a thousand years.

Yet the entire system failed, probably in the first two decades of the 7th century. It was a famous calamity at that time. The revelation of the Koran occurred in this period, and in chapter 34, the social disaster is, thus, described as:

> *'For the natives of Sheba …. there was a garden on their left and a garden on their right…...But Allah unloosed upon them the waters of the dams and replaced their gardens by two others bearing bitter fruits, tamarisks and a few nettle shrubs (Dawood, 1956).*

The immediate cause of this collapse appears to have been the inability of the state to keep up with the maintenance needs, especially sediment control, of a large dam on a waterway that carried a heavy silt load. But we have to look at this in its longer-term context. The region around the southern Red Sea had enjoyed a long period of prosperity. At the time of the dam's failure, it was controlled by the kingdom of Saba (or Sheba). That kingdom, and other neighbours such as Himyar, may have reached the highest point of wealth and success around the 1st century. The Bible says that, after the birth of Jesus, three kings brought gifts of gold and myrrh and frankincense (Bible): these were costly indicators of the highest esteem. Saba and adjacent kingdoms gained great advantages by their control of overland trade routes, along which the incense products of myrrh and frankincense were brought, from their sources beside the Gulf of Aden (and perhaps gold, mined in India), up to Egypt and to cities of the 'Fertile Crescent', such as Damascus or Jerusalem.

But that trade advantage weakened, from the 1st century onward. Egypt was being integrated into the Roman Empire. Maritime trade up the Red Sea became more secure, and gradually began to replace the overland trade. This must have weakened the revenues of Saba and the other states near the Ma'rib dam

The de-silting of the Ma'rib dam must have been a huge operation. Labour forces of 20,000 had to be assembled (Brunner, 2000), at long intervals, to perform the tasks. It is quite possible that part of such a large force would be obtained by capture of men in wars from neighbouring states; but it seems sure that a strong state was necessary, and that the task of de-silting became more difficult, and probably less frequent, as the state weakened, until at last it was insufficiently done, and the irrigation system was overwhelmed in a high flow. So, this seems to be a case where sustainability persisted while the state was wealthy, but was lost in a time of economic weakness.

In north central Sri Lanka, nearly twenty large earth dams (several of which were contemporary with the Ma'rib Dam) offer an example of a different sort for sustainability. The first of the major dams, Tissa Wewa, was built in the 3rd century BC, but substantial structures of that kind probably date back to around the 5th century BC (Brohier, 1934). As with other examples of large engineering works, it is reasonable to assume that the skills necessary for building such dams would have been developed on previous, less ambitious projects. Early builders had to learn the correct selection and placement techniques for the construction materials, optimal gradients of the dam walls, planning of spillways, and design of flow-control devices that could be opened or closed under the pressure of as much as 10 metres of water. It seems sure that many failures must have occurred, as the learning process went on. It seems fair to speculate that such smaller efforts must have been started by the 6th century BC.

The construction of the major dams, of lengths that range from 1 or 2 up to 8 Km, happened between the 3rd century BC and the 13th century. This was not a continuous process. There were centuries in which several dams were built, and other centuries without any new ones. In general, construction of a large dam was associated with the reign of some successful king.

When we look at these dams today, and the beautiful man-made lakes retained behind them, and the extensive productive lands below them, producing two or three crops per year, the question of sustainability does not seem relevant. Yet these dams have been through centuries of failure.

From the earliest recorded times, until about the end of the 10th century, the kingdom in which the dams were built was based around the great city of Anuradhapura. The earliest large dams were built there, and in the succeeding centuries others were constructed on watercourses to the east, providing food for the expanding kingdom. Then there came a period in which the kingdom was taken over, following an invasion from southern India. In the 12th century, native Sinhalese dominance was restored. The kings, Vijayabahu and his successor Parakramabahu, set about restoring the kingdom, around a new capital, Polonnaruwa, which was placed farther to the east, reflecting the growing importance of trading connections to other states across the Bay of Bengal.

At Polonnaruwa, existing reservoirs were linked behind the largest dam of all, to form the great lake called Parakrama Samudra, the 'Sea' of Parakrama.

However, by the end of the 13th century, these grand works had been abandoned, and it seems likely that from about that time, until well into the 20th century (when they began to be restored, by the Sri Lankan government aided by foreign donors), none of these remarkable dams was fulfilling an irrigation function.

Why were these great facilities not sustainable after the 13th century? One possible explanation is that there was a period of invasions and political instability, causing the Sinhalese kings to remove themselves and their capital southward. But the Ma'rib dam seems to have survived through various changes of control, and struggles amongst the Yemeni and even the Abyssinian kingdoms. Any conqueror has a strong motive to keep such valuable facilities functioning, in the lands that have been taken over. A change of regime does not seem to be a likely cause for a large system to be made unsustainable.

Three other possible causes for the loss of sustainability in north central Sri Lanka have been advanced. One is about finance and governance: put simply, in more modern terms, the 12th century kings, notably Parakramabahu and his successor Nissanka Malla, over-stretched the budget, spending capital resources on too many big new projects, for which the cost of maintenance would be excessive. De Silva (1981) described 'a conspicuous lack of restraint' by the kings (de Silva, 1981), in their expenditure on reservoirs and other large public projects. This led on to failure and collapse. The kingdom had been able to collect resources that were sufficient for the capital construction of great reservoirs; but keeping those works in good order, with proper maintenance, required further continuous involvement of the state, and this could not be delivered.

Another possible explanation of the failure is the spread of malaria through the population around that time, which must have weakened the labour force. Labour has been an essential requirement for maintenance, until its gradual replacement by machinery in recent decades. A third possible explanation is that there may have been a climate change, which impaired the flow of water in the streams feeding the great reservoirs.

These explanations are not mutually exclusive, and it seems quite possible that all three of them may have had some role in the abandonment of the reservoirs and their irrigated lands. Indeed, one of the first efforts to resuscitate one of the reservoirs – the setting up of a private company in 1920, to restore and use the 4th-century Minneriya reservoir – failed quickly, due largely to the continuing prevalence of malaria, which could not be combated effectively until another two or three decades had passed.

Throughout these times, while the famous large dams of Sri Lanka were being constructed and used, small-scale construction continued in the island. Panabokke, Sakthivadivel and Weerasinghe (2002) have estimated that, between 300 BC and 1300, about 15,000 small reservoirs were built (Panabokke et al., 2002). Moreover, they estimate that about half of these are still functioning. Such estimates are obviously not precise, but it is certain that many of these small 'tanks' in Sri Lanka are very old.

Panabokke et al. (2002) describe the contrast between the large, state-governed systems and the smaller, locally-managed systems, like this:

> *'While there was a decline and decay of the major irrigation systems of the dry zone from 1200 AD onwards, these small tank systems continued in varying degrees of utilization and operation, on their own internal organisational strengths.*
>
> *'The investment of village labour in the successful innovation and construction of these village tanks resulted in the development of a strong sense of common property that ensured the maintenance and stability of these small village tanks over hundreds of years. Through this, they also developed a high degree of resilience to various stresses compared to the larger tanks, which were managed by a central bureaucracy, which easily succumbed to the stresses consequent to the collapse of the central governments of the medieval kingdoms.'*

By the beginning of the colonial period in Sri Lanka in 1815, there were thousands of small, locally managed irrigation systems, but, of the twenty or so large dams built by the earlier kings, perhaps not one was still serving its purpose.

Indeed, small, self-managed irrigation systems had appeared within parts of the areas that had been commanded by the large ancient dams; and, when the rehabilitation of the large dams occurred around the 1960s and 1970s, such self-managed systems were taken back into state-management.

Early irrigation systems provided their users with the capacity to grow food for their own families: subsistence agriculture, or perhaps a little more. One of the laws of Hammurabi of Babylon states that the penalty for allowing excess water to ruin a neighbour's crop was to repay that neighbour at the rate of about 330 kg/ha. This suggests that crop yields were normally at that level, which seems very low today. In those early times, urban populations were small, and the vast majority of families were producing their own food.

These conditions changed, with the passage of time. Urban populations increased, and rural crop yields increased. These changes caused the inter-dependence of rural and urban societies to develop. Irrigation farmers could produce a surplus, beyond their families' needs, and there were markets for their surplus, in the towns and cities.

There were, of course, many different responses to these trends. In relation to the study of sustainability, we may consider two types of response. In many places, where land was often not owned by its users but by wealthier landowners to whom the users must give a part of their crops, there were laws and other means for forcing the users of the land to remain and to cultivate, though with little benefit for themselves. We see evidence of this attitude in Cambodia during the Angkor kingdom, or in the systems of serfdom and other kinds of virtual slavery that were introduced in Russia and elsewhere, to keep people on the land, performing productive activities on which the urban populations depended.

On the other hand, there were places where the dependence of the city on the production of lands nearby was recognised, through mutual co-operation. Perhaps the most celebrated case of this kind is at Valencia, in Spain (Segura Graiño, 1996; Glick, 1970).

Long-sustained governance systems and procedures, with similarities to the Valencia arrangements, have been reported in several places. Examples are the Sayama-Ike system in Japan (Kinda, 2005), systems in rural Switzerland (Reynard, 2004), or the Chhattis Mauja and other systems in Nepal (Yoder, 1994).

Especially interesting, at Valencia, is the evidence of remarkable sustainability. Despite very great changes of the political and religious environments, it has survived for a duration that may be approaching a thousand years. In the 19th century, when the period of rapid extension of irrigation under state sponsorship was beginning, people came to Valencia from various other countries to seek inspiration from its management techniques. It may be from here that the idea came, for the warabandi time-sharing procedure of water distribution in Punjab.

We should note too that Valencia was not a solitary, isolated example. Several similar systems existed along the south-eastern coast of Spain, and they were not always under the same political regimes. Valencia is the best-known of these, being on a large river.

The basic essentials of its management institutions were probably in existence when the region was under an Islamic kingdom, and continued after the Christian conquest in the early 13th century, and then through various changes in the political power balance. Little is known now about management in the Islamic phase, but it is clear that the subsequent Christian kings of Aragon and Spain did not interfere closely, but rather saw their role simply as guaranteeing the local rules against any challenges.

The governance arrangements at Valencia, and at other irrigation systems down the south-eastern coast of Spain, illustrate a pattern that was mainly, but not entirely, self-governed. For the city of Valencia, it was important that the irrigation system that surrounded it should function successfully, delivering food and marketable products, so, although it seems that most of the management was done by the users themselves, the city sponsored arrangements that aimed to ensure, among other things, transparency and adherence to rules.

Glick (1970) noted that:

> *'the basic water-use unit in medieval Valencia was the community of irrigators comprising all who drew water from a single canal system.'(Glick, 1970)*

The sharing of the parent river's water among the seven main canals (of different sizes, and irrigating different areas) was done in accordance with an ancient set of rules whose basis went far back in time, and which were accepted as fixed. Within each main canal, water-sharing was done by proportionally-dividing structures that released water in accordance with the size of the irrigated areas. In times of stress, the system changed to time-based allocations, under which the user received water for periods of time that were in proportion to that farmer's area of land.

Each of seven main canals had its own irrigation officer, who had authority to assign penalties for breaches of rules, and to arbitrate in disputes between members of the canal community.

Above these seven irrigation officers was the Tribunal, meeting once a week in public, before the city's principal religious building. The seven officers, and one or two other local dignitaries, sat as the Tribunal's members, to hear cases that might cause dispute between different canals, or might be appeals from within a canal.

The processes varied down the centuries, and are too complex to review here, but we may note some points that show the emphasis on transparency and on the rule of observance. The meetings of the Tribunal were held weekly, at the same time, and on the same day (Thursday). Weekly sessions ensured that conflicts were settled quickly, thus reducing the risk of prolonged inter-family quarrels. The meetings were held in the open air, outside the cathedral (which had been the mosque in earlier centuries), thus ensuring that everyone who felt any interest in the proceedings could attend and hear all that was said. When a farmer was charged with some offence (such as taking water during someone else's turn), the irrigation officer of his own canal would state the case against him; but then the irrigation officers of the canals on the opposite bank would discuss, and decide the verdict and any penalty.

But, in regard to sustainability, we should note that Glick, writing just 20 years after the construction of a major new dam in the upper reaches of the river, expressed the opinion that:

> *'Elements of the old institutions of water control lost their effectiveness as the conditions which they were designed to serve were altered. The completion [of the modern reservoir] by assuring the Valencia huerta of the permanent availability of irrigation water, initiated the decline of the venerable Tribunal of Waters, the most salient component of the traditional system of control, whose purpose was to resolve conflicts in times of water shortage.' (Glick, 1970)*

From the first half of the 19th century, the colonial system became dominant in many of the countries where irrigation is most significant. This phase, continuing for more than a century, saw a huge increase in the extent of state-controlled irrigation systems.

Dhillon (1980) described the situation in the Punjab and the Indus basin, in 1840, at the end of three centuries under first Mughal and then Sikh rulers, and just before the region was taken over by the British, as follows:

> *'Summing up it can be said that during this phase, large number of inundation canals were built and most of these by private efforts.*
>
> *'The government efforts were mainly concerned with the construction of canals to take water to government gardens and palaces.*
>
> *'The only documented efforts to use canal water for irrigation is from Hansli Canal and that too during the late phase just before the advent of the British rule (Dhillon, 1980).*

The British regime proceeded to change that, by building some of the largest structures in the world, in the form of diversion barrages and large canals, which gradually brought water to each of the four great 'doabs' (inter-river plains) of Punjab. By the first half of the 20th century, such efforts extended through much of Sind as well, culminating in the Sukkur barrage in the 1930s. During this period, irrigation facilities of many different scales, from very large to quite small, were also being installed on the sub-continent's other river basins, but (as rainfall generally increases in an easterly direction) it was in the drier west, in Punjab and Sind, that the social effects of these new facilities were most dramatic.

Very large state-governed irrigation systems appeared in many other river basins. In Egypt, parallel developments occurred. Egypt was not formally under the colonial system of control, but from about 1800 to 1950 French and British engineers and technical officials held great authority. Willcocks and Craig (1913), who were both senior officials in the Egyptian system, stated very clearly the need for effective rules in an irrigation system:

> *'History tells us that just as irrigation was the oldest applied science in the world, so the first civilised communities on this earth were formed in the irrigated valleys of the Nile and the Euphrates. Once people took to irrigation, they had to form laws and respect them, for disobedience and wilfulness spelt ruin not only to their neighbours but also to themselves. When the water that irrigates your field has to flow in a channel that passes the fields of all your neighbours, and cannot be maintained in a state of efficiency unless all do their duty, it is easy to understand how method, order and obedience to a properly constituted authority very soon developed themselves. (Willcocks and Craig, 1913)*

This is valid everywhere; but most of the rule-system that they describe, in Egypt in the later half of the 19th century, was based on edicts that came down from the Khedive (ruler) and his government. Until 1889, maintenance of irrigation structures depended on the corvée, or forced labour, according to which every male between 15 and 50 years must attend for this work. The farmers who were better-off could escape from this duty by paying certain amounts of money; that money went to a government account, and the maintenance work therefore had to be shared among the poorer farmers who could not afford this 'ransom' payment. The quality of work done through this system of compulsory labour was poor, and people were often put to work on canals from which they themselves derived no benefit; therefore, they lacked motivation.

These arrangements for state control of governance probably seemed obvious in the context of Egypt, dependent on a single very large river without tributaries. In the first half of the 19th century, major mainstream barrages began to be installed, and canals built from them; such large structures could be built only by the state, and the state therefore felt entitled to compel those who benefited from these works, to obey its rules, and to contribute to sustaining them, but under rules that were devised by the state, not by the farming community.

Farther up the Nile, the Gezira system came into existence in Sudan, from the 1920s, with remarkably tight controls by the state, which decreed exactly what crops each farmer must grow, when water would be issued, and much else. In Sudan, as in India and Pakistan, large bureaucracies developed, observing the farmers' compliance with rules: these organisations became some of the strongest state organisations in their countries.

These systems, therefore, followed management methods that were quite different from those of the self-governed Valencia-type system. Rules were designed by the state, and were enforced in courts. It is always difficult to make bureaucracies act transparently, and, as time passed, the role of farmers in management dwindled usually to a very small level.

Through the colonial era, the sustainability of irrigation systems was not a significant issue. Urbanisation was not yet rapid: rural populations, and rural labour forces, remained high. State bureaucracies were interested in expanding irrigation systems for various reasons. In rural India, land taxes were an important source of revenue for local government, and the tax on irrigated land was substantially higher than on unirrigated farmland, so officials were happy to promote more irrigation. The cotton production of the Gezira provided the foundation for export earnings, and therefore financial self-sufficiency, for Sudan. The fact that insufficient numbers of Sudanese people wanted to become cotton-growers, in the 1930s, was not a real obstacle: in the colonial context, new farmers could be imported from Nigeria and Egypt, to ensure successful output.

The colonial period, when the powers of governments were very great, also produced errors in the planning and design of irrigation systems. A prominent example of that is in Pakistan, where, in the early 20th century, extensive canal systems were laid out by government. In many of these systems, large proportions of the land subsequently became unproductive due to salinization of the soils. There were essentially two kinds of error in the designs of such irrigation facilities: insufficient provision of drainage allowed groundwater levels to rise too near to the land surface, bringing saline groundwater into the root-zone; and the canal systems were laid out too extensively, which meant that the quantities of water being delivered to each plot of land were small.

The case does not amount to systemic failure; but substantial proportions of the land that was brought into irrigation in Pakistan in the first 60 years of the century have proved to be unsustainable. In the first decades of the post-colonial, donor-financed period, a large fraction of the financial aid given to Pakistan's irrigation had to be directed towards correcting these mistakes, and trying to sustain at least part of the systems that had been installed previously.

The total extent of irrigation in Pakistan is very large, and a great deal of analysis has been done on different forms of these problems, so general statements can always be challenged. But we may note two points here. First, irrigation is an expensive business, and there has always been a historic tendency to avoid or defer the added cost of installing adequate drainage. Secondly, in state-installed irrigation systems, there is often a political dimension to decision-making. In this case, the state chose to deliver water to as large a number of villages and communities as possible, even though that meant supplying it in quantities that were less than adequate in a technical sense.

Thus, when we try to analyse the sustainability of various modes of management, we should keep in mind that some systems fail only partially. In some of the salinized irrigation systems, as unsuccessful farmers abandon their land, their departure allows a little increase in the water available for those who remain. In the end, we may then have 'partial sustainability' for half of the original system.

The development of river-basin management institutions is, in much of the world, quite new, but it has large implications for the institutions of irrigation management. The need for overall governance arrangements for water, or for river basins, has become clear in the past decade or two, largely because of recognition of the rapid rise in abstractions from the resources during the second half of the 20th century, and the danger that the usable resources are being reduced by pollution. Demand for fresh water continues to rise quite rapidly, in most developing countries, and the past fifty years have seen large growth in the requirements due to urbanisation and industrialisation of these countries. But the recognition that these concerns need to be formalised, and addressed by appropriate institutional mechanisms, is rather recent.

In two of Europe's important rivers, the Rhine and the Danube, basin-management agreements and institutions exist, but they are not old historically. Early agreements, such as that of 1831 on the Rhine (Hollaender, 2001), tended to address river navigation, and the development of a more comprehensive system of basin-governance for that river took many decades thereafter. On the Nile, agreements began to be made early in the 20th century, and in Asia agreements on governance of international basins, such as the Indus and Mekong, began in the second half of that century, and remain incomplete. Even within sovereign nations, efforts to forge institutional arrangements that can be effective for overall basin governance, including allocation, protection, financing and enforcement, are generally new, and not yet strong.

Institutional arrangements for governance of irrigation systems are in general much older. It seems clear that the governance of an irrigation system must become subordinate to that of the river basin from which it derives its water. But there are obvious difficulties in making an older institution become subordinate to a newly-created one. For this reason, in many Asian basins, where irrigation is the dominant use of water, there is a tension between these two layers of governance.

Irrigation governance is however a different matter from water governance. In irrigation, there is a clearly identifiable set of people who use the system. Irrigation is expensive. It requires large initial investments of capital, followed by continuing expenditure on operation, maintenance and renewal of the facilities created. Moreover, it needs significant resources of land and water, and the financial investment of capital does not happen unless these other resources are assigned for it, sufficiently securely for a long term. So, it needs a governance arrangement that will ensure that those tasks are performed; and if its own governance is to be subordinate to overall water basin governance, it will still need adequate security of the right to abstract and use water resources.

A problem that arises both in general water governance and in irrigation governance is that the interests of upstream and downstream users are not the same. It is worth noting that international co-operation on the use of the Rhine began with questions of navigation, which could bring benefits to upstream countries wishing for guaranteed access to the sea for trade. Today, with the decline of river navigation, it has become more difficult to identify how upstream countries or districts may derive benefits from co-operation. On international rivers, it is usually downstream countries (Egypt, for example, or Cambodia) that are more enthusiastic for creating basin organisations with real powers, while upstream countries show lesser interest, and want to give such institutions lesser powers.

In a similar way, governance of irrigation systems is often seen as more beneficial for the downstream users, or ‘tail-enders’, who may want strong rules and enforcement, in order to ensure that a sufficient and reliable proportion of water arrives at their fields. It is a mistake (but, at the present time, a quite common mistake) to suppose that all users of an irrigation system share an equal desire, concerning the characteristics of their local governance arrangements.

When the colonial era came to an end, over the two decades or so after 1947, irrigation systems and their users had to adapt to new political and financial contexts, and new threats to sustainability appeared. In the decade after 1959, the modern system of development assistance appeared, from the World Bank and the national aid-agencies of the wealthier countries. By the 1970s, the flow of new international capital for construction of new irrigation facilities had become very large, but in general these funds were provided only for construction, and not for operation, maintenance or management.

This produced some alarming effects within the irrigation bureaucracies of recipient countries. The best staff wanted to work in the active fields of design and new construction, where earnings, and the prospects of promotion, were high. The fraction of staff resources devoted to operation and maintenance decreased, and those staff tended to be older. Maintenance especially tended to be neglected.

Ultimately, these changes led to the policy of irrigation management transfer, which began in the Philippines in the 1970s, and spread to at least fifty other countries. Essentially, this policy meant that, in state-controlled irrigation systems, the duties of operation and maintenance were transferred, at least at local levels, to organisations formed from each system’s user-farmers, and some part of the taxes and charges raised by the state were also transferred to these local organisations. A major cause of this policy was that the state-run processes were becoming unsustainable, following the rapid growth of the irrigated areas in the post-colonial period.

However, in a great many cases, this transfer policy was promoted by the state and its external donors, rather than by the users themselves. Demand among users, to take over the responsibility for management, is often weak; and this is not surprising. The users of other state utilities, such as electricity, do not usually want to take over those services and run them themselves.

In considering the implications for sustainability, after irrigation management transfer programmes have been imposed, it is worth looking at the principles specified by Ostrom (1992) for successful self-governing irrigation systems (Ostrom, 1992):

- there are clear boundaries, and rules about who has rights to water;
- rules ensure that each member’s benefits and contributions are in balance;
- rules can be modified by collective decision of the members;
- monitoring of conditions and actions is done by users or by people accountable to them;
- violators of rules receive graduated penalties, decided by other users or by people accountable to them;
- arrangements exist for settling conflicts, among users or between users and officials, quickly and at low cost;
- government authorities recognise the users’ right to devise their own organisation and rules;
- there are different levels of organisation, which deal with different functions and decisions.

In the organisations that are set up under programmes of irrigation management transfer, several of these important rules, especially numbers 2, 3, 6 and 7, are often not observed. On the other hand, if we look back at such a long-sustained management system as that of Valencia, we see that it complied probably with all of these principles.

As we have seen above, state-managed and self-managed irrigation systems have always existed. The past two centuries saw a great increase in the proportion of state-managed systems, while the most recent 30 years have seen a tentative reversal of that trend. But we must be careful, in drawing conclusions about the long-term effects of this change, for sustainability. These new management systems do not seem to have the same characteristics as truly self-managed irrigation systems have. As yet, it seems too early whether they will prove to be sustainable.

The historical evidence about management of irrigation systems is inadequate in many ways, but it does indicate that there have been various threats to sustainability. These threats are not constant. The conditions within which an irrigation system and its users have to function will always be liable to changes. External changes, in the political system, or the demands for crop products, or other matters, have often been more significant than the internal behaviour of each system’s management. The lesson from this is that management arrangements, such as governance, constitutions, and finance, should be flexible, and able to adapt themselves swiftly to new challenges.

A frequent threat, in the present time, derives from the need to correct the effects of over-reach by the state in the past one or two centuries. When a state is strong, its irrigation systems may grow rapidly, and the bureaucracies that handle the management of these systems also grows. The state has capacities to invest in new capital projects, and it can afford numerous staff for management tasks, and its courts can ensure the administration of rules. But no state remains strong for ever. When the state weakens, its capacity for dealing with the complexity of irrigation management is reduced. Cases as far apart as Polonnaruwa in Sri Lanka and Ma'rib in Yemen provide evidence of this.

A different factor, in the quest for sustainability, is the need for social cohesion and co-operation among a system's users. Irrigation systems have large number of users. The personal interests of the users are never all the same, never uniform; they may grow different crops, their land may lie upstream or downstream, their soils may vary, the numbers of active young people in the families will vary. But, for the success of the system as a whole, they must accept some common practices, and prohibit some kinds of behaviour. We see in the earliest evidence of irrigation management, in the laws of Hammurabi nearly 4,000 years ago, that severe punishments were decreed against behaviour that tended to damage social cohesion.

A major way of ensuring social cohesion within an irrigation system is to develop institutions and procedures for the swift resolution of conflicts among its users. Such institutions work well if they are understood and respected by all users. The cases of Valencia and other systems along the south-east coast of Spain have given long-term evidence of the role of such transparent, user-based institutions for sustainability.

The possibility of corrupt behaviour will always be present. People who are supposed to act as judges may favour their own friends, and may accept payments. This kind of problem is the basis of Ostrom's rules 5, 6 and 7. We may assume that it is also the reason for Valencia's tradition of open, public weekly sessions of their tribunal, in the city centre. The members of an irrigation system must be able to choose and appoint the judges for their own system, and (probably more important) to dismiss them if their performance is unsatisfactory. Social cohesion depends on confidence, among the members, that the institutions and procedures are fair.

Finally, in assessing the lessons of history for sustainability, we should consider certain modern threats for which history can offer less guidance. Irrigation systems, and the communities of people who use them, have been changing rapidly in the past fifty years, and those changes will continue for some time to come. If they are to be sustained well into the future, many practices that were previously considered normal will have to be changed.

The process of urbanisation has been very rapid, in the past half-century, throughout the Asian and North African countries, where more than two-thirds of the world's irrigated lands lie. This can bring benefits as well as threats to communities of irrigators, but at present there are many national policies that seem to strengthen the threats.

The loss of labour, especially young labour, from the rural environment is an obvious problem. Young people move to the cities, for a large number of reasons: among these, better income is a common reason, but there are many other social factors, such as better schools and health-care, and more varied opportunities. This has tended to mean that the labour forces remaining in the irrigation systems are fewer and older.

History tells us that maintenance is important, and is a major factor in ensuring the sustainability of an irrigation system. Maintenance suffers, in these circumstances of labour shortages. It can be seen first in mountainous regions, where terraced systems require close attention to maintenance and stability; but in due course labour deficiency causes threats to stability in systems of every kind. Labour can of course be replaced by mechanical equipment, but that requires investment, which in turn requires a reliable financial basis. The substitution of machinery for labour is also more difficult in remoter and steeper irrigation systems, so the sustainability of those becomes less secure.

Abandonment of irrigated land has been another consequence of the drift of population to the cities. This is usually a gradual process. People who find work in cities may not wish to lose control of their pieces of land, so they may rent it out, or they may cultivate it in only one season instead of two or three, or they may choose to work with crops that need less labour. Their strategy will vary, according to the rules and laws of that country. But, when any piece of land is abandoned, even partially, the contribution of that farmer to the management of the system will always become less.

Simple economics would indicate that urbanisation should bring great benefits for irrigation systems. As the cities grow, and the rural population reduces, the number of customers for the surplus production of an irrigated farm family increases, so it would seem that the farm family must become prosperous. That does indeed happen, sometimes. But more commonly we see a different trend. World indexes of food prices have shown increases in recent years, but, when they rise, little benefit is felt at the level of the irrigation farmers. Governments tend to take actions to control or suppress rises in food prices in the cities, as those who are resident in cities can more easily protest and demonstrate against such rises.

A different threat to the sustainability of traditional irrigation systems comes from the rapid growth of demands for water for other uses. This is related to urbanisation and to the general increase of population, but also to the growth of other economic activities such as manufacturing.

In countries where a large proportion of agricultural land is served by irrigation, the proportion of water that is used by irrigation, in relation to water used by all human activities, is high; often the share of irrigation water is around 80% of all water abstracted for human uses. Moreover, the demand for water by irrigation systems varies widely by seasons, and tends to reach its maximum in the hottest season of the year, which means that it often coincides with the time of least availability of water.

Over the past two decades, many countries have been moving towards institutions of river-basin management, in order to deal with the stresses of growing demand for water, which is caused by two major trends: population increase, and changes to lifestyles in which the domestic and industrial uses of water are much more than in the past. In many places, the users of irrigation systems have tried to insist that their abstractions of water are validated by long history and custom, and they have been reluctant to submit to the much newer, often weaker, institutions of river-basin management. But it seems that it will be necessary for this attitude to change, as modern densities of population make management of the entire river-basin essential for sustainability of society and of many sectors of the economy.

The role of groundwater in developing-country irrigation (other than the shallow groundwater that could be accessed with animal power) is relatively recent. Since the 1960s, as small pump equipment became cheaper and especially as rural electrification schemes expanded, the use of groundwater, both by individuals and by organised groups, has been increasing rapidly. This is posing numerous new problems, in water governance as well as in irrigation governance.

There are many basins (Punjab is a prominent example) where groundwater levels have fallen with remarkable speed in recent decades. This is clearly not a sustainable trend. Ancient water-delivery tunnels, such as the Qanats of Iran or the karez of Xinjiang, are failing, as the water-tables from which they draw their supply are depleted.

While the powers of river-basin institutions may be new and weak, institutional control of groundwater basins has proceeded even more slowly. It is more difficult to define the boundaries of a groundwater basin, and to develop an effective set of procedures for monitoring, abstraction permits, penalties, and so forth, for the control of groundwater, than for a river-basin.

However, the history of older irrigation systems shows very clearly the importance of developing sets of rules for water use, with accompanying procedures for open allocation of penalties to any users who try to break the rules. For sustainability, these lessons will have to be learned and applied in the modern use of groundwater.

Over the past 50 years, since the ‘green revolution’ of the 1960s brought in more productive types of crops, the pace and variety of changes in the irrigation business have been vast: urbanisation, population increase, groundwater extraction, building of large dams, economic changes, democratisation, and many other aspects of life have changed, and seem sure to continue to change. In these circumstances, it seems clear that the organisations that manage irrigation cannot stay the same. They also will have to change.

Therefore, for sustainability of our irrigation systems, the management arrangements will need a high degree of adaptability. It is interesting, and valuable, to study the older forms of institutions and procedures for irrigation management; but, while many lessons can be learned from them, they will not have much success or sustainability now, if they try to adhere too closely to the past. To achieve sustainability, we shall need institutions that are built on the basis of past traditions, but are sufficiently flexible to change and adapt themselves rapidly, as external conditions change.

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CHAPTER – 4

History of Irrigation in Thailand and its Sustainability

Chaiwat Prechawit [a]

INTRODUCTION

Thailand is a country with long history of irrigation development; its total irrigated area is now about 4.8 Million ha making it to the rank of ninth in the world in terms of net irrigated area. The country, situated in Indo-China peninsula, has an average yearly rainfall of about 1,200 - 1,400 mm. While this figure is not very low, due to poor distribution, supplemental irrigation is always needed to prevent crop damages during the period of drought and to ensure reasonable yields.

The settlement in this area can be dated back to many thousands of years ago in prehistoric period. Early settlement can be found in the Northeastern region near Khon Kaen, Udon Thani and Sakon Nakhon provinces. It was assumed that the type of cultivation at that time was shifting paddy cultivation mainly supported by natural water and fertile soils.

IRRIGATION DURING PREHISTORIC PERIOD

About 3,000 years ago, economic conditions changed because the agricultural societies discovered how to use metal tools and water buffaloes for ploughing. Thus, paddy cultivation in this period was provided with water from diversion systems, which resulted in higher yields and no land shifting. The evidence of this kind of cultivation was found in the Sakon Nakhon Basin in the northeast.

During the 12th-16th Buddhist Centuries, under Dvaravati influence, people usually dwell in town near their agricultural land area which was surrounded by moats and dikes which served as protection measures and also for providing water for the town and cultivation. Such cities influenced by Dvaravati culture were found to have their city planning in circular or ovular shape surrounded by moats (Figure 4.1).

Figure 4.1 Moats surrounding the city

The Khmer influence, during 15th-18th Buddhist Centuries, spread over Chi and Mun River basins and Lopburi and Saraburi provinces. The cities of this period were square in shape surrounded by moats and walls. Barai, a large scale pond or reservoir, was constructed either inside or outside the city wall. Barai was used to store water for consumption and cultivation. Dikes were sometimes constructed to divert water to cultivated areas or reservoirs. The diversion and retention of

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water by earth weirs and the construction of canals and Barai reflected the development of technology in water control and retention (Figure 4.2).

Figure 4.2 Barai

The Sukhothai Kingdom was founded in the 18th Buddhist century with the center located at Sukhothai City and Sri Satchanalai and later expanded along the Ping, Yom, Nan river basins from Uttaradit province down to Nakorn Sawan province.

The main topographical characteristic of Sukhothai is foothill plains. Ruins of dikes constructed to control water were found throughout Sukhothai. Sarid Phong (storage dam) located in the South-western part of Sukhothai was used to store runoff from the mountain and supply to the moats and ponds, called Traphang, in the city and cultivation area nearby. It was also found that some ponds received water through pipes made of clay (Figure 4.3). Sarid Phong and Traphang were mentioned in the famous Stone Inscription of King Ramkhamhaeng, the great King of Sukhothai period (Figure 4.4).

Figure 4.3 Clay pipe Moat

Figure 4.4 Sarid Phong and Traphang in Sukhothai

Evidences of weir construction were found in many places on the Sukhothai slopes from the hills to the Yom River. For the city moat lying along the slopes, weirs were constructed across it at intervals to maintain water at its full capacity. In addition, the embankments were constructed along the slope in the plain to divert water to the required area, for example, to divert water from communities to the nearby creeks for flood protection in rainy season.

The area located between the Yom and Nan rivers was mostly flood plain lying from Uttaradit province down to the area above the merging point of the Yom and Nan rivers in Phichit province. It was, therefore, unsuitable for settling any community. The traces of human habitation and irrigation were not found, as in other parts of Sukhothai Region. Only one evidence was found, a stone inscription stating Phanang, an embankment constructed to protect flood overflowing to the cultivated land.

ANCIENT IRRIGATION IN NORTHERN THAILAND (MUANG FAI SYSTEM IN LANNA REGION)

Figure 4.5(a) Lanna Kingdom

Figure 4.5(b) Nawarat Bridge in Chiang Mai

Lanna Region comprises Phrae, Nan, Tak, Lampang, Phayao, Chiang Rai, Lamphun, Chiang Mai, and Mae Hong Son provinces of the upper northern part of Thailand at present.

The history of Lanna Region appeared in the beginning of the 19th Buddhist century when Phraya Mangrai founded Chiang Mai as the centre of the Lanna Region in 1296 (B.E. 1839). From the legend, Phraya Mangrai was supported by King Ramkhamhaeng of the Sukhothai Kingdom and Phraya Ngam Muang of Phayao to establish Chiang Mai. Thus, the city planning was square in shape surrounded by city walls or moats with the Ping River on the east and the city sloped from the foothill to the river on the east, just like that of Sukhothai.

The main topographical characteristic of the Lanna Region is mountainous terrain. The communities were settled in the valley plains. Some plains were small and some were vast such as ones in the Ping, Kok, Ing, and Wang river basins. Such features required the method of water control and impoundment to support cultivation, especially rice, the main food of the Lanna community. Thus, traces of weirs constructed from natural materials across the stream to raise up and divert water to paddy fields through ditches were found throughout the area (Figure 4.6).

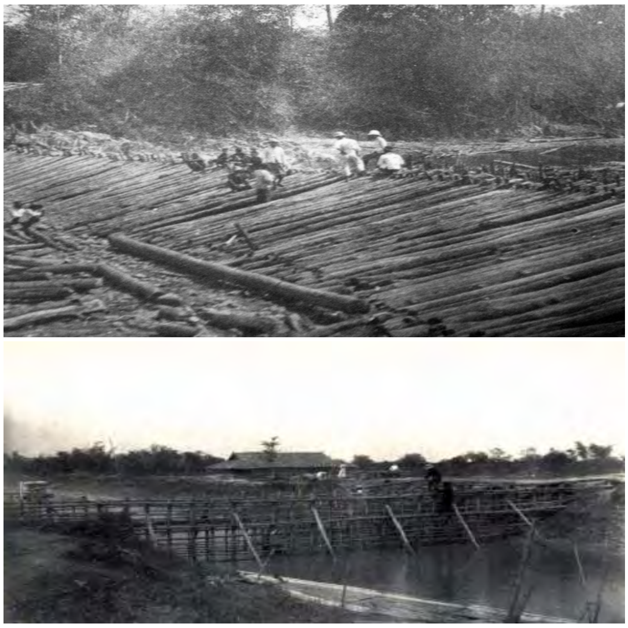


Figure 4.6 Construction of weir

These weir type irrigation systems were practiced from those times until recently. The water management system with the Kae Muang (Ditch Headman) and the water user with necessary regulations were established.

'When a weir is constructed, it is necessary to have rules and regulations under which the management will be effective. Because of this reason, Mangrai Sart or Phya Mangrai's Laws include the regulations on the matter in great details. No matter how good the irrigation is, confusion and disputes can arise if it lacks rules and regulations to control.' Those rules and regulations are now known as 'Sanya Muang Fai' or muang fai agreement. It was developed and adjusted to use in the People's Irrigation System in Lanna areas till now.

EARLY DEVELOPMENT OF IRRIGATION IN THE CHAO PHRAYA DELTA

Ayutthaya Kingdom was established in 1350 (B.E. 1893) in the delta area of the Chao Phraya river in the central plain of Thailand. This delta was formed by sediment carried by the Chao Phraya, Mae Klong, and Bang Pakong rivers to be a vast fertile Chao Phraya plain (Figure 4.7).

Such flood-plain topography is advantageous to irrigation management since the level of water in the river and the flat paddy fields is not much different. Only the dredging of canals from the river is enough for supply of water to the required area. Paddy growing was, therefore, quite successful here.

Paddy cultivation in the Ayutthaya Period was aimed at having sufficient rice for domestic consumption, thus, irrigation systems were implemented only to guarantee such requirements. Excess rice would be sold, only if available. By the end of Ayutthaya Period, rice was generally exported to China and the nearby countries such as Indonesia, except in the years of low yields and times of war when it was saved for domestic consumption only.

Figure 4.7 Chao Phraya River and other main rivers

However, canal excavation in Ayutthaya period was aimed more at improving inland navigation than for cultivation because the canals were dredged in grid to cover the whole island of Ayutthaya. Due to good circulation, water quality was good and could be served for domestic consumption as well. To speed up travelling time along the river from Ayutthaya to the Gulf of Thailand, excavation of shortcuts at the river's most winding courses was done not only to save time but also to facilitate the passage of big ships (Figure 4.8).

Figure 4.8 Waterway in Ayutthaya

At the end of the Ayutthaya Period, water control structures were constructed in various places, for example, in the King Prasat Thong reign. The King graciously initiated the construction of Than Thong Daeng Reservoir in Saraburi province and using the weir system as in the Lanna Period due to its mountainous areas. In the reign of King Narai, the King graciously initiated the construction of Huai Sap Lek and Thale Chupson Reservoirs (Figure 4.9). Both reservoirs were located outside Lop Buri at a location higher than the city so that pipes could be laid to deliver water to the palace for consumption and forcing up fountains in the royal garden, a first trace of water usage for recreation apart from cultivation and transportation.

Figure 4.9 Huai Sap Lek reservoir in Lopburi province

During Thon Buri Period, the reign of King Taksin, the Great development of water resources in the lower delta had begun. However, the style of development was not different from the Ayutthaya Period i.e. excavation of canals for multi purposes - transportation, commerce and security control besides for cultivation purpose. This was the first time that people were moved to settlements along the canals to promote agriculture.

In the beginning of Rattanakosin Period, it was also dredging of canals for transportation, cultivation and domestic water supply. During the reign of King Phra Buddha Yod Fa Chulalok, the Great or King Rama I, the founder of the Chakri Dynasty, water resources were developed not only for such usage but also for military purpose. In 1782 (B.E. 2325), a canal named Bang Lamphoo was excavated by Cambodian and Laotian labourers to link with Ong Ang Canal to serve as the city moat (Figure 4.10). Many forts and city gates were also constructed along the canal but only a few remain until present.

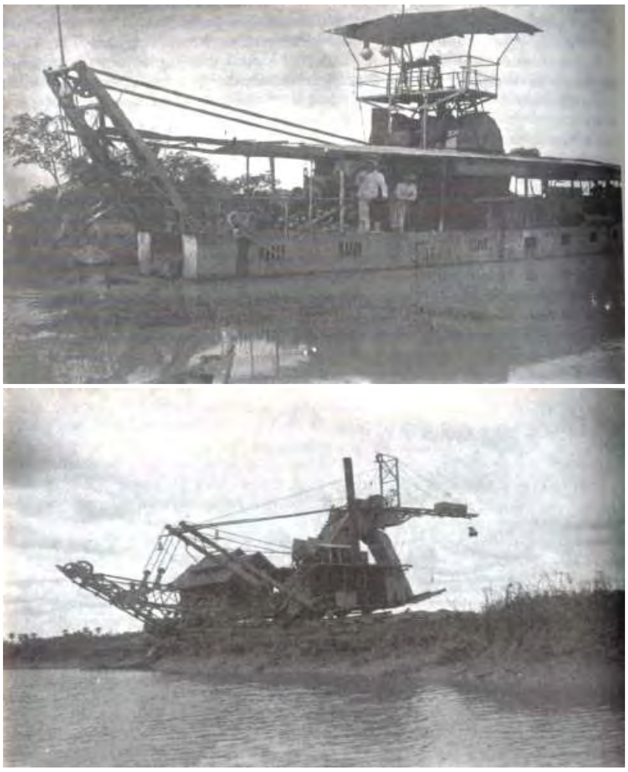


Figure 4.10 Dredging of canals

In the reign of King Phra Buddha Lert La Nabhalai or King Rama II, the King initiated an excavation of a canal named Sunak Hon to link the Mae Klong River with the Tha Chin River in 1817 (B.E. 2360). The canal served as a military route to Myanmar and Malayu, and for transportation of goods (e.g. sugars, spices, and salt) to the capital, and for cultivation. In 1823 (B.E. 2366), Lat Luang or Pak Lat Canal, at present, was excavated in Samut Prakan province as a shortcut of the Chao Phraya river to the sea but proved to result in intrusion of sea water, thus was closed during the dry season. Consequently, after the excavation of a canal named Bang Kaew, a diversion dam was constructed in the Chao Phraya River at Ang Thong province to divert water into the Bang Kaew and Pak Lat canals for solving the problem of salinity intrusion into cultivated and city areas.

In the reign of King Phra Nang Klao or King Rama III**,** due to frequently occurring floods in the Central Plain, the King gave a royal initiative to install a stone water level gauge in front of the Tham Mikkarat Temple in Ayutthaya province in 1831 (B.E. 2374) (Figure 4.11). The measured level was recorded as official messages and used to forecast the economic situation of the country. The stone has become the first water level gauging station of Thailand and still in use for over 170 years. In 1838 (B.E. 2381), the Chinese labourers were employed to excavate Bang Khanak Canal to merge with Saen Saep Canal, and Bang Khun Thian Canal for transportation of goods and agricultural products.

Figure 4.11 Stone water level gauge

When King Phra Chom Klao or King Rama IV ascended to the Throne, several changes occurred in Siam. After the engagement in Bowring Treaty in 1846 (B.E. 2389), more communication and commerce were made with western countries and agricultural products (e.g. rice, sugar, pepper) were exported. Consequently, the King gave his initiative on water resources development for agriculture that *'...Nowadays our country is prospering, the number of people is many times higher than the past. Therefore, our capital city should be extended wider...'* Several canals were excavated with an aim to increase rice cultivation. They are, for example, Phadung Krungkasem Canal, the first canal of this reign, being not only an important transportation route, since its construction, but also the last and outer most city moat of the country. In 1857 (B.E. 2400), another canal was excavated as a shortcut between Phadung Krungkasem and Phra Khanong Canals for transportation of commodities, and graciously named as the King Thanon Trong Canal or Hua Lam Phong Canal.

In 1861 (B.E. 2404), some areas of Bangkok were extended for house construction in European style and several canals were excavated, so that Bangkok was known to western countries as Venice of the East. In the same year, His Majesty was pleased to excavate Mahasawat Canal to link the area of Bangkok with Nakhon Chaisi for mutual benefit in transportation and irrigation of the area on the west bank of the Chao Phraya River. Therefore, the farmland was expanded and His Majesty also gave the land nearby the canals to people in the royal family and government officials. So, this period is deemed as the beginning of land consolidation. Moreover, during 1867-1868 (B.E. 2410-2411), several canals were excavated as the transportation route for agricultural products, e.g., Phasi Charoen Canal, linking the Chao Phraya River with the Nakhon Chaisi River; Damnoen Saduak Canal, linking the Nakhon Chaisi River with the Mae Klong River; Don Chan Canal, linking the Samut Songkhram with orchards and mangrove forest around Bangtabun Sub-district.

In conclusion, during the reign of King Rama IV, water resources development around the Chao Phraya Delta was not widely implemented. Few canals were excavated for extending the area of Bangkok and for transportation of commodities particularly in the west bank of the Chao Phraya River. However, some canals were also excavated with an aim to make use of the idle land on their banks for rice cultivation, namely Mahasawat, Phasi Charoen and Damnoen Saduak. These canals cannot be deemed as irrigation works because water would be available only when the river overflows its banks. It is noted that though farmland was extended due to the canal excavation, it was given by the King to people in the royal family or nobleman who later left it idle again or with less usages.

THE BEGINNING OF THE MODERN IRRIGATION SYSTEM

In the reign of King Chulalongkorn the Great or King Rama V, due to promotion of relationship with foreign countries, new techniques of water resources development were introduced and implemented. During 1870-1904 (B.E. 2413-2447), H.M. the King decided to manage water resources in the area of Eastern Bangkok systematically and in accordance with the irrigation principles. Construction of various distribution canals and appurtenant structures, such as Phrem Phrachakorn Canal, excavated straight from Ayutthaya province to Bangkok; Nakhon Nuang Khet Canal, a shortcut from Bangkok to Chachoengsao province; Phrawet Burirom Canal, linking Saen Saep Canal with Samrong Canal; Thawi Watthana Canal, linking Phasi Charoen Canal with Mahasawat Canal; Rangsit Phrayunsak Canal, excavated through eastern area or Thung Luang - northeast of Bangkok with the appurtenant structures, such as Chulalongkorn Regulator, Saowapha Phongsi Regulator; Phraya Banlue Canal, linking the Chao Phraya River with the SuphanBuri River, etc. In addition, the King set the rules and regulations for canal excavation called Notification of Canal Excavation in 1877 (B.E. 2420) in which new policy on land holding of both sides of newly excavated canals was introduced for promotion of using the area for rice paddy. Being a King of long vision and wisdom, King Rama V realized the importance of canal excavation for irrigation that provide benefits to his people as evidenced in a section of his speech, *'... For the Kingdom of Siam, canals are important. Each year, at least one canal should be excavated since it will increase prosperity of the country. Even though it costs thousands and thousands of Baht, it is worth the investment...'*

The King gave the concession to Siam Land, Canals and Irrigation Company, a private company to commence the excavation of Rangsit Canal in the plain area of the east bank of the Chao Phraya River on 24 February 1890 (B.E. 2433). The excavation was done in an area of PathumThani province, once called Thung Luang and renamed Thung Rangsit. It was implemented by excavating a main canal linking the Chao Phraya River with the Nakhon Nayok River and then constructed canal network system and regulators as well as ship locks for controlling the water and transportation. The new canal was named Rangsit Phrayunsak Canal.

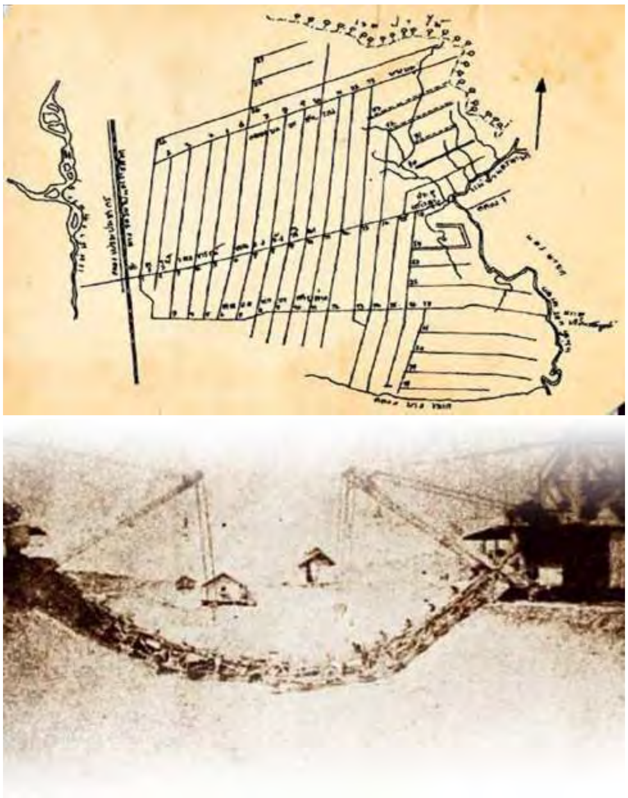


Figure 4.12 Plan of canals in Rangsit Scheme excavation of Rangsit Canal

Having considered that several canals undertaken by officials or Siam Land, Canals and Irrigation Company or private agencies were so shallow (perhaps due to silting), the King mentioned, *'...Cultivation, commerce, and communication in this Kingdom rely mainly on canals. At present there are a large number of canals, but most of them have become shallow due to insufficient maintenance (lack of de-siltation)...'* The King then proclaimed the Canal Conservation Act Rattanakosin Era 121 for the purpose of preventing the shallowness of canals caused by different activities. In addition, His Majesty also set the rules for vessels transportation and authorized the Minister of Agriculture to collect money from vessels passing the maintained canals (Figure 4.13). This Act has been enforced until present. Later, His Majesty assigned the government to recruit Mr. J. Homan van der Heide, a Dutch expert on irrigation from Java, to study and undertake the irrigation project planning in the Central Plain in 1902 (B.E. 2445).

Figure 4.13 Rangsit Canal

Figure 4.14 Plan of the Greater Chao Phraya Scheme by Homan van der Heide, 1902

THE BEGINNING OF THE GREATER CHAO PHRAYA SCHEME

King Chulalongkorn or Rama V had great vision and he realized the need for good systems of irrigation in order to increase the rice growing area and so the economy. He asked the government to find expatriate expert to help in planning and implementation and to help in managing various klongs (canals) and to solve problems with the Siam Land, Canals and Irrigation Company. Mr J. Homan van der Heide, a Dutch expert on irrigation from Java, was asked by the Thai Government to prepare a report regarding the feasibility of irrigation in the Central Plain. He submitted a report of his finding to the Thai Government on 24th January 1903 (B.E. 2446). The way Homan van der Heide studied the feasibility of irrigation in the Lower Chao Phraya was systematic and scientific with extensive inspection trips and water measurements. It was well accepted by many but not everybody agreed with the report. His proposal was that irrigation was not only feasible but useful for the economy and the irrigation schemes that he proposed should be constructed. He also urged the government to set up irrigation department. Even though there were some opposition to his report and other proposals but it was evident that preparation for and implementation of the works, as well as management and maintenance, required a permanent irrigation department. On 17th August 1903 (B.E. 2446) the Minister of Agriculture signed a contract with J. Homan van der Heide and appointed him as the Director General of the newly established Krom Klong (Canal Department) to be responsible for canals and water resources development (Figure 4.14).

The plan of the Chao Phraya project drafted by Homan van der Heide in 1902 (B.E. 2445) was so good that developments afterward followed it closely. However, because of high cost of investment and Thailand at that time had to choose between construction of railroad to the north or construction of a very large irrigation system; the government finally chose to construct the railway first because of urgent security problems in the north. Implementation of the whole project had to be delayed and only selected part was constructed given budget constraints.

The works included dredging works in Phasi Charoen, Damnoen Saduak, Saen Saep, Tha Khai, Bang Khanak, Samrong, Phrawet Burirom Canals, etc. Also implemented were navigation lock construction works to facilitate navigation in the canals, e.g., Prathumwan shiplock in the Saen Saep Canal; Phra Khanong, Samrong, and Krathumbaen shiplocks on both sides of the Phasi Charoen Canal, etc. (Figure 4.15). Moreover, there were regulator construction works to maintain water levels in the canals for cultivation at the end of the wet season for the area of 300,000 rai (48,000 ha), e.g., Prathumwan Regulator in the Saen Saep Canal; Phra Khanong, Khlong Dan, Bang Pla Ma, Phasi Charoen and Krathumbaen regulators on both sides of the Phasi Charoen Canal.

After working in Thailand for 7 years the plan for the Greater Chao Phraya project still awaited the budget required for implementation and Homan van der Heide requested to leave the Canal Department in 1909 (B.E. 2452).

Prathumwan shiplock

Construction of Krathumbaen shiplock

Samrong shiplock

Figure 4.15 Some of the shiplocks in the Greater Chao Phraya Scheme

In the reign of King Mongkutklao or King Rama VI, during 1911-1914 (B.E. 2454-2457), drought frequently occurred, resulting in damages to rice cultivation in the Chao Phraya delta plain. Farmers were in trouble as inputs got expensive, costs of living became high, and bandits became more prevalent in the region. His Majesty the King graciously appointed a committee presided by Kromluang Ratchburidirekrit, the Minister of Agriculture, to consider and develop corrective measures for solving these problems, to accelerate irrigation work development urgently, and to request technical assistance from the Government of England. Later on, Sir Thomas Ward, an English expert, came to assist in studying irrigation system planning. After having gathering information about irrigation in Thailand, he proposed to develop the country to be the main hub of rice cultivation in the world. He emphasized that the irrigation works should be implemented in accordance with appropriate techniques and principles.

The irrigation projects should be planned and implemented by taking into consideration the financial situation of the country and also the socio-economic condition of the area. Therefore, the Chao Phraya delta plain was divided into 7 zones according to irrigation potential as follows: Suphan Buri River, Noi River, Lop Buri River, Mae Klong River, Pasak River, Western Bank Basin, and Eastern Bank Basin. Because of urgent needs of irrigation, specific works were accelerated and extended to meet the needs of people. In 1913 (B.E. 2456), King Rama VI issued the Act for Water Hyacinth Eradication for the purpose of canal maintenance and preventing them from clogging. In 1914 (B.E. 2457), in the reign of King Rama VI, the name of the Canals Department was changed to Krom Thod Nam (the Barrages Department) to better suit the new mandate of carrying out the drainage, land improvement, flood mitigation, and hydropower generation. And Mr. R.C.R. Wilson, an English engineer, assistant to Sir Thomas Ward was appointed to be the Director General of the Barrages Department. In 1915 (B.E. 2458) the Barrages Department implemented the South Pasak Irrigation Project by constructing a barrage across the Pasak River, the first barrage of Thailand, at ThaLuang Sub-district, Tha Rua District, Ayutthaya province. The Barrage was named Rama VI Barrage. The Rama VI Barrage was the first large scale irrigation project of Thailand constructed in accordance with modern civil engineering principles. It was constructed to raise water level upstream in the Pasak River for diversion into the main canal, Raphiphat Canal, and distribute water through secondary canals to farmlands in Saraburi, Ayutthaya, and Pathum Thani provinces. Since the completion of the Rama VI Barrage project, large scale irrigation project construction works have been scattered throughout Thailand (Figure 4.16).

The name of Krom Thod Nam (the Barrages Department) was again changed to Royal Irrigation Department in 1927 (B.E. 2470) to suit the increasing scope of work of the Department.

Figure 4.16 Rama VI Barrage

THE MODERN DEVELOPMENT OF THE CHAO PHRAYA BASIN

After World War II countries had to cope with economic depression. Thailand needed to restore its economy by accelerating developments in various sectors especially increasing the rice yield for export. Therefore, there was an urgent need to develop better irrigation systems. The government therefore, reconsidered the master plan of the Chao Phraya project as drawn up by Homan van der Heide. The construction of the Chao Phraya barrage at Chainat province could divert irrigation water to the largest rice growing area in Thailand of about 1.2 Million hectare in 17 provinces. The Royal Irrigation Department approved to construction of Chao Phraya barrage by a loan from the World Bank. The Chao Phraya Barrage was the first very large scale irrigation structure to be constructed in Thailand with 12 gates of 16 m width each. The construction of the Barrage took place from 1952 (B.E. 2495) to 1957 (B.E. 2500), while the canals and appurtenance structures were completed much later (Figure 4.17).

Figure 4.17 Chao Phraya Barrage

After completion of the Chao Phraya Barrage and the canal system, it was realized that there was a need for storage dams upstream for providing storage for keeping water for dry season and during period of low flow in the Chao Phraya River. Besides, at that time, the government was also looking for hydroelectric power to promote industry, therefore a large multi purpose storage dam was needed. Prime Minister, P. Pibul Songkram, instructed the Royal Irrigation Department to implement the program for which a large storage dam on Mae Ping River was planned. After detail studies and investigations, a feasibility report was prepared. The dam, a concrete arch type, 154 m high with crest length of 486 m, was the highest in Southeast Asia and ranked no. 7th in the world at the time of construction. Construction period was from 1957 (B.E. 2500) to 1964 (B.E. 2507) with preparation period started as early as 1952 (B.E. 2495). The construction cost was financed partly by World Bank loan. It has storage capacity of 12,200 Million m^3 and it was the major contributor to the supply of water not only to agriculture in the Chao Phraya delta but also to all sectors of water users in the area from Bangkok Municipality and all the 17 provinces. The dam was named Bhumibol dam, after the name of King Rama IX, Bhumibol Adulyadej (Figure 4.18).

Bhumibol dam

Sirikit dam

Figure 4.18 Bhumibol and Sirikit dams

Following the success of construction of Bhumibol dam on the Ping, a tributary of the Chao Phraya River, a storage dam on the Nan river, another tributary of the Chao Phraya was constructed during 1968 (B.E. 2511) to 1972 (B.E. 2515). The dam is the largest earth dam in Thailand, 114 m high with crest length of 800 m long and has the storage capacity of 9510 Million m^3. The dam was names Sirikit dam after the name of Queen Sirikit of King Bhumibol Adulyadej.

These two large storage dams not only guarantee the sustainability of irrigated agriculture in the Chao Phraya delta but they also mitigate the losses from flooding of the agricultural land and also cities. Water management in the lower Chao Phraya plain by these two storage dams, the Bhumibol and Sirikit dams, together with the diversion dam, Chao Phraya barrage, have made possible the growth and sustain of rice yield in the single largest rice growing area in Thailand.

After construction of these important dams, Thailand had arrived at a modern pace of development. The Royal irrigation Department had constructed various projects of Large and Medium size storage dams for developing more irrigated area and also construction of many smaller reservoirs to help farmers as domestic water supplies and for growing vegetable and some cash crops.

Some of the more important storage dams for the Chao Phraya River basin are Mae Ngad and Mae Kuang dams in Chiang Mai, Kwai Noi dam in Phitsanulok, Pasak Jolasid dam in Lopburi and Khun Dan Prakarnchon dam in Nakhon Nayok (Figure 4.19).

Pasak Jolasid Dam

Khun Dan Prakarnchon Dam

Bang Lang Dam

Mae Yom Weir

Figure 4.19 Important storage dams in Chao Phraya River Basin

Total storage volume till 2014 (B.E. 2557) was about 79,899 Million m^3 or about 37% of total runoff (213,424 Million m^3) and the total irrigation area was 4.84 Million hectare.

There were the National Economic and Social Development plans that laid out guidelines for developments in each sector. Thailand already had 11 of these National Economic and Social Development plans from 1961 (B.E. 2504) – 2016 (B.E. 2559) and now are under the Twelfth Plan from 2016 (B.E. 2559) – 2021 (B.E. 2564). From the Eight Plan 1997 (B.E. 2540) – 2001 (B.E. 2544), there was a significant shift in the country's development planning from a growth-oriented approach to a new model of 'people-centred development'. Each Plan gives different emphasis on key philosophy of development and the Eleventh Plan addressed changing situations in the worlds such as aging societies, global food and energy security, etc. or local changes such as depleted natural resources, climate changes, etc. The Plan also stated that *'Strengthen water and land management to support food security and economic restructuring: Water resources should be developed, improved or restored to increase the water supply. Fair water distribution networks and security should be ensured. Water use should be more efficient. Exhausted land should be restored and improved for agriculture. The problem of invasion of conservation areas should be stopped. The land management system should be improved through more equitable distribution. Small farmers should be protected against loss of their land.'*

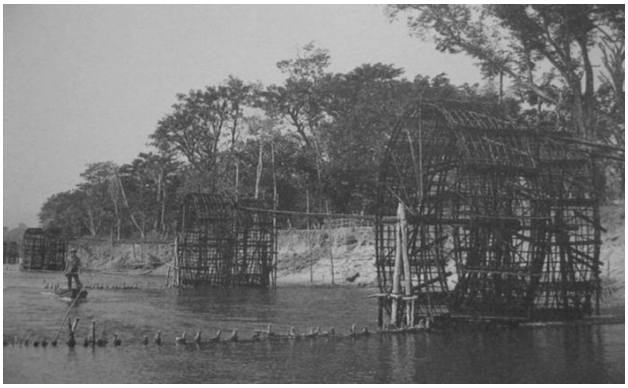
Irrigation and Sustainability in Thailand

Irrigation has been practiced in Thailand for several hundreds of years now and for most areas the irrigation systems are still working (Figure 4.20). That is sustainability in terms of the irrigation facilities only. But there are many attributes that could be considered as object of sustaining, such as: Irrigation facilities, production potential, operational performance, and irrigated agriculture. Participation from the water users is one of the key factors in making an irrigation project successful and sustainable.

Figure 4.20 Thailand map showing the irrigated area (in yellow)

In Thailand, farmers have always been participating in the project ; more than 700 years ago the system of Muang Fai (canals and weirs) in Lanna or Northern Thailand in which water use members of the Muang Fai system helped each other in constructing weirs. The Muang Fai communities then formed an organization of administrators and managers in charge of systematic water usage for cultivation. The ancient King of Lanna, at that, time even issued the irrigation law 'Mungrai Sart' to solve disputes among water users (Figure 4.21).

Muang Fai



Other irrigation methods

Figure 4.21 Traditional irrigation methods

Later on people participation became less as the government constructed the irrigation systems for people. However, the Irrigation Department tried to involve the farmers in all activities. In 1963 (B.E. 2506), the Irrigation Department set up the first water user group at Kud Ling Ngor Reservoir in Udorn Thani province. Irrigation Department then carried on this idea further. There were many types of farmer groups: from a small water user group in a small tertiary canal, to an irrigation association, much larger with legal identity, to water user cooperatives (Figure 4.22).

Figure 4.22 Water users group in the Northern Region

Lately, the participation of farmers has a modern concept of 'Participatory Irrigation Management', where more users from various sectors and representative from province administration participate in the meetings and the water allocation processes (Figure 4.23).

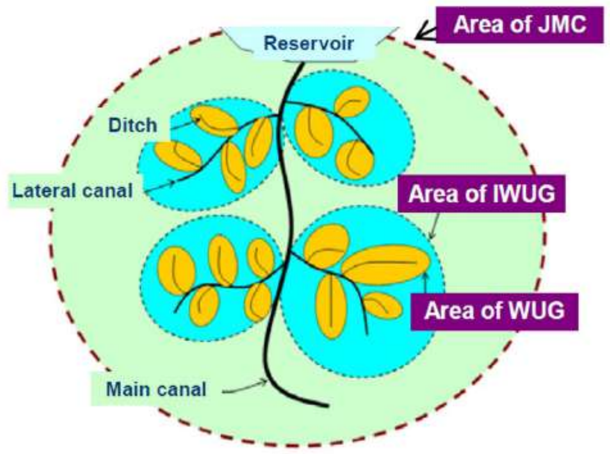


Figure 4.23 PIM concept

The Irrigation Department fully supports the idea of participatory irrigation management because it can solve misunderstanding and promote cooperation among parties involved. Examples of the more successful projects on involvement of farmers are Krasiew Project in Suphan Buri province and Mae Yom Project in Phrae province (Figure 4.24). Both projects received awards from the United Nation (Figures 4.25 and 4.26).

Figure 4.24 Water users group in Phrae province constructed a sandbag barrier to raise water level and pump to their farm lands

Figure 4.25 United Nations Public Service Award 2011 2nd Place Winner (Category 3: Fostering Participation in Policy-Making Decisions through Innovative Mechanisms, Asia and the Pacific) Krasiao Operation and Maintenance Project

Figure 4.26 United Nations Public Service Award 2012 1st Place Winner Category 3: Fostering Participation in Policy-Making Decisions through Innovative Mechanisms, Asia and the Pacific – Mae Yom Project

SUMMARY

Thailand is a country with a long history of water resources development for irrigation. Early settlement had seen excavation of canals and construction of small reservoirs. Later on, there were construction of small weirs and small canals together with water user groups in Northern Thailand. After the World War II, expansion of irrigated land was increased to cope with the need for increasing food production. Excavation of canals and construction of other water control structures were given high priority by the Thai government from the period of absolute monarchy to the present democratic.

The concept of the modern irrigation system was initiated in the reign of King Chulalongkorn (Rama V) about 120 years ago when his majesty acquired the service of Mr. J. Homan van der Heide, a Dutch irrigation engineer, to plan a large irrigation scheme in the Chao Phraya basin in the central plain of Thailand. From that beginning, the irrigated area in

Thailand increases steadily and Thailand is one of the top 10 countries with largest irrigated area. With a keen interest in irrigation development, Thailand cooperated with India and other 9 countries to set up the International Commission on Irrigation and Drainage in 1950 to be the platform for exchanging of experiences and learning new technologies.

Irrigation and drainage have helped stabilize and increase Thailand's agricultural production, making Thailand to be the world's leading country in exporting rice after India. Some may even call Thailand as the "Rice Bowl of Asia".

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CHAPTER – 5

Qanats of Iran: Sustainable Water Supply Systems

Ali Asghar Semsar Yazdi [a] and Majid Labbaf Khaneiki

Qanat is a gently sloping subterranean canal, which taps a water-bearing zone at a higher elevation than cultivated lands. In 2014, there existed some 37000 active Qanats running all over Iran, discharging about 7 B m^3 of groundwater a year. However, the number of Qanat is on the decline due to the modern development. It is obvious that only a balanced aquifer can secure the sustainability of a Qanat system, but it is apparent that the drawdown of aquifer is becoming critical for the existing Qanats, for which human overexploitation of groundwater resources is mostly responsible. Overexploitation of groundwater by means of pumping wells, negligence, and some legal gaps in the existing legislation on groundwater withdrawal have been leading to the decline of Qanats in some parts of Iran. This chapter briefly describes some examples of the important Iranian Qanats and then provides some information on the contribution of Qanat systems to the existing agricultural system. In a traditional realm, Qanats were embraced by a socio-economic system which guaranteed their sustainability. The chapter examines the facets of this socio-economic system, which used to operate closely together and made it possible for the Qanats to remain over the past centuries. In other words, we try to answer the question: what is the key of sustainability in Qanats, and why they can stay alive in their own traditional context.

INTRODUCTION

The origin of the word Qanat is still controversial. Some believe that it has a Persian origin and changed into the present pronunciation. According to this theory, the word Qanat derived from the Persian word Kene and it means digging. But some believe that this word was originally Arabic and the English word Canal has been derived from it. Throughout the world, there are over 27 names for this traditional technique. For example, the names used in southwest Asia are: Quanat, Canant, Connought, Kanat, Khanate, Khad, Kanayet, Ghannat, Karez, Kariz, Kahriz, Kahrez, Karaz, Kakoriz, and Falaj. Also one may come across the following names for Qanat in northern Africa: Foggara, Faghare, Mayon, Iffeli, Negoula, Khettara, Khottara, Rhettara, and Foggaras. All these names refer to a horizontal tunnel which drains groundwater, usually in alluvial fans. The mechanism of this structure is the same around the globe; a horizontal tunnel with a gentle slope that partly cuts through the aquifer. Water in saturated layers seeps into the tunnel, accumulates and flows down the tunnel.

It is very typical for deserts to have a landscape of many craters in a row. The craters, which can be easily seen from air, are actually the mouths of a Qanat's running across a desert. These wells are vital for Qanats as they act as means of ventilation as well as a way through which debris and excavated materials can be hauled onto the surface (Figures 1 and 2).

GEOGRAPHICAL AND CLIMATOLOGICAL CONDITIONS OF IRAN

In order to show the role of Iranian Qanats in sustainable water management, first of all, it seems necessary to look at the geographical and climatological conditions of Iran. The natural infrastructure had an important role in creating and developing the Qanat systems.

Suffice to say that Iran has a variable but, in general, arid climate, in which most of the relatively scanty

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Figure 1. Aerial photograph of a Qanat in Yazd, photo by Mehdi khebreh

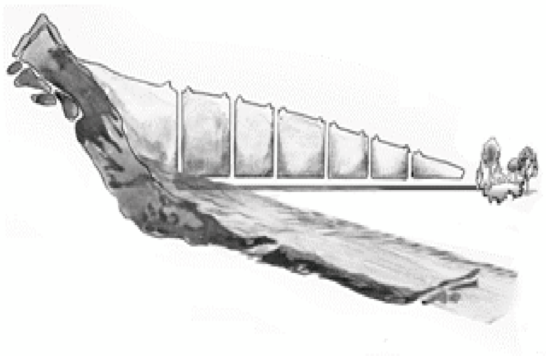

Figure 2. Profile of Qanat indicating its hydraulic relationship with aquifer

annual precipitation falls (October through April). In most of the country, yearly precipitation averages 250 mm or less. The major exceptions are the higher mountains of the Zagros and the Caspian coastal plain, where precipitation averages at least 500 mm, annually. In the western part of the Caspian, rainfall exceeds 1000 mm annually and is distributed relatively evenly throughout the year. This contrasts with some basins of the Central Plateau that receive 100 mm or less of precipitation annually.

SHORT HISTORY ON QANAT FORMATION

It is Henry Goblot who explored the genesis of this technology for the first time. He argued in his book entitled 'Qanats; a Technique for Obtaining Water' that during the early first millennium before Christ, for the first time, some small tribal groups gradually began immigrating to the Iranian plateau where there was less precipitation than in the territories they came from. They came from somewhere with many surface streams, so their agricultural techniques required more water than was available in the Iranian plateau. So, they had no option but to attach their hopes on the rivers and springs that originated in the mountains. They faced two barriers; the first was the seasonal rivers which had no water during the dry and hot seasons. The second was the springs that drained shallow groundwater and fell dry during the hot season. But they observed some permanent runoff flowing through the tunnels excavated by the Acadian miners who were in search of copper. These farmers established a relationship with the miners and asked them to dig more tunnels in order to supply more water. The miners accepted to do that, because there was no technical difficulty for them in constructing more tunnels/canals. In this manner, the ancient Iranians made use of the water that the miners wished to get rid of, and founded a basic system named Qanat to supply the required water to their farm lands.

According to an inscription left by Sargon II, the king of Assyria, in 714 BC, invaded the city of 'Uhlu' lying in the northwest of Uroomiye lake that lay in the territory of Urartu empire, and then he noticed that the occupied area enjoyed a very rich vegetation even though there was no river running across it. In fact it was Ursa, the king of the region, who had rescued the people from thirst and turned 'Uhlu' into a prosperous and green land. Goblot believed that the influence of the Medeans and Achaemenids made the technology of Qanats spread from Urartu to all over the Iranian plateau.

Distribution of Qanats in Iran

The Figures 2 and 3 show the distribution of Qanats annual discharge as well as distribution of their numbers across the country. As shown in these figures, the eastern and central regions of Iran had the most Qanats due to low precipitation and lack of permanent surface streams, whereas a small number of Qanats could be found in the northern and western parts which received more rainfall and enjoyed some permanent rivers. In 2014, there existed some 37000 active Qanats running all over Iran, discharging about 7 B m^3 groundwater a year.

Respectively, the provinces Khorasan Razavi, Southern Khorasan, Isfahan and Yazd accommodated the most Qanats, but from the viewpoint of water discharge, the provinces Isfahan, Khorasan Razavi, Fars and Kerman were ranked first to forth (Figures 3 and 4). Among these Qanats, there were some prominent Qanats which would be taken up in the subsequent part of this chapter.

Important Qanats of Iran

Many of the Iranian Qanats bear some characteristics which allow us to call them feat of engineering, considering the intricate techniques used in their construction. Here we tried to single out some Qanats which are renowned for some particular reasons. For example, extremely deep wells in some Qanats make them outstanding and a two storey tunnel in another Qanat atracted our attention. Though each Qanat has some characteristics which made them deserve to be included in this part, we had to choose only the Qanats which have been documented earlier.

Figure 3. Discharge of Qanats in each province

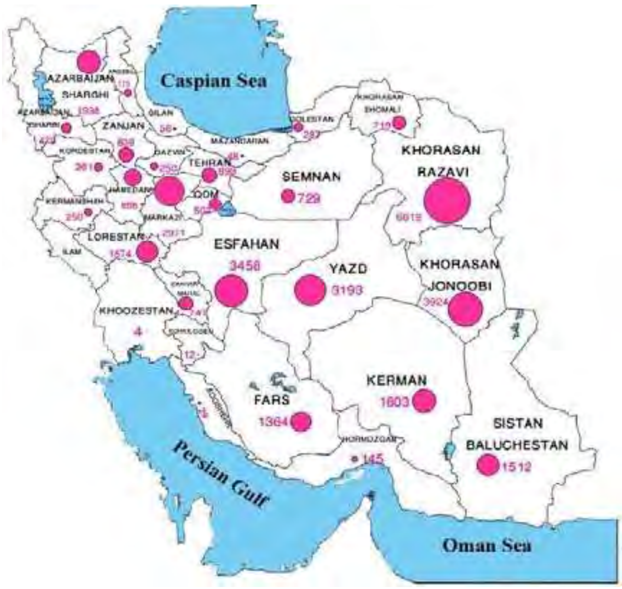

Figure 4. Number of Qanats in each province

Ghassabe Qanat, Gonabad

Gonabad Qanat is one of the most famous Qanats of Iran. According to some archaeological evidences, its construction dates back to the Achaemenid era (3rd – 4th century BC), and it has been, active from that time until now. This Qanat is named Gonabad Qasabeh Qanat because it has been used for irrigating some of the lands in Qasabeh which was a part of Gonabad (Figure 5). Gonabad Qanat is a plain Qanat which has 2 main branches: Ghassabe and Doolabeno, and 6 side branches. There are 182 shaft wells on the main branch and the total number of Qanat shaft wells amount to 427.

The Qanat is 11,579 m long (the distance between the mother well and the mouth). The depth of the primary mother well is more than 150 m, though some references suggest a depth of 300 m.

Its discharge in July-August 1995 was 105.9 lit/s, in July-August 1998 it was 99.5 lit/s and in September 1998 was 135 lit/s. The Qanat discharge was reported to be 150 lit/s in 2011. The water of Gonabad Qanat was and is still used to irrigate lands and farms of 'Ghasabe' and 'Noghab' that are situated in the east of Gonabad. People from Ghassabe use the water of this Qanat for agricultural purposes, the system is peasant owned, and its irrigation cycle is 24 days. An area of 685 ha is irrigated by this Qanat and 2000 shareholders are entitled to it.

Figure 5. The gallery of Ghassabe Qanat with its two branches joining

The quality of water of this Qanat improves from north to south. The water of Gonabad Qanat includes the minerals as shown in Table 1.

Qanat of Zarch, Yazd

The Qanat of Zarch is a plain Qanat with a gallery length of 80 Km, mother well depth of 90 m and more than a thousand shafts. It is partially active in the face of severe decline of the aquifer.

Table 1. Chemical composition of water in Gonabad Qanat

HCO_3^- meq/lit	CO_3^{--} meq/lit	Cl^- meq/lit	Ca^{++} & Mg^{++} meq/lit	Na^+ meq/lit	SAR	TDS mg/lit	EC ds/m	pH
6	-	14	-	17	-	1040	1.6	7.8

According to the existing documents, this Qanat dates back to the time before Islam. History books too, indicate that this Qanat had been active and was running across Yazd city about 700 years ago and people used its water for drinking and sanitation through payabs[1].

The beginning of this Qanat is in the village of Fahraj located in the north east of Yazd. The Qanat runs at the depth of 30-40 m under the city of Yazd. Then it reaches Zarch, where the water is used for irrigation, past the city of Yazd (Figure 6).

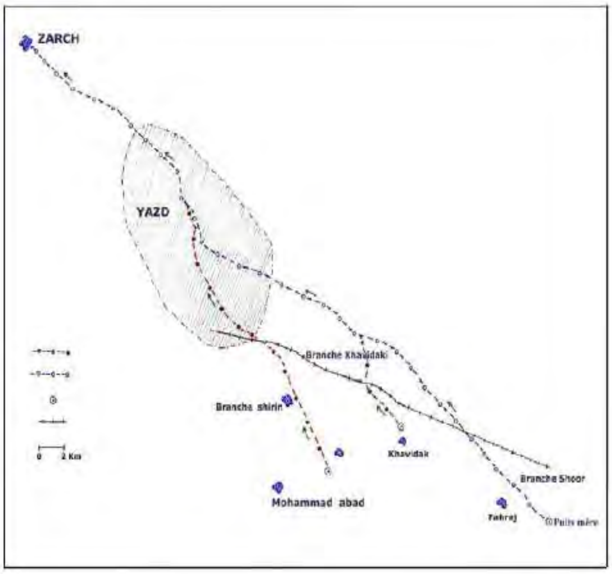

Figure 6. Qanat of Zarch running across the city of Yazd

It has 3 branches named: Shour, Shirin and Ibrahim Khavidaki, of which the only active one is the Shour branch whose water production section is about 4 Km long. This Qanat could irrigate about 300 ha of farms and orchards of Zarch in the past, but because of a considerable fall in the water table, nowadays it can only cover a few hectares of farm land. In fact, the discharge of the Qanat of Zarch has declined considerably: according to the available records and verbal descriptions, this Qanat had a discharge of 150 lit/s of water at its exit point in the 1950s whereas nowadays it has dropped to 5 lit/s.

In ancient times, this water was used for drinking, sanitation and irrigation, but nowadays it is only used for irrigating a few farms in Zarch, because the quality and purity of its water has been deteriorated due to domestic waste water leaking into the Qanat.

It is worth nothing that the existence of a species of fish in this Qanat proves the high quality of its water in the past.

The Qanat of Zarch has a perfect system of water-rights measurement and ownership (Figure 7). The cycle of irrigation of this Qanat is once every 15 days, in other words, each farmer can use his water right every 15 days. These cycles amount to 24 rounds per year. Each round is 140 joreh and each joreh is broken down to 6 dongs or shares. So, the 15 day's cycle of water consists of 12,600 shares or 2,100 joreh[2].

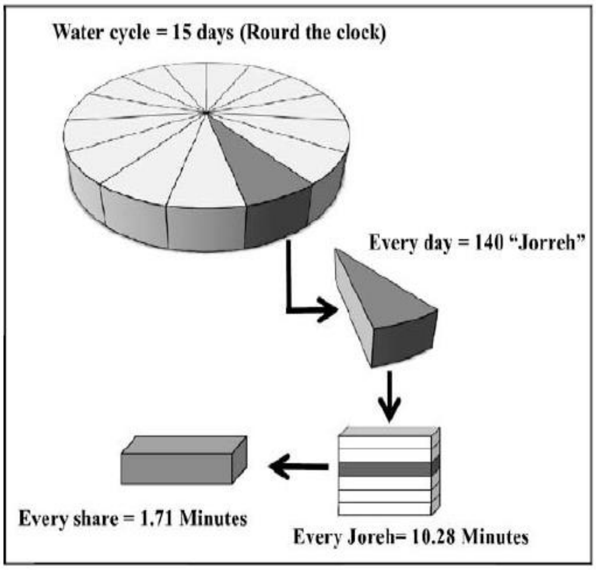

Figure 7. Qanat of Zarch Ownership system

The Qanat is owned by the farmers. Research on records kept in the register office of Zarch identified 1037 stakeholders, holding 11,656 shares out of 12,600. The ownership of the other 944 shares remains uncertain, maybe because some farmers have not got around to registering their shares.

It is worth nothing that the main stakeholders and farmers of the Qanat include some wealthy citizens of Yazd, as well as some residents of Sarcheshmeh and Toodeh in Zarch, who rent out their water rights to farmers. Sometimes the irrigated lands exceed the water right and farmers are forced to rent some water under the supervision of the Qanat manager. Even though his main duty is to handle the water distribution related affairs, he is quite knowledgeable about the stakeholders, farmers and water rights. The Qanat of Zarch is managed by the Qanat council, benefiting from a custodian to deal with its affairs (Figure 8). In addition, some other people, including the supervisor, manager and water distributor with defined duties are involved in the issue. Furthermore, a representative was traditionally appointed to investigate any issues/problems.

1 Payab is a traditional structure which is put up wherever people want to get access to the water flowing down a qanat. Payab is a stairway through which people can go down and collect water from a qanat's current or use this water for washing or laundry, etc.

2 Joreh determines the amount of shares of a shareholder in Qanat. For example, if a person owns 30 Joreh of a qanat, this means that he owns this amount out of the total shares of the qanat, which is usually equal to 2304 Joreh. He/She is allowed to use the same amount of Qanat water in one irrigation cycle which is normally equal to 12 days

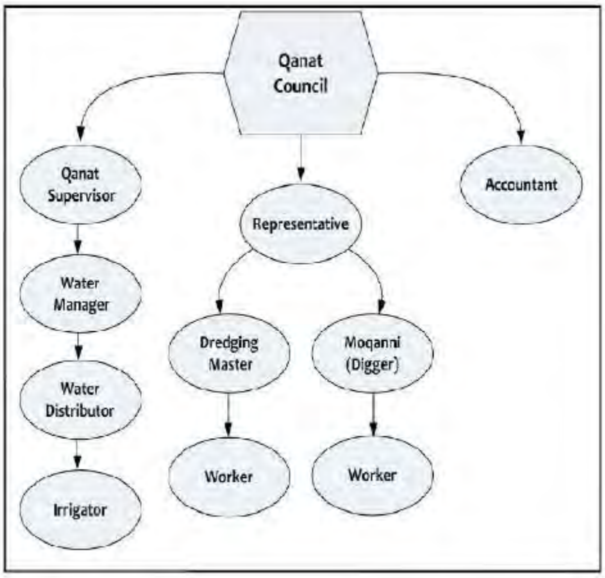

Figure 8. Management system of Zarch Qanat

Figure 9. The well of Saheb al-Zaman sunk in the village mosque, Qanat of Gowhar-riz, photo by Ali A. Semsar Yazdi

In order to rehabilitate this Qanat, some measures are needed, for example, cleaning the destroyed parts of the gallery and preventing the discharge of waste water into the Qanat.

Qanat of Gowhar-riz (Gauhariz), Jupar, Kerman

This Qanat gained its fame from the book 'Blind White Fish in Persia' by Anthony Smith. This book revolves around the Qanat of Gowhar-riz and how this irrigational system plays a central role in the ordinary life of the people of that region. This Qanat runs in Joopar, a small town near Kerman. Gowhar-riz in Persian means jewel pouring, and some believe that the Qanat was called after a nomadic woman named 'Gowhar' who in the past possessed all the shares of this Qanat, and she handed over her water shares to the farmers. The oldest water ownership proof which indicates the persons jointly entitled to this Qanat dates back to 1926.

This Qanat has six branches which are in sum 3556 m, with 129 shaft wells (Figure 9). The discharge is 240 lit/s, which can irrigate 330 ha of orchards and farms. In the view of the local people this Qanat carries a kind of religious value, so they believe if somebody writes their wishes on a piece of paper and drops it in the well sunk in the middle of the village mosque, their wishes will come true. The people are in the habit of dropping coins in that well in order to utter their wishes. Once in a while these coins are collected and go to the maintenance of the mosque.

This Qanat is unique in that it has six active branches, which is attributable to the fact that a hard impermeable layer intercepts the main channel so that it cannot be extended forward. So this situation has led to the construction of side branches as follows:

- *the branch of 'Darvaze Chah Gavgard'*. This branch is 890.7 m long with 25 shaft wells. Its mother well is 41.6 m deep and the last well close to the joining point is 14.54 m deep. The water in the mother well is 0.05 m deep and in the last well is 0.2 m deep;
- *the branch of 'Roobah'*. This branch has 14 shaft wells and a length of 310.99 m. Its mother well is 31.98 m deep and its last well is 19.55 m deep. The water in the mother well is 0.09 m deep and in the last well is 0.11 m deep;
- *the branch of 'Nakh-e Tol Sefid'*. This 409.36 meter long branch has 16 shaft wells, the deepest of which is 45.15 m. The depth of water in the mother well is 0.05 m and in the last well, which is 18.79 m deep, it is 0.2 m;
- *the branch of 'Khatmi'*. This branch has 18 shaft wells and a length of 361.98 m. In its 35.15 meter deep mother well the depth of water is 0.1 m and in the last well, which is 20.6 m deep, it is 0.13 m;
- *the branch of 'Haj Mohammad Noosh'*. This branch is 540.9 m long and has 18 shaft wells. Its mother well is 30.4 m deep and the last well close to the joining point is 18.23 m deep. The water in the mother well is 0.08 m deep and in the last well is 0.18 m deep;
- *the branch of 'Tol Sefid'*. This branch is the longest, with a length of 1333.55 m and 37 shaft wells. In its 50.24 meter deep mother well the depth of water is 0.21 m and in the last well, which is 4.57 m deep, it is 0.26 m. In fact this branch is the main channel of the Qanat that leads to the exit point in which the water is 0.52 m deep.

After the water of Qanat reaches the surface, it is directed to some dividing outlets named 'maqsam' (Figure 10). At this spot the water is divided into six parts, each of which goes to a particular area. The irrigated area of this Qanat is some 330 ha belonging to 500 shareholders.

Figure 10. Maqsam; water dividing structure in the Qanat of Gowhar-riz, (*Photo by Ali A. Semsar Yazdi*)

Qanat of the Moon, Ardestan

The Qanat of the Moon in Ardestan is a double-gallery Qanat, with two galleries running parallel but not at the same level - hence it is called a two-stage Qanat. The water flow in each gallery is independent of the other gallery's water. These two galleries are named 'upper stage' and ' lower stage'. The upper gallery is about 3 m higher than the lower one, but because of the geological structure, its water does not leak into the lower gallery.

The first shafts of this Qanat are located in 'Mahal' in the south of Ardestan. The Qanat's mother well is a twin well: i.e there are two mother wells near each other. One belongs to the upper gallery, with a depth of 27 m and the other to the lower gallery, with a depth of 30 m. The other shafts of these Qanats are shared. The above mentioned two mother wells have some separate branches which do not intersect.

An impermeable clay layer spans the 3 meter vertical distance between the two galleries. As mentioned, the shafts belong to the both galleries but they reach to the lower gallery at the end. The upper gallery goes around each shaft in a half circle direction when it meets them, and then it goes through its last direction which is a parallel line to the lower gallery.

The length of the Moon Qanat is 2 Km, the number of its shafts are 30 and its discharge is 60 l/s. The cycle of irrigation of this Qanat is once every 10 days. This cycle consists of 20 'taghs'[3] or 1320 shares. So, each 'tagh' is equal to 66 shares and each day (24 hours) is equal to 132 shares or 2 'taghs'. The water source of the upper Qanat and lower Qanat is not the same, so their color and taste is different. Also, the upper water is colder than the lower one. These two streams join each other after they reach the surface. The area covered by the upper Qanat for irrigation is about 100 'jarib'[4] or 160,000 m^2 and the area covered by the lower Qanat is 150 'jarib' or 240,000 m^2. So, the whole area is 250 'jarib' or 400,000 m^2.

Qanat of Vazvan, Isfahan

The town of Vazvan is some 85 Km south of Isfahan where some considerable Qanats are running. This Qanat lies 2 Km north of Vazvan. The Qanat is about 1800 m long and has an 18 m mother well. In 1989, the discharge of the Qanat was measured to be 50 lit/s and its annual output was estimated to be 1,577,000 m^3 . Twenty two years later in 2011, the discharge of this Qanat fell below 23 lit/s. This Qanat has 64 shaft wells sunk in a straight line. The wells are 27 m apart in the water transport section and 20 to 21 m in the water production section. Like every other Qanat, the excavated materials have built up around the mouth of well, making a row of craters showing the direction of the Qanat. These craters in the water transport section are built of a very soft soil which implies that the tunnel and wells in this part are prone to collapse, something that happened in 1994 resulting in the death of one of the Qanat practitioners. The Qanat of Vazvan is unique in that it has an underground dam (Figure 11). One of the disadvantages that the critics always attribute to the system of Qanat is that this system constantly drains groundwater even when no water is needed, for example in winter when cultivation is at a standstill. However, this underground dam provides a convincing illustration that we can prevent unwanted discharge just by constructing an underground dam across the tunnel. This method recently has inspired some Iranian engineers to install a kind of tap in the tunnels of some Qanats in order to stem the water flow, if necessary.

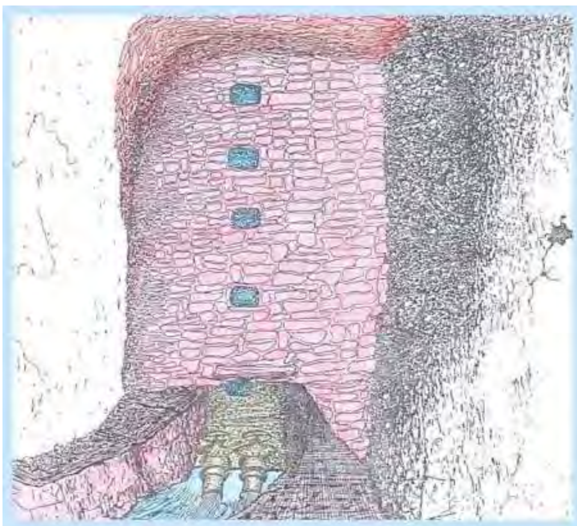

Figure 11. Underground dam of the Vazvan Qanat

3 Tagh: A time unit equal to 12 hours.

4 Jarib: = 1600 m^2

Just on the border between the water production section and the water transport section, this dam has been constructed, which is in fact a brick and stone wall built across the tunnel. This dam has some holes or outlets in it. When people want to shut down the Qanat, especially in winter, they stuff some potteries or ceramic jars into the holes in the wall to make the Qanat cease flowing. Water accumulates behind the dam and stays in the water-bearing zone, which can better feed the Qanat when opened. In spring when their farms need to be irrigated, they enter the Qanat through the dry tunnel until they reach the dam. Then they smash the upper pottery to let the water out. Needless to say if they open the lower holes first, the dam may give way under the head of water, and the person would be washed away. That is why they open the outlets from top to bottom in order. After they open the first outlet, they wait until the water level goes down to the second outlet and so on. Thus it takes them several months or more to open all the outlets. 750 shareholders are entitled to this Qanat and this Qanat enjoys two types of water rotation; 7 and 14 days rotations.

Qanat of Vaghf Abad, Yazd

This Qanat is a mountainous one which is situated in a very deep valley southwest of Taft. It has two branches: one of them is 250 m and the other is 1500 m long, therefore the total length of the branches is 1750 m. This Qanat has 44 vertical shafts. This Qanat was built some 700 years ago by 'Seyyed Rokn al-din'. The Qanat used to join other five Qanats and travel a 25 Km tunnel to Yazd. The Qanat was later endowed by the aforementioned person for the purpose of watering the greenery of Yazd.

According to the statistics (1980-1996), the minimum and the maximum discharge of this Qanat were 12 lit/s and 50 lit/s, respectively. Chemical analysis of its water in 1996 showed a chloride concentration of 205 mg/l.

Vaghf Abad Qanat runs through a village called Islamiyeh and joins five other streams of Qanats and a surface stream after reaching the surface. The water produced by these six Qanats and the stream flow to the city of Taft through a canal. Before entering Taft, another stream of surface water joins the water of the canal.

The measurements of the 17 years (from 1980 to 1996) showed that the minimum and maximum discharge of the six Qanats together were 97 lit/s and 346 lit/s, respectively. The average discharge of the final stream during these 17 years was 203 lit/s. The last survey, conducted in 2000-2001 showed a considerable decrease in the amount of discharge due to the drought in these years. Table 2 shows the amount of discharge of the six Qanats in 2000-2001.

Table 2. Discharge of the six Qanats in 2000-2001

Qanat Name	Vaghf Abad	Raiis Aldin	Roshan Abad	Nahr e Kheiri	Khaje Ghiass	Mirzaii	Sum
Discharge (lit/s)	8.5	22	19	14.5	4.2	-	68.2

Hasan Abad Moshir Qanat, Yazd

It is said that about 700 years ago, two righteous persons named Hassan and Hossein Shah managed to dig a Qanat with 17 side branches at the base of 'Shirkooh mountain', but none of the branches ended up with a good discharge. So they vowed to donate one fifth of the water to people in need, just for the sake of god and as charity, if the Qanat happened to bring a large quantity of water. Their wish eventually came true, and one of these branches called 'Kooh Sorkhi' hit a fault with a big source of water resulting in a considerable discharge with no fluctuation over time. Hasan Abad Moshir originates from Ebrahim Abad valley near the town of Mehriz and travels 45 Km to Yazd. This Qanat has 1000 shaft wells, and according to a measurement made in 2011, its discharge amounted to 187 lit/s. The water of this Qanat is collected at three spots; the town of Mehriz, the village of Dehno and Yazd (district of Hasan Abad) (Figure 12). Water rotation varies in these places as it is 6 days in Mehriz, 8 days in Dehno and 15 days in Yazd, Hasan Abad. This water is divided into 6240 shares in Dehno and 15700 shares in Hasan Abad.

Contribution of Qanat systems to the existing agricultural system:

In the course of history, almost all the agricultural societies in the central plateau of Iran lived off the groundwater resources obtained from Qanats and springs. Although the advent of modern pumped wells leading to over-exploitation of groundwater has taken a heavy toll on the Qanats in this region, in some areas this technique has retained its vital role. At present (2014), throughout the country 37,000 active Qanats are running, with a total discharge of 7000 Million m^3 a year making up 11% of the overall withdrawal from our groundwater resources. This considerable volume of water from the Qanats goes to the agricultural sector. The diagram below (Figure 13) shows the portion of Qanat output in the country.

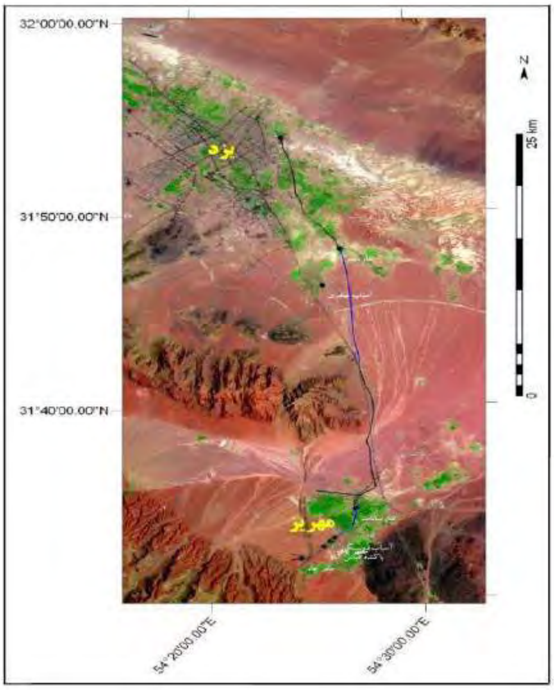

Figure 12. Direction of Hasan Abad Moshir Qanat

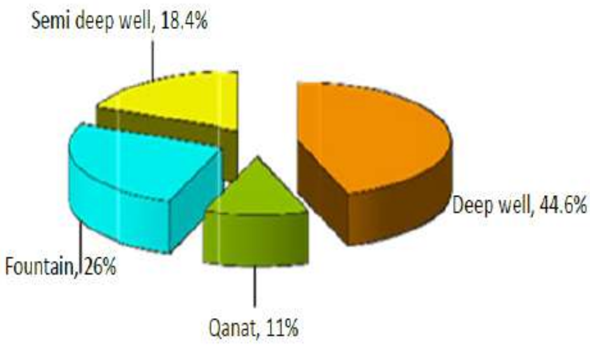

Figure 13. Portion of Qanat output in the country

The region of Bam situated south of Iran is a good example of how efficiently Qanats contribute to agricultural production systems. This agricultural area is completely dependent on groundwater which is extracted by Qanats and pumped wells. The Qanats drain out 457 Million m^3 water a year, whereas the discharge of the pumped wells has been estimated to be 420 Million m^3. This water can satisfy all the irrigational demand in the area in order to yield over 401,000 tons of agricultural products every year.

Qanat and groundwater drawdown

One of the most important subjects to focus on in arid areas is the drawdown of underground water and its control. This problem has been faced in several desert regions of the world and therefore the role of water resources management becomes important. It is worth noting that although the groundwater resources are decreasing, the demand for water is steady rising. The only way to use water in the past was Qanats and groundwater drawdown rarely happened because Qanat itself was a way to sustain groundwater resources as its discharge was more in the wet years and it was less in the dry years keeping its discharge and recharge in complete balance. This process kept the drawdown of groundwater at bay. But after the advent of the new technologies for drilling and introduction of pumped wells, the natural recharge of the aquifer could no longer offset its discharge, so the water table went on declining over time, leading to poor quality water in most cases. Moreover, the drawdown of groundwater and Qanats drying in villages of arid areas in which people live off agriculture leads to an unliveable condition and as a result abandoning the villages.

The population growth over past decades and also the increase in the demand of water cause a boom in deep and semi deep wells in arid and semi-arid areas of the world and the groundwater is exploited faster. Whereas the capacity of an aquifer is limited and it needs enough time to be replenished through rainfall and infiltration. Therefore, water drawdown and the decrease in the capacity of the aquifers have caused a critical condition in some dry land regions.

In order to prevent more water drawdown, we should take important measures. In this matter, the following solutions seem to be useful: Preventing irregular exploitation, artificially recharging the aquifer, preventing water outflow from the aquifer, and enhancing public awareness on preservation of groundwater resources.

Qanat and sustainability

Qanat is a sustainable technique to tap groundwater without inflicting any damage on the aquifer. Qanat system carries some advantages as follows:

- Qanat system works only with the force of gravity and does not consume any kind of fuel unlike pumped wells;
- Qanat system just drains out the overflow of groundwater and does not throw the aquifer inflow-outflow off balance. For Qanat does not use up the groundwater and empty the porous layers of water, no soil compression would come about and accordingly no subsidence on the surface;
- given that Qanat does not suck up the groundwater, the water extraction by means of Qanat does not make the saline water creep into the fresh water reserves;
- Qanat system does not disturb the texture of soil, so it does not diminish the soil capacity to hold groundwater.

In a traditional context, the technique of Qanat and agricultural systems are in a perfect harmony. In fact, traditional irrigation has an inherent mechanism to adapt water use to the environmental conditions. This mechanism works through technical factors as well as water management. For example, in case of a drought, the users of a Qanat have two choices to cope with this situation technically: either to extend the gallery of the Qanat by digging it back through the aquifer; or to adjust the area of farm land to the available water. The farm land is divided into two areas, one for trees and the other for vegetables. The ratio between the areas of orchards and farms is such that the minimum amount of available water would be able to meet the irrigational need of the total area. They adjust the area of the cultivated lands and the cropping pattern to the existing discharge rather than place pressure on groundwater sources in order to make it through the drought.

Moreover, Qanat-related water management is very flexible in relation to environmental conditions. It should be noted that a Qanat may belong to hundreds of farmers who take turns getting their water to irrigate their lands within a particular irrigation cycle or rotation. This water division system can match up with all likely changes in the volume of water during the year, while satisfying the farmers' irrigation needs. For example, if the volume of water decreases due to a drought, every farmer receives twice his normal share but only once every two rotations, so that the water can reach every corner of the farm.

Facets of sustainability in Qanat

If we look at Qanat from an interdisciplinary point of view, many aspects of its sustainability come to light, which used to guarantee its existence in an intricate network of social, economic and environmental interactions. These facets used to work together systematically and in harmony to sustain Qanats, like the cogs of an integrated machine. Any disorder in one facet could hamper all the system, and accordingly put the Qanats at risk, and as a result sound the alarm about the sustainability of the beneficiary society. In nutshell, sustainability of Qanat was anchored in the balanced interactions between some structural and non-structural facets which were strongly observed by the society. The necessity of preservation of these facets was internalized by the people who really cared about the destiny of Qanats. They kept track of the facets to make sure that they still functioned properly through some social mechanisms, and any disorder was tried to be fixed as timely as possible to ensure balance and sustainability. These aspects or facets can be categorized into two main groups as follows:

STRUCTURAL FACETS

Correct location

Correct location of Qanat ensures its efficient function over time. A minor technical error can lead to an inefficient Qanat, its malfunction and eventually its annihilation. The traditional Qanat masters enjoy a vast knowledge enabling them to locate Qanat as accurately as possible. The first thing that a Qanat master considers to locate a Qanat is the gradient of the ground which dictates the depth and length of the Qanat. Afterwards, Qanat practitioners use the natural indications found in the area to locate a new Qanat. For example, gullies, seasonal rivers, mountain foothills, alluvial fans, etc are among the signs which imply that a particular area enjoys a reliable groundwater reserve. Also lush vegetation gives a clue to the existence of groundwater at a reasonable depth. The Qanat masters are knowledgeable of the characteristics and life cycle of the wild plants growing in their vicinity. For example, if they see a concentration of Alhagi somewhere in the desert, they conclude that there is groundwater at a depth of less than 15 m, because the roots of Alhagi feed on fresh water at such a depth or less. Situation of soil, colour of geological formations and order of soil layers help the Qanat masters designate a suitable place for digging a new Qanat. The Qanat masters also use geological stratification to spot the impermeable layer, its conductivity, thickness and depth. They pay attention to a cross section of ground stratification at a ravine or cliff. The Qanat masters may study the situation of the other groundwater resources nearby to deduce how their new Qanat is going to be. If the Qanats and springs in the area would be drizzling or fluctuating, they would not fasten their hope on a new Qanat nearby as all are draining in the same aquifer. All such knowledge has been built up through generations in the due course of time which ensures sustainability of the Qanat.

Engineering of Qanat construction

Qanat is one of the most complicated traditional technologies which require knowledge of nature ranging from land and its quality, vegetation, groundwater and its management etc. This indigenous technology is used to bring water efficiently from tens of kilometres away to the thirsty lands. In many of Qanats, which were constructed hundreds of years ago, no technical errors took place, and their present structure is witness to this fact. This source of knowledge behind the system of Qanat can be ranked among the wonders of human civilizations, and this knowledge has given rise to this sustainable water mining system. Traditional Qanat know-how encompasses a wide range of indigenous knowledge from geometry to botany. The Qanat masters envision a system that can last for centuries. To do so, they apply their elaborate knowledge of engineering. For example, if the gallery meets a shallow aquifer, the Qanat masters manage to reach a deeper aquifer by an amazing technique, because a shallow aquifer do not guarantee the continuity of the Qanat flow. To do so, they dig overhead from the tunnel ceiling up toward the earth surface and they apply some interesting mathematical equations to minimize their error. Qanat engineering is a collective knowledge and expertise built up through centuries of cooperation which is the key element of sustainability.

Reinforcing of Qanats after construction

A Qanat should be protected against the natural and human threats in order to ensure its function. Flood and land subsidence are among the most important hazards. After the workers finish digging the well, they manage to line the well with bricks or concrete hoops though brick lining is more common. In a well, such lining is usually done from its middle upwards. To do so, they cut a groove round the side of the well with a depth of about 15 cm, and then they put a row of bricks into the groove such that half of them stick out, providing a base for the lining. Afterward more bricks are stacked up and attached together with a mortar of cement or lime until it reaches the well opening. In the end a concrete round lid – called 'Sargir' - is put on the well opening to block it. They also install such a lid in the middle of the well. Also, a shaft well may be shored up with ceramic or concrete rings called 'Towqeh' which are circular in shape with a diameter of 75-80 cm. Those rings are used to prevent collapse, only in shaft wells, whereas those used in the gallery are oval in shape to better resist more pressure from the top of the tunnel. The most common method to prevent a tunnel from collapsing is to use ceramic or concrete hoops. In the mountainous areas where large flat stones or slates are abundant, the workers prefer to line the tunnel with stones rather than install hoops, because hoops are much more expensive than the natural stones strewn all over the area free of cost. The workers manage to install oval hoops as soon as the tunnel cuts through soft crumbling soils to keep their Qanat healthy for a long time.

Qanat rehabilitation and maintenance

When the workers wrap up the construction of Qanat, it does not mean that their job is over. They have to keep tabs on the Qanat all the time to keep its water flowing out. They have some tools and methods to gauge Qanat discharge to know whether or not something wrong has taken place in the gallery underground. They apply a variety of traditional methods to keep a Qanat in shape such as determining Qanat bound, extending its gallery into water bearing zone, deepening, branching, dredging, lining, etc. They also use some techniques to ward off the devastating phenomena such as floods and protect from earthquakes, their impact on Qanats and how to keep them at bay.

Construction of lateral structures

Qanat related structures play an important role in ensuring the sustainability of Qanat. Application of Qanat is not only limited to water supply, but it may encompass the other fields like generating energy, breeding fish, sanitation, air-conditioning, etc. For example water mills used to be built in the Qanat gallery in order to exploit water energy and its revenue went back to the Qanat maintenance and rehabilitation. Also, water reservoirs were built for storing drinking water, which highlighted the necessity of keeping Qanats.

Construction of complementary structures to Qanat

There were also some structures to make the most of groundwater in a very sustainable way. For example in some Qanats, underground dams were built to cease the Qanat flow in winters when the farmers no longer need water for irrigation. This way, the water was stored in the porous sediment, increasing the Qanat flow when needed. Also artificial recharge dams used to be built on the ground surface for harvesting seasonal runoffs. During the rainy seasons, the runoffs flowing down the surrounding hills were directed to the dams. In the dams, the stored water gradually percolated into the aquifer which fed the surrounding Qanats, in order to guarantee their discharge for a long time.

NON-STRUCTURAL FACETS

Traditional Qanat management

It is very typical to see a small current of water flowing out of a Qanat in an Iranian desert village. There are hectares of farmlands, all dependent on this water, and many farmers are entitled to receive a portion of his water for their farms and orchards. No dispute or even argument breaks out among the shareholders, and it is all indebted to an intricate water management system which has evolved over hundreds of years. In case of some Qanats, a flow of 100 lit/s may be divided among more than 1000 shareholders who have learned how to live and work side by side through the water management systems, ensuring the sustainability of Qanat itself.

Economic diversity and efficiency

Qanat was not only a means to supply water to the cultivated lands, but it has had some other economic functions like fish breeding, providing energy for watermills, supplying water for the domestic use etc. Therefore, the revenue of a typical Qanat has not been limited to the irrigation and agricultural productions. The multiple economic benefits of Qanat gave it a better chance to survive in the course of history. In the face of many natural and human-induced disasters in the past, over two thousand years, Qanat had stayed at the hub of local economy in Iran.

Cooperation and social convergence

In Qanat, traditional water division systems exemplify the soul of coexistence and cooperation which have always drew people together in this region. Cooperation among a particular society is considered as a kind of intangible social capital which proved a predisposition for development. In traditional water management system, a slight disagreement among some water shareholders can throw all the irrigation system into disorder and endanger the Qanat sustainability itself. Therefore, consensus is what everybody benefited from, and the water management system has evolved into a state that now guarantees the collective interests. We believe that the traditional water management system has nourished social convergence on which 'cooperation' has been established. Though, soul of cooperation is rooted in Qanat water management, it has spread to the other social domains such as family life, education, production, etc. Even today, it is easier to bring people together to launch a cooperative economic activity in the regions with a history and tradition of water management than the regions where such a social foundation is missing. Water has always been the cornerstone of civilizations in the arid and semi-arid regions of Iran, and all the social foundations revolving around water have become a kind of model for the other aspects of social life. The following model shows the socio-economic effects that Qanat traditional water management system directly or indirectly has on different aspects of social life.


قبض رسید نقفه حسین آباد رستاق یزد
تاریخ ... ماه ... ۱۳۱۵ نمره ۹۸
مبلغ ... ریال توسط ... بابت ... جره مالکی ...
جهت حفر کار جدید نقفه در سال ۱۳۱۵ واصل و عاید گردید
محل امضاء مباشر نقفه محل امضاء ناظر

Figure 14. A traditional bill to collect the shareholders' contribution to the maintenance of Qanat of Hossein Abad Rostaq in 1936

Logical approach toward nature

Qanat exemplifies reconciliation between human and nature. Qanat has an ecologic relationship with environment, as it does not drain surplus to the water input. In a Qanat system, the overflow of groundwater pours into the gallery and unlike the tube wells - never sucks up groundwater disturbing its balance with the natural aquifer. The core concept of Qanat is that: 'humans adjust themselves to the water available and not the other way around'. As mentioned before, in many Qanats, especially mountainous ones,

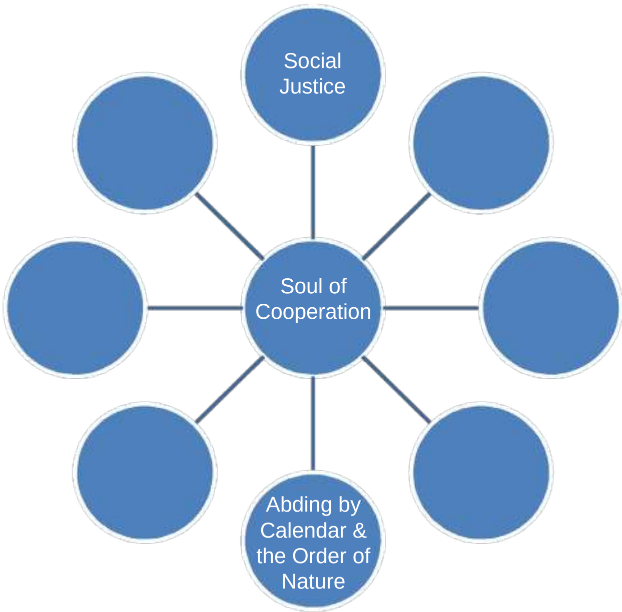

Figure 15. Socio-economic effects of Qanat water management system on different aspects of social life leading to its sustainability

fluctuation of water was inevitable in the wake of changes in annual precipitation. Therefore, the farmers used to take two strategies to tackle the negative impacts of the water fluctuation. When the Qanat water dwindled, the cultivated lands shrank or the cropping pattern was changed to a more drought resistant crops or even both. But the modern approach tends to keep the area of cultivation with the more profitable cropping pattern, and the cropping pattern is not in balance with the water being discharged from the aquifer.

They adjust the area of the cultivated lands and the cropping pattern to the existing discharge rather than place pressure on groundwater sources in order to make it through the drought.

Systematic interactions between Qanat and society

One of the key elements of Qanat sustainability is a mutual interaction which has always existed between Qanat and society. A Qanat underlay agricultural economy, supplied water for domestic uses, provided energy needed to operate the watermills, and eventually Qanat used to meander along the alleys and beneath the houses to provide the inhabitants with pleasant ambience. Even Qanats dictated the layout of a desert city and embodied the social stratification according to the amount of access to the Qanat water. On the other hand, Qanat was completely dependent on the society through its traditional maintenance systems.

Lack of intervention of government

Qanat enjoys one of the most efficient traditional management systems. It has always relied on the local potentials and its owners' contributions. The managerial and financial systems have evolved in compliance with the environmental and social conditions over hundreds of years ago, and any careless manipulation can put all the human ecology of the region including the Qanats at risk. Government does not have a systematic relationship with Qanats, and their uncontrolled intervention does not bode well for the Qanats.

CONCLUSION

Qanats have played a vital role in groundwater extraction since very ancient times. Qanats run across the desert, like veins and arteries in the body, bringing life and prosperity to the people who used to live off the water flowing down the Qanats. This technology was the focal point of the genesis of civilization in some parts of the world. The harsh environment drove them to invent the technology of Qanat and the know-how revolving around it. Qanat carried a tradition of science and technology which used to be practiced in order to overcome the technical obstacles in Qanat construction. Thus Qanat was not only a source of irrigation but also seen as a technical and cultural legacy which deserved more attention.

It has been shown that the existence of 37000 Qanats in Iran heralded their sustainability. Some Qanats go back to over 1000 years in antiquity, and they are still in active use. They still exist because they are sustainable. As a result we want to identify the secrets of this sustainability to better preserve the existing Qanats and also generalize the principles to be used in other developmental activities. The first secret of Qanat sustainability was anchored in the approach of this technology towards the nature. It has been argued that Qanats had been sustainable due to their perfect harmony and balance with groundwater reserves. Due to their distinctive features, Qanats discharged the aquifer water in a continuous manner, so that users (farmers, settlers, nomads, etc.) could perfectly adapt themselves to water fluctuations induced by droughts and wet years. In other words, Qanats had always enjoyed compatibility with the nature as a means for rational discharge of groundwater, proving that the forefathers had guaranteed the sustainable balance of the water table through their wise attitudes and policies. Unfortunately, the wise practices have been disturbed and excess mining of water using modern technologies such as deep wells and electrical pumps have been practiced which has resulted in a threat to the underground resources in arid and semi-arid zones. Thus, we can clearly observe the fast decline in water tables throughout those regions. Therefore, Qanats as the only means of sustainability of these aquifers and their rational mining should be taken into consideration. On the other hand, the sustainability of Qanat is contingent on the balance of aquifer as well as a perfect system of structural and non- structural facets. The core concept of Qanat was that: *'humans adjust themselves to the water available not the other way around'.*

The second secret pertains to the dependence of people on them. Qanat was the cornerstone of the prosperity of the desert towns and villages. In the arid and semi-arid regions that lack surface water, it was always Qanat which made life possible. All the agricultural and industrial activities had always revolved around Qanat systems, and no water meant no activity and no life. Therefore, such a deep dependence on Qanat water drove those communities to bend over backwards to maintain and preserve this system and hand them down to the next generations.

The third secret of Qanat sustainability was its effective management and the precise regulations ruling over it. The water-right timing system, ownership and management system of Qanat, and the remaining deeds of endowments, all showed how much our ancestors were concerned. The three essential elements were: effective preservation, renovation and sustainable exploitation of this ancient hydraulic structure. Scarcity of water in the central plateau of Iran and the difficulty of utilizing groundwater had brought about such an accurate know-how. The existing system, not only deals with the water owners and the water users transactions, but also indicates their commitments to Qanats.

The forth secret of Qanat sustainability was rooted in its economic role. The agricultural economy of the beneficiary communities relied on the water coming out from the Qanat. As mentioned, Qanat not only came up with the revenue in agricultural sector, but also brought some indirect benefits. Society never gave up such a profitable system, but regularly monitored and cared for it.

The fifth secret had to do with the social convergence and cooperation. Social cooperation could be traced everywhere in Qanat whether in its construction or its maintenance or operation or management. Long term utilization of Qanat was impossible without collaboration.

These secrets have been mentioned in this chapter to shed a light on the reasons of Qanat sustainability during the course of history. This chapter helps answer the questions, how and why some Qanats failed to function, what were the recent threats to the Qanats, and eventually to apply these secrets to our modern systems as well to better secure their sustainability.

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CHAPTER – 6

The Beemster, A Drained Lake that Already Proved to be Sustainable for More Than 400 Years

Bart Schultz [a]

Drained lakes are polders that were created by draining areas that were previously permanently under water. In the beginning of the 16th century, this became possible by the invention of the windmill with a revolving cap. Initially several small shallow lakes were drained and reclaimed. At the beginning of the 17th century, a start was made with placing the windmills in a series. This enabled the reclamation of larger and deeper lakes. The first lake that was reclaimed in this way was the Beemster of 7,100 ha. As a private enterprise, it was reclaimed in the period 1608 - 1612 with fifteen series of mainly three windmills. After the reclamation, the area has shown a prosperous development during its more than 400 years of existence. In 1999, the polder was declared a UNESCO World Heritage site. Together with the fertile soil and the rational lay out of the drainage system, initially consisting of open tertiary, secondary and primary drains, an adequate water management has been established in the climatic conditions of the Netherlands.

The main land use in the polder has been agriculture and livestock, with over the years gradual changes and improvements in the crops that are cultivated, as well as in the livestock production. A certain urbanisation has also taken place together with recreation facilities.

As far as organisation of water management and flood protection is concerned, it is important that directly after the reclamation, the lands were distributed among the stakeholders who were involved in the reclamation. Since then, the stakeholders were and still are responsible for operation and maintenance, as well as for upgrading of the water management system and the surrounding dikes. Changes in the water management system over the years resulted in gradual improvements of the water level and water quality control. Nowadays, the two electrical drainage pumping stations are fully automatic, resulting in marginal fluctuations in the water levels in the drains compared to the preferred water levels.

This chapter focused on the developments in the technical and institutional aspects of the 'Beemster'. An analysis is given of the perceived reasons for the successful exploitation of this drained lake, followed by an outlook in the future.

INTRODUCTION[1]

Drained lakes are polders that have been created by draining areas that were previously permanently under water. In the beginning of the 16th century this became possible by the invention of the windmill with a revolving cap (Schultz, 1992 and 1993). During this century, several small shallow lakes were drained and reclaimed, while by that time the windmills could only lift the water by 1.5 m. At the beginning of the 17th century, a start was made by placing four windmills in a series. Because of this, it became possible to drain and reclaim larger and deeper lakes. The first lake that was drained in this way was the Beemster of 7,100 ha, reclaimed in the period 1608 - 1612 with fifteen series of mainly three windmills. The reclamation was a purely private enterprise, primarily undertaken by rich merchants that lived in nearby Amsterdam. After reclamation, the area has shown a prosperous development during the more than 400 years of its existence. In 1999 the polder was declared a UNESCO World Heritage site (United Nations Educational, Scientific and Cultural Organization (UNESCO), 1999).

1 This chapter is to a large extent based on the paper The Beemster, a drained lake since 400 years by the author. In: Proceedings International Seminar on Historical Water Sustainability: Lessons to learn, 24 June 2012, Adelaide, Australia.

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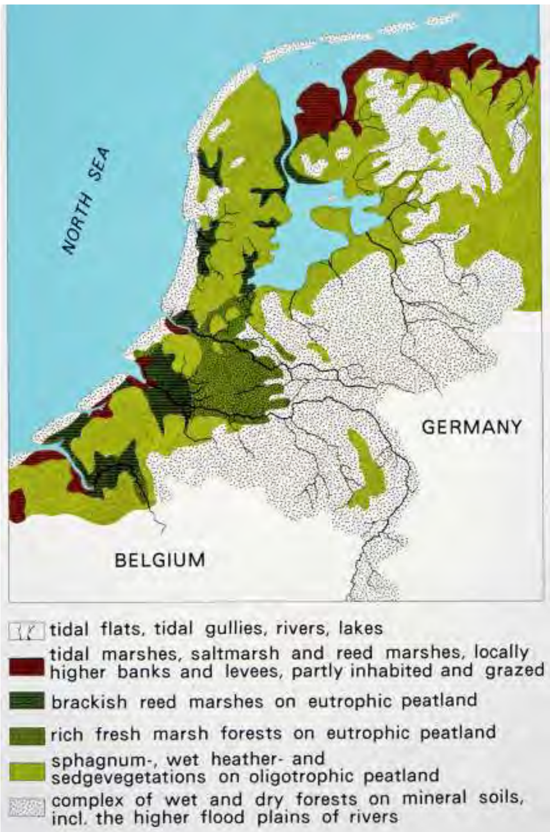
Changes in water management over the years have resulted in gradual improvements of water level and water quality control. Nowadays, the two electrical drainage pumping stations are fully automatic, resulting in marginal fluctuations in the water levels in the drains compared to the preferred water levels.

In this contribution the focus will be on technical and institutional aspects of the polder and developments in these aspects over the more than 400 years. An analysis will be given of the perceived reasons for the successful exploitation. This will be followed by an outlook in the future.

The history of water management of the Netherlands shows how the original natural landscape in a continuing struggle with the water was transformed into a cultural landscape. The Low-Netherlands currently represents a largely man-made landscape: a patchwork of embankments, polders (including lands gained on the sea and drained lakes) and lakes, intersected by numerous ditches and canals (Figure 1) (Van de Ven, 2004).



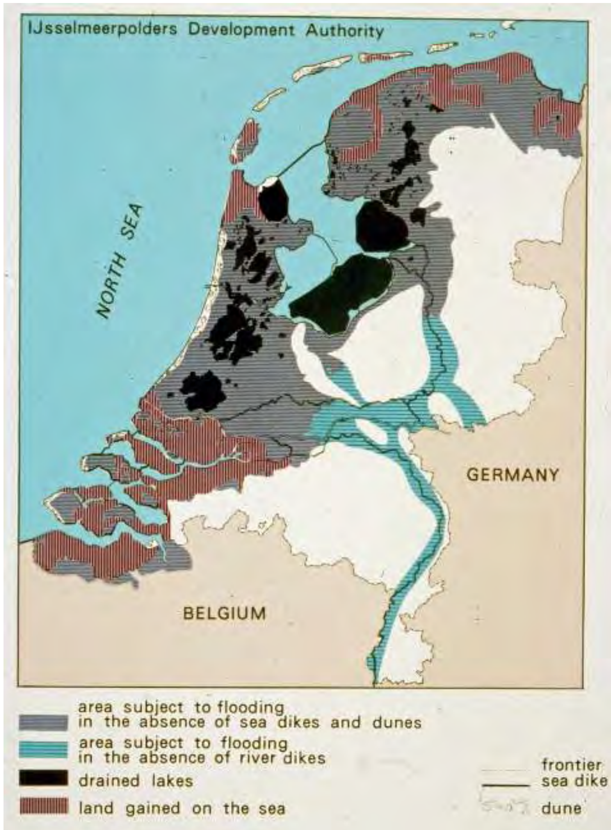


Figure 1. The Netherlands about thousand years ago and at present based on the four types of polders (after Van de Ven (ed.), 2004 and Schultz, 1982)

When, due to the sea level rise, flooding problems increased, people in the flood prone areas of the Netherlands gradually entered the stage of passive defence, which implied that they started to live on artificial mounts when the areas surrounding these mounts were flooded. This took place until about the end of the first millennium. By that time the surface level of the lowlands was at 2 - 3 m +MSL (mean sea level) (Figure 1). Under these conditions, the first human influence on the hydrology of the Netherlands started. Since then, different stages can be distinguished in the water management of the country:

- The first stages concerned reclamation by opening up of lands and simple measures in the field of drainage. However, due to these measures a slow process of oxidation and land subsidence was initiated that in combination with rise of the mean sea level resulted in an increasing requirement to take measures in the field of drainage and flood protection (Schultz, 1982; De Bruin and Schultz, 2001; Van de Ven, 2004);
- Then came the stage of active defence, which implied the construction of dikes and drainage systems with discharge sluices. In the second part of this stage, the local dikes were connected, thus creating defence lines against flooding;
- The lands became deeper and deeper and it became a requirement to shift from drainage by gravity to drainage by pumping. In fact, we entered, in the beginning of the 15th century, in the stage of water quantity management;
- In the middle of the 16th century, the draining of lakes started. In this period windmills and their lifting devices were gradually improved. During the 19th century, most of the windmills were replaced

by steam power drainage pumping stations that in their turn at the beginning of the 20th century were replaced by diesel and electrical pumping stations. Nowadays, we have generally fully automatic electrical pumping stations;

- After the Second World War, water quality problems rapidly increased due to untreated release of urban and industrial waste waters and increased application of fertilisers and pesticides in agriculture. With the *Pollution of Surface Waters Act* (Ministry of Transport, Public Works and Water Management, 1970), the Netherlands entered in the stage of water quality control as well. Originally different organisations took care of water quantity and water quality control, but rapidly these organisations were merged;
- We are now in the stage of integrated water management. This stage was even more enforced by the *European Water Framework Directive*, stating that water has to be treated as an ecosystem and that the environment may not be deteriorated (European Commission, 2000);
- Most probably the present stage will not be the last one and we may enter into a stage of integrated environment management, in which we better integrate land use planning and water management planning (Schultz, 2006).

RAINFALL AND EVAPOTRANSPIRATION

We can live and work in the conditions as outlined above, while the rainfall in the Netherlands is moderate, as shown in the Figures 2 and 3 that show the situation for the Beemster. Figure 2 shows the average monthly rainfall, reference evapotranspiration and rainfall surplus. Under average conditions there is a monthly rainfall deficit from early April till early August. However, this deficit is normally such that the predominantly clay soils in the polders have such a high water-holding capacity that only in excessive dry periods, supplementary irrigation may be required. Because of this the water management systems in the polders are primarily drainage systems.

In light of the question of sustainability, it is also interesting whether there is a certain trend in the rainfall data and if such a trend can have significant influence in the functioning of the water management system. For the station West Beemster, a series of daily rainfall data since 1953 is available. The annual data, including the linear trend line, are shown in Figure 3. It can be observed that over the past sixty years, there is indeed a certain trend. However, this trend is such that measures, like increase in storage or in pumping capacity, can be easily taken when they would become required. This also applies, more in general, to the polders of the Netherlands (Schultz, 2008; Van Boetzelaer and Schultz, 2011).

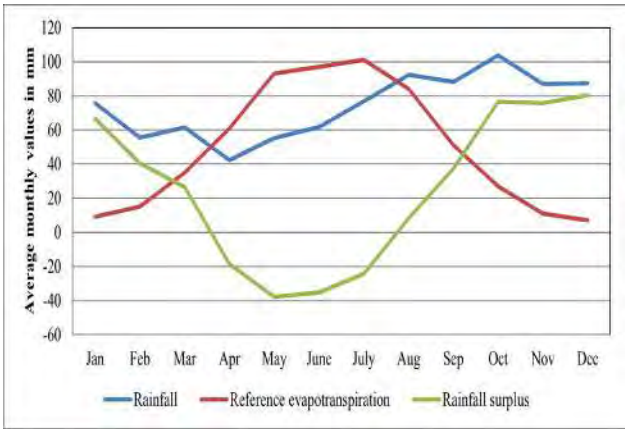


Figure 2. Average monthly rainfall, reference evapotranspiration and rainfall surplus for the conditions in the Beemster for the period 1981 - 2010

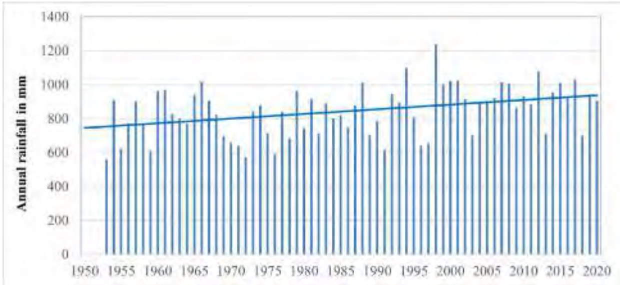


Figure 3. Annual rainfall data of station West Beemster for the period 1953 to 2014

WATER MANAGEMENT AND FLOOD PROTECTION

Water management

For the design of water management systems we distinguish in the rural areas preferred water levels, design water levels under extreme conditions - normally the winter situation with a chance of occurrence of 10 - 20% per year - and bankfull (1 - 2% per year). In the urban areas, the design of urban canals is generally based on the same principles. The design criteria for the rainwater sewer pipes (generally 60 l/s/ha) come in addition. Based on these design criteria, the water management systems in the rural areas of the polders can be characterised by (Schultz, 1992):

- spacing between subsurface pipe drains (clay soils) or open field drains (peat soils);
- depth of the subsurface pipe drains (clay soils) or open field drains (peat soils);
- polder water level in the open collector, or main drains;
- percentage of open water;
- pumping capacity.

For urban, recreation and nature conservation areas in polders, similar characteristics can be applied. For urban areas, especially since 1950, landfill has been applied.

Flood protection

With respect to the physical provisions for flood protection in the Netherlands, a distinction is made between primary and secondary structures. The primary structures concern the protection provisions along the coasts - dunes, dikes and storm surge barriers - and along the rivers and the IJsselmeer - dikes, weirs, discharge sluices and special provisions. The design standards for the primary defence structures per type of dike-ring area[2] are shown in Figure 4. As far as the level of protection is concerned, a distinction is made between densely populated areas and less densely populated areas that can be flooded from the sea, areas that can be flooded by the main rivers and transition areas that can be flooded from the sea or by the rivers. Even higher safety standards are foreseen in the near future.

Figure 4. Safety standards per dike-ring area in the Netherlands (Technical Advisory Committee on Water Defences, 2000)

The dike surrounding the Beemster is a secondary dike. It has a safety standard of 1/1,000 per year. This dike has only breached during the construction in 1610 and has proven its value since then.

Responsibility for water management and flood protection

In water management and flood protection, a distinction is made between the National level and the regional level. At National level, the responsibility rests with the Ministry of Infrastructure and the Environment with its implementing agency Rijkswaterstaat. The responsibility at regional level rests at present with 23 Water Authorities. The Beemster is under the responsibility of the Water Authority Hollands Noorderkwartier. Originally, it had its own water Authority that was only responsible for the Beemster. The excess water was pumped in the collection and transport system that was under the responsibility of the Principal Water Authority with the name *'Uitwaterende sluizen van Kennemerland en West-Friesland'* (Van de Ven, 2004). This Principal Water Authority was responsible for the management of the collecting and transport system where the water of the Beemster was pumped in, temporary stored and brought to the sea and for dikes that were protecting the lands under their responsibility from flooding of the Zuiderzee and the North Sea. Since the 1960s, there have been very significant mergers of the Water Authorities. In the framework of this process, all the Water Authorities in the Province of North-Holland above the North Sea Canal from Amsterdam to the sea at IJmuiden have merged and now operate under the name Hollands Noorderkwartier.

The small watercourses have to be maintained by the landowners/leasers themselves under the supervision of the Water Authority. The operation and maintenance cost for water quality control, water quantity control and flood protection are fully covered by the inhabitants of the area. In case of the Beemster, these costs are nowadays directly charged on an annual basis by the Water Authority Hollands Noorderkwartier. For upgrading or modernization works, there may be government subsidies.

THE DRAINED LAKES

Initially windmills for pumping were provided with a paddle wheel that could lift water up to 1.5 m. Such windmills could be used to drain relatively shallow lakes. However, the larger lakes in the Northwest of the Netherlands were too deep to pump them dry with one windmill. This was solved at the beginning of the 17th century by placing the windmills in a series (Figure 5), a series of maximum four windmills, lifting the water to successive water levels, was very important for the pumping of drained lakes.

Figure 5. Still existing series of three windmills in polder De Schermer, nearby the Beemster

2 A dike-ring is the area of land that is protected from flooding by an individual dike.

Nowadays, there are 445 drained lakes in the Netherlands with a total area of 311,710 ha. The drained lakes can be divided into two groups as shown in Figure 6 (Schultz, 1992 and 1993). The first group consists of drained lakes that came into being by reclaiming lakes or parts of the sea. The second group is formed by the drained lakes whereby lakes or ponds were created by peat-digging.

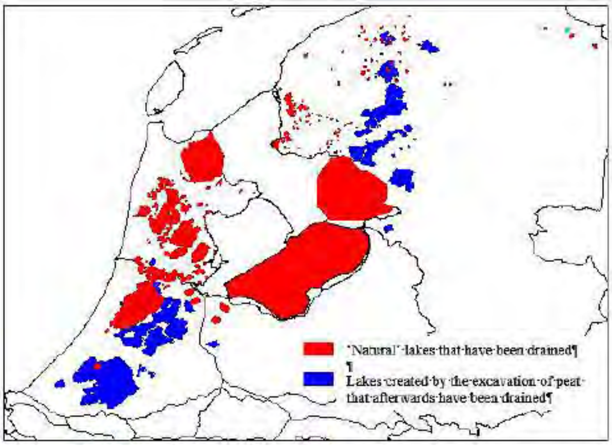


Figure 6. The drained lakes of the Netherlands

The history of the draining of lakes started with the Achtermeer, a lake of 35 ha near AlKmaar, reclaimed in 1533 (Schultz, 1992). In the history, there are three significant developments with respect to the drained lakes, the Beemster (7100 ha, reclaimed from 1608 to 1612), the Haarlemmermeer (18,100 ha, reclaimed from 1840 to 1852) and the IJsselmeerpolders (165,000 ha, reclaimed from 1929 to 1990).

RECLAMATION OF THE BEEMSTER

The Beemster, as the oldest large drained lake in the Netherlands, deserves a prominent place in our history of land reclamation. The main land use in the polder has been agriculture and livestock, although there have been gradual changes and improvements in the crops that were cultivated, as well as in the livestock production. A certain urbanisation has taken place recently together with some recreation facilities.

The reclamation started with the making of the surrounding dike and the ring canal into which the excess water would be pumped during the emptying of the lakes (3.5 – 4.0 m water layer) and the resulting water management of the polder. During the construction period, there has been a storm resulting in the dike collapse. However, this was no reason to stop with the reclamation. Interesting from the reclamation period is also the number of windmills that were required to pump the lake dry. In order to achieve this, there was a contract between the developers and contractors prescribing (Bouman, 1857):

> 'To be sure, *whether the reclamation could be accomplished with 16 windmills, the contractors have committed themselves and promised that within 4 weeks of their intervention, a trial would be done in front of representatives of the developers. And if it was found that the 16 windmills would be unable to do the work, the contractors would install sufficient additional old or new windmills as to be approved by the representatives.'*
>
> *However, the following quote prescribed the result:*
>
> *'Moreover, they soon became convinced that the number of windmills initially had been set too few, and that it had to be increased from 16 to 25. As a result, the developers, as well as the contractors themselves, recognizing the non-sustainability of the contract, presumably jointly came to the decision to terminate the contract and to make another contract by which the contractors were dismissed, while the reclamation would be completed and only be continued at the account of the developers.'*

Finally, fifteen series of mainly three windmills each were used to drain and reclaim the Beemster. Together with the fertile soil and the rational lay out of the drainage system, initially consisting of open tertiary, secondary and primary drains an adequate water management was possible in the climatic conditions of the Netherlands (Figure 7). Also, due attention was paid to the water management system and the percolation of the newly reclaimed land.

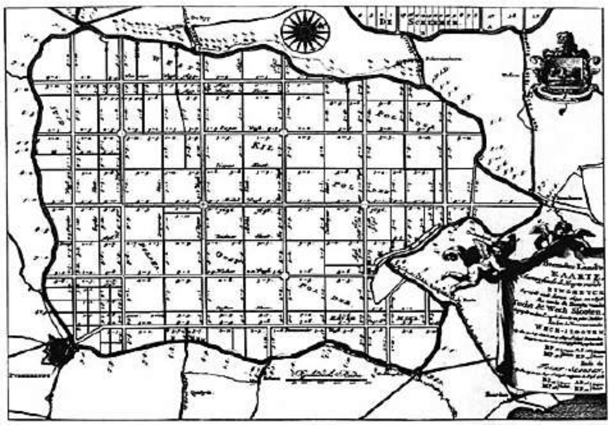


Figure 7. Map of 1696 showing the dimensions of the drains of the Beemster. This is as far as we know the oldest map in the Netherlands where such information is shown

As far as the organisation of water management and safety is concerned, it is of importance that directly after reclamation, the lands were distributed among those who were involved in the financing of it. The pieces of lands were distributed proportional to the amount of investment that each stakeholder had made. Since then, the stakeholders have been responsible for operation and maintenance, as well as upgrading the water management system and the surrounding dike. These stakeholders were free to cultivate the lands themselves, or to sell or rent their lands to others (Van Zwet, 2009).

Jan Adriaansz. Leeghwater

Very much linked to the reclamation of the Beemster, as well as to reclamation of other lakes in the same period was Jan Adriaansz. Leeghwater (this name was an alias) (Figure 8). He was originally a millwright and became involved in several of these projects in the Netherlands and in some other places in Europe, as well as in quite a range of other technical activities. However, it is still debated as to what extent he was really involved. The author is of the opinion that in the field of water management and flood protection, he has been a unique person in the history for reasons as explained underneath.

Figure 8. Mr. Jan Asz. Leeghwater and one of the labourers in action. Painting by H. Mollinger, picture Purmerends Museum

It is for sure that he was a millwright, that he was involved in quite a number of projects and that he made several improvements in the construction of windmills. However, the more interesting may be that he, as far as can be traced, was the first person that understood more or less the process of seepage, which was by that time completely unknown. This can be derived from the following quote from his Haarlemmermeer book (Leeghwater, 1641):

> *'I am well aware, that there are some lakes that cannot well be reclaimed, but the cause of this is that: or the clay is located too deep, or those lakes border hilly land, or coarse sand that is very permeable, as I have observed and found myself, or because the ground is raised and covered with bushes or leaves of trees, and therefore remains permeable and spongy. As also can be observed from the fact that some of these lakes will not be covered very well with ice, even when the frost is strong, which is a sign that the ground is open, spongy and leaky.*

The Haarlemmermeer was a lake between Leiden and Amsterdam and during storms, the banks were eroded by the waves. Therefore, since the beginning of the 17th century, reclamation of the lake was being discussed. Finally, after more than 200 years of plans and discussions, the lake was reclaimed in the middle of the 19th century (Schultz, 1992). In this area, nowadays, Schiphol Airport is located. In his Haarlemmermeer book Leeghwater developed a complete plan to drain and reclaim the Haarlemmermeer with 160 windmills. The book contained a map of the reclamation that is shown in Figure 9 *(Leeghwater, 1641)*.

Figure 9. Map of Leeghwater of 1641, to drain the Haarlemmermeer with 160 windmills (Leeghwater, 1641)

In order to proof the benefits of the possible reclamation of the Haarlemmermeer, he also did applied research to prove that the soil in the lake was very fertile. He did his research under the supervision of the mayor of the nearby village of Aalsmeer in order to prevent that his observations could be debated. This was also a very innovative approach for that time. The following quote is interesting with respect to this:

> *'As regards the soil of the Haarlemmermeer, I can only find and understand that it is very good, since I have determined the level, taken samples, felt it and investigated it at many different places with the mayor of Aalsmeer and some labourers. Based on this, I can only conclude that the lake has a topsoil of good clay, usually 7, 8 and 9 feet thick.'*

In my opinion these examples sufficiently prove that he has been a unique person in the history of water management and flood protection in the Netherlands.

First example of subsidence

With respect to the Beemster, the first example of recognition of the subsidence process was also seen as described by Bouman (1857):

> *'The drains became increasingly narrower and shallower and could not always accommodate the abundantly falling rain water, therefore many times more or less considerable portions of the polder became inundated.'*

When one had to lower the desired polder water level:

> *'This was a highly useful measure, while not only the bottom of the new polder had significantly subsided in the first twenty years after reclamation, but also, because the windmills were only placed*

in series of three, one had set the desired polder water level initially too high, so that the ground never could subside as required.'

IMPROVEMENTS SINCE THE INITIAL DEVELOPMENT PERIOD

As described before, initially the windmills were provided with paddle wheels as lifting devices (Figure 10). In the middle of the 19th century the paddle wheels were replaced by open Archimedes screws. All in all, for about three centuries windmills have taken care of the water management of the Beemster.

Figure 10. Location of windmills in the Beemster

The capacity of windmill was such that one windmill could drain 400 to 600 ha. However, it has to be realised that in time of the windmills, the objective was to have the lands dry from April till October in order to enable the cultivation of one crop during the summer period (April - September). In winter, the lands were waterlogged, or even inundated. When by the middle of the 19th century, the windmills could be provided with an open Archimedes screw, a series of four windmills could be replaced by a series of two windmills.

By the end of the 19th century, the windmills of the Beemster were gradually replaced by three steam power pumping stations, in their turn, in the beginning of the 20th century in several stages, they were replaced by diesel and electrical pumping stations. Nowadays, the discharge of the excess water from the polder is done by two fully automatic electrical pumping stations (Figure 11).

The steam power pumping stations of the Beemster were provided with centrifugal pumps. The disadvantage of steam power pumping stations was that it took quite some time before they were really operational. When operational, their capacity was about 8 mm/day. The steam power pumping stations also made it possible to have relatively low preferred water levels in the winter period, which contributed to improvements in the soil quality by creating better drainage conditions. This, so called winter drainage, was introduced by the end of the 19th century.

Figure 11. Electrical pumping station Jacobus Bouman on the Eastern side of the Beemster. One of the two fully automatic electrical drainage pumping stations

With the coming of the diesel and electrical pumping stations, the centrifugal pumps were gradually replaced by screw pumps. This finally resulted in the two electrical pumping stations with a capacity of approximately 14.5 mm/day. Together with the percentage of open water in the polder and the preferred water levels, a very accurate water level control has been achieved. In the polder, there are quite a lot of sections with different water levels. For some of the larger sections, automatic control of the water level with movable weirs has been established (Figures 12 and 13).

Figure 12. Road with trees and road drains in the Beemster

Figure 13. Weir controlling the upstream water level in a section of the Beemster

Within the polder, it is to some extent surprising that the main original lay out of the plots as shown in Figure 7 has almost not changed over the past four centuries. It, therefore, looks like our ancestors had developed a very sustainable lay out. However, one significant change has occurred in the fields. This has been the installation of subsurface pipe drains in most of the fields during the second half of the 20th century. With these drains, a more accurate control of the groundwater table is possible, again improving the overall conditions. Pictures 14 and 15 show, respectively, the dike inside the polder with the seepage drain and the dike outside the polder with the canal of the collection and transport system (about 0.50 m-MSL).

Figure 14. Inner side of the dike, with seepage drain, surrounding the Beemster

Figure 15. Outer side of the dike with canal of the collection and transport system

As far as the outside conditions are concerned, since the closure in 1932 of the Enclosing Dam in the North of the Netherlands, the Zuiderzee was transformed in a fresh water lake, called the IJsselmeer. Because of this, the risk of the effect of storm surges along the east coast of the Province of North-Holland has been significantly reduced. However, an even more significant improvement is that the saline water of the Zuiderzee has been replaced by fresh water in the IJsselmeer. This water is intensively used to flush the drains in the polders of North-Holland, which has significantly improved the conditions, especially during the summer period.

OUTLOOK IN THE FUTURE

Over the past more than 400 years, the Beemster has proved to be sustainable, while the stakeholders have proven to be able and willing to take care for the water management and flood protection systems. Economically, the inhabitants in the polder are doing well, as can be illustrated by the average full time annual income that was € 32,500 in 2010, which is slightly higher than for the Province of North-Holland and about 10% higher than the average for the Netherlands (Statistics Netherlands, 2011). At the occasion of the 400 years of the existence, there was a rich variety of activities organised by the local population. At the initiative of Antiquary Serendipity, an impressive book describing the salient points of the history of the Beemster, was published (Figure 16) (Falger *et al.*, 2012). As far as agriculture and livestock is concerned, for example the cheese from the area is well known and is exported to many countries (Figure 17).

Figure 16. Cover of the book published at the occasion of the 400 year of existence of the Beemster (Falger et al., 2012)

Figure 17. Beemster cheese

Also in the Netherlands, there are quite some discussions on the possible impacts of climate change on water management and flood protection provisions, as well as on the sustainability of the polders. However, the possible impacts of climate change are marginal in the conditions of the Netherlands as compared to the human induced changes in land use (Schultz, 2008; Van Boetzelaer and Schultz, 2011). With respect to the drained lakes, it has been observed that subsidence has come to an end. It may, therefore, be expected that similar gradual improvements will be possible as those that have been introduced gradually over the past 400 years. When the accurate operation and maintenance of the water management and flood protection systems can be maintained in the forthcoming 400 years than the sustainability of this drained lake seems to be assured.

ACKNOWLEDEMENT

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CHAPTER – 7

The History of Irrigation Sustainability in Malaysia [a]

INTRODUCTION

Irrigation in Malaysia is generally associated with paddy and not for non-paddy crops as it is still insignificant in comparison to area and volume of water use. The average annual rainfall is between 2,500 to 3,000 mm and this is estimated to yield 559 Billion m^3 (Bm^3) of water resources of which 496 Bm^3 is surface water and 64 Bm^3 is groundwater recharge.

The water demand of Irrigation Sector (for paddy) was estimated to be 8,266 Million m^3 (Mm^3) per year in 2010 and this was 56% of the total water demands for potable water and agriculture (14,789 Mm^3/year (Figure 1)). Paddy is grown to match the rainfall pattern and this is generally defined as the Wet (Rainy) Season during the North East Monsoon between October and March and the Dry Season during the South West Monsoon that prevails between April and September. Irrigated paddy contributed more than 90% of the total of 2.6 Million tonnes of national paddy production (2012). This was just over 70% Self Sufficiency Level (SSL) of rice for the country with over 29 Million population.

	MCM/year	
	2010	2050
Total Surface Runoff	494,260	494,260
Total Water Demand (Water Supply, Irrigation, Livestock)	14,789	18,250
% of Water Demand	2.99	3.69
% Balance Surface Runoff	97.01	96.31

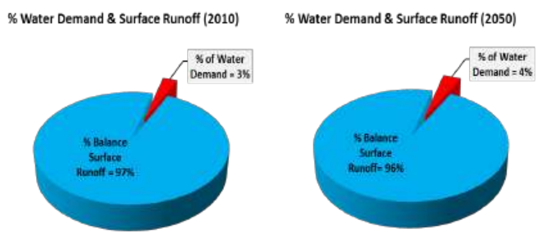

Figure 1. Surface runoff and water demand in 2010 and 2050

Rice is the staple food in this country and paddy planting has been practiced since time immemorial and is still sustained. Initially, it was rain-fed production followed by irrigation for single cropping and subsequently double cropping. This development was in response to the social and economic challenges of that time.

This was a brief history of how those challenges were addressed and the responses managed to sustain irrigation for paddy in the changing social and economic environment thereby transforming agriculture-based economy to one that was more diverse and complex economy with a growing and more urbanised population. However, the contribution from agriculture sector to the GDP declined to 7% in 2010 and is expected to further decline down to 4% by 2050.

THE HISTORY

Pre 1800s: The early days (Pre 1800s)

The geographical and climatic conditions have always been conducive to paddy farming. The vast rich coastal plains and pockets of relatively flat river valleys were the natural hosts for the paddy areas and the local traditions had developed around the culture of paddy farming. The system was characterised by the need of community participation for the labour-intensive transplanting and harvesting activities (Figure 2). Paddy planting was for subsistence and the system was rainfed for a single crop planted during the annual rainy season. Yields were less than 1 ton/ha. The irrigation system was rudimentary and where possible water was diverted into channels by gravity from the nearest river. These were single purpose dual function channels for both irrigation and drainage. This limited

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the width and spread of the irrigated area. Overall, the production was just dependent on rainfall. As such it was subject to the vagaries of the weather and crop failures due to dry years or floods was common. Sustainability was an issue and therefore many areas were not planted continuously and some even consequently abandoned.

Figure 2. Transplanting method

The 1800s-1930s: Beginning of government interventions

The 1800s to 1930s was characterised by the beginning of Government interventions in irrigation development. At the same time, it was also an era of innovations in irrigation technology and development that led to confidence in increasing areas under paddy by farmers and the Government (Figure 3). The single channel and dual-purpose channels were still in use and the system was known as 'back irrigation' or 'negative irrigation' where water flew in the channels were blocked by simple gates or earth and forced to overflow and flood the adjacent paddy areas during planting season. The water was released gradually towards the harvesting period. Irrigation intakes from rivers included the construction of wooden (brushwood) weirs across rivers and wooden water wheels to lift water from the river into the channels. These, however, were not permanent structures and deteriorated over time. Sustaining them was difficult. Siltation often forced the brushwood dams to be periodically reconstructed at a new site and flood damages on these and the water wheels were common occurrences.

Figure 3. Typical layout of positive irrigation

Figure 4. Wooden waterwheel and brushwood dam

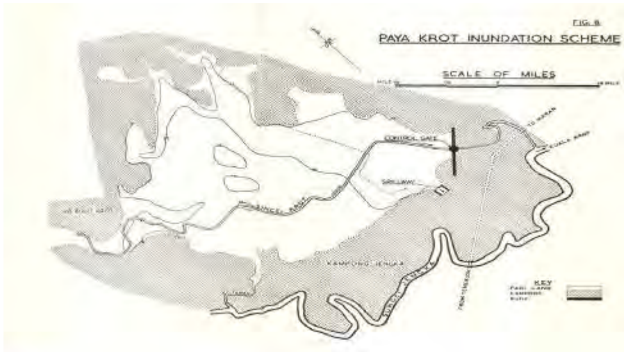

Figure 5. Paya Krot Inundation Scheme

An interesting and unique innovation was the '*Paya Schemes*' (Inundation Irrigation Schemes) developed exclusively in the small valleys in Temerloh region in the State of Pahang (BPSP MOA 2007). In this system, a low weir was constructed across the river and the weir length extended beyond the river to tie up with the adjacent spurs of the foothills. During the planting season, the control gate at the weir was closed to retain water upstream and gradually released at the end of the season. The 'floating' variety of paddy was planted here and it is said that at times, harvesting was performed in chest-deep water and the harvest loaded on to a boat.

In 1885, Wan Mat Saman initiated a large-scale irrigation development on what could be termed now as a public-private initiative project. This project saw the construction and completion in 1895 of a 35 Km channel for irrigation and drainage (now known as the Wan Mat Saman Drain) in return for rental of adjacent lands from the State Government. Subsequent development here in later years led to the development of the largest irrigation scheme in Malaysia, the MADA Granary.

Figure 6. Wan Muhammad Saman Ibni Wan Ismail

Government's initial intervention assisted in opening up of new lands and gradual intensification of irrigation and drainage channels using mechanical dredgers. The systematic applications of science and engineering in irrigation planning and design with consideration on aspects of hydrology and floods as well construction of permanent structures using concrete were introduced. This approach significantly improved the irrigation development and management sustainability.

In 1906, the Bukit Merah Dam was constructed for irrigation supply to the Kerian Irrigation Scheme. This dam is now the oldest large dam in Malaysia and the Kerian Irrigation Scheme has developed into one of the 12 Granaries for the country.

The 1930s-1950s: Systematic irrigation development

The 1930s was a significant milestone marking the beginning of a systematic and sustainable irrigation development and management in Malaysia with full Government interventions.

In the late 1920s, incidences of food (rice) supply shortages were frequent and in 1929 the situation was severe. This incidence highlighted the issue of widespread poverty, especially amongst the paddy farmers. This prompted the Government to introduce two major policy objectives namely to reduce the incidence of poverty and to increase the nation's rice production. Since agriculture was the main occupation, irrigation for paddy was the strategy adopted towards achieving these objectives. Following this, the Government institution named the Drainage and Irrigation Department (DID) was formed in 1932 as a department dedicated solely for irrigation and drainage development in Malaysia.

As a dedicated department, the DID was able to undertake not only short-term plans but also long-term planning. This allowed focus and time to continuously gain experience and strengthen knowledge and skills in the science, technology and management for irrigation system planning, design, construction and operations and maintenance. Critical areas of expertise and skills such as in hydrology, hydraulics, canal, drain, dams, hydraulic structures, flood and coastal engineering were developed continuously over the years. The irrigation system design introduced single function channels that separated irrigation (canals) from drainage (drains). Hydraulic structure capacities increased along with canal and drain densities. More new lands were reclaimed and new techniques in land reclamation for large areas were developed. One of these was the construction of pilot drains using dredgers to reclaim swampy areas. These pilot drains were then left for 2 to 3 years to drain out the excess water. Once the soil strength increased, the land was cleared of vegetation and the irrigation system installed.

The designs were for once-a-year planting during the wet season and the purpose of irrigation was to increase the chances of success of the production for that one season every year. With continuous Government support in the scheme operations and maintenance, the system reliability increased. Yields increased to 2 tons/ha and paddy production and therefore income increased and became stable. Farmers' confidence also increased and this ensured that the paddy planting was sustained.

To protect Government investments in irrigation and to reinforce sustainability, the State Governments introduced laws in the form of Irrigation Areas Enactments. The enactment provided for the commitment of farmers to plant paddy and manage water judiciously. Penalties could be imposed on acts that led to water wastage (such as poor maintenance of field bunds (*batas*)), blocking flows and polluting water. The Government was committed to operate and maintain the irrigation systems and in return farmers needed to pay Water Rates. The amount of Water Rates was not based on volume of water used but based on the land ownership size. Further assurance of irrigation scheme sustainability was reinforced by these enactments with the need for the lands within the scheme to be gazetted for single purpose use i.e., only for paddy planting and conversion to other forms of land use was subject to approval from the Government. In 1953, these enactments were harmonised for the whole country by the Irrigation Areas Act (1953).

The 1960s-1970s: Irrigation intensification for double cropping

The irrigation development by the Government was sustained and continued into the 1960s and onwards consistent with the policies to alleviate poverty and to increase food (rice) production. By 1980s there were 936 irrigation schemes spread all over the country. Of these, 8 are large schemes of more than 4,000 ha each totalling 212,764 ha and the other 928 are small schemes covered 132,736 ha.

One of the reasons for the sustained and standardised irrigation development in Malaysia was the provision made in the Federal Constitution of Malaysia. Malaysia is a Federation of 14 States and the Constitution defined the areas of jurisdiction of the Federal and State Governments in the form of 'Legislative Lists'. This list defined areas exclusively under the jurisdiction of the Federal Government (List I - Federal List), those exclusively by the State (List II - State List) and shared areas of jurisdiction (List III - Concurrent (both Federal and State)). Drainage and Irrigation was under the Concurrent List and this in many ways had facilitated the development and financing of irrigation scheme development by the Federal Government.

In the 1960s, the Government introduced programs for economic diversification beyond agriculture sector. With agriculture still as the backbone of economy, irrigation continued as the strategy for the poverty alleviation and food production policies. Double cropping (planting paddy twice a year) was introduced to the irrigation schemes that were already for single cropping. The idea was that this would then double the income and the production of farmers and more as yield increases.

Double cropping required a major change in system design and operations. Timeliness of operations became critical in order to meet the two-season planting cycle every year. This required the development of water resources (such as dams, pumping stations, head works) to ensure adequate irrigation water, especially for the dry season planting. Conveyance and delivery channels also needed to be intensified for timeliness of supply and consequently irrigation supply schedules became the pivotal point of time for planning and implementing all the farm activities.

Two major irrigation projects for double cropping that were implemented in the 1960s were in the Muda Irrigation Scheme and the Kemubu Irrigation Scheme. Both were large schemes formed by consolidating the irrigation systems of contiguous small schemes within their same regions. These developments set the early standards for all other irrigation designs for double cropping in the country. Subsequently the Muda Agriculture Development Authority (MADA) was formed in 1970 and the Kemubu Agriculture Development Authority (KADA) in 1972 and dedicated to ensure the sustainability of these projects. Over the years the teams from these two organisations have not only developed to become experts in irrigation and paddy production but also have cultivated strong bonds with the farmers in their respective schemes. This bonding was also one of the key factors for sustaining irrigation schemes in Malaysia.

The 1980s-1990s: Irrigation in a changing economy

By the end of 1970s, the initial infrastructure installed for double cropping was found to be inadequate to sustain the rigid requirements of seasonal schedules. Many areas were out of phase from the schedule and re-synchronising them, sometimes, required sacrificing one season of planting. The response was to install tertiary canals, drains and farm roads that effectively increased the overall infrastructure densities to 30 m/ha. These allowed for faster delivery and removal of water and therefore, improved timeliness of operations. Sustainable water supply was crucial for irrigation and the water management strategy for irrigation water savings. The strategy was to use as much of the effective rainfall as much possible first and then supplemented by the unregulated flows in adjacent rivers. Releases from reservoirs were used only when water from those two sources was inadequate. This, however, was not easily implemented in practice. To improve this, large schemes were equipped with computer-based water management decision support system (DSS) linked to hydrological data collection stations sending information via telemetry system (Figure 7). This was also supported by trained technicians for on-the-ground visual inspections on water use and watching for leakages in the system.

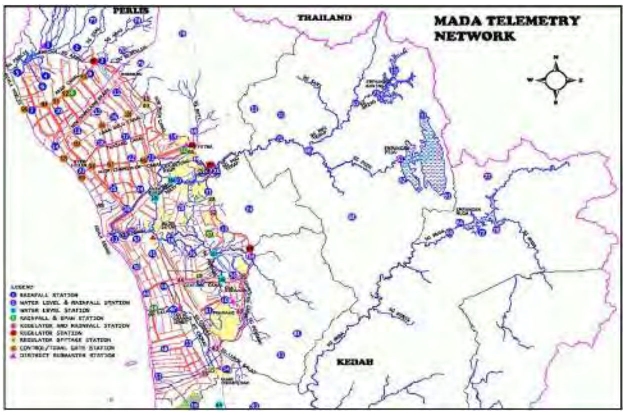

Figure 7. MADA telemetry network

Farmers played a crucial role in the water savings and were therefore encouraged to practice good on farm water management practices. One aspect was to encourage them to undertake land levelling and construct field channels on the farms. Their responses were poor as they were not willing to invest in these, since the transplanting method did not require accurate levelled fields.

To encourage farmers' participation and support in water savings, the National Water Management Training Centre (NWTC) was established in 1982 for capacity building. This centre was also to train irrigation systems managers. Trainings were also provided on-site to the farmers and system managers.

In the mid-1980s, the large irrigation schemes began to form Water User Groups (WUG) (also known as Water User Associations in other countries). The main objective was again to encourage good water management practices by the farmers by adhering to irrigation schedules and on farm water savings.

The mid-1980s saw the impact of an economy in transit on irrigation. The economic diversification plans initiated by the Government in the 1960s began to take effect. The impact was labour migration from the rural based irrigation schemes to the urban areas. As a result, many of the small irrigation schemes were abandoned not due to lack of water resources but rather due to lack of labour for the labour-intensive transplanting and harvesting activities. However, the large schemes survived due to economies of scale. The influence of these large schemes also supported the survival of the small schemes in the fringe areas.

The response initiated by farmers in these schemes was to convert the transplanting method to the less labour-intensive direct seeding and also increased use of mechanised harvesters as well as land preparation machineries. Direct seeding required more precise on farm water management and this encouraged farmers to invest in land levelling and field channels. It also required more precise irrigation water supply and drainage regimes in the systems that were originally designed for transplanting. The system managers' response to this change was adjustments to the irrigation and drainage system management instead of resorting to any capital-intensive structural adjustments.

The shrinking of irrigation schemes threatened the national rice production. In response, the Government introduced a policy that the Self Sufficiency Level (SSL) for rice should be at a minimum of 60%. In addition, the Granary Policy was introduced that designated eight (8) large irrigation schemes of not less than 4,000 ha and they have proven resilient in the changing economy as the main paddy production areas of the country. These were the MADA (96,558 ha), Pulau Pinang (10,138 ha), Kerian-Sungai Manik (28,448 ha), Seberang Perak (8,529 ha), Barat Laut Selangor (19,701 ha), KADA (31,464 ha), Kemasin-Semerak (5,560 ha) and Ketara (Besut) (5,110 ha) totalling to whopping 205,508 ha.

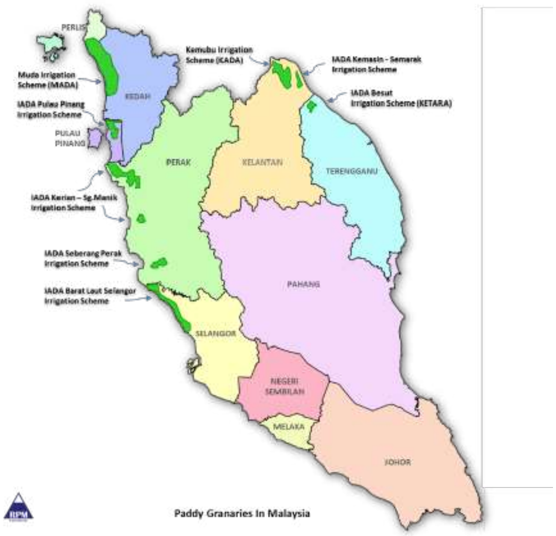

Figure 8. Eight (8) Matured Granaries in Peninsular Malaysia

As Granaries, these large schemes were given special attention and support of the Federal Government to be the focus areas for rice production in the country. The Integrated Agriculture Development Project (IADP) organisations set up with World Bank financing continued to provide the management and administrative support for these Granaries. The small non-Granary irrigation schemes were allowed to be converted into other land uses such as for vegetables, oil palm, livestock rearing and even into housing development. The non-Granaries that were still active with paddy planting continued to receive the government support as necessary.

The 1990s to Early 2000 - from farm worker to farm manager

The pace of irrigation development in Malaysia had increased since the 1960s and peaked in the early 1980s and this was in part due to the World Bank encouragement and financial support that ended in the 1980s. With the success of a more diverse economy, interests in large scale irrigation investments faded and focus shifted towards improved irrigation performance improvements for water savings, efficiency, operations and maintenance. Capacity building programs led by the NWMTC continued for the system managers and WUGs.

At the same time, concerns on stagnant yields hovering at just below 5 tons/ha, small operating land size (average below 1 ha) and aging farmers began to emerge. Programs on Participatory Irrigation Management (PIM) for eventual takeover of the tertiary level facilities, operations and management by the WUGs and group farming and paddy estates for commercial farming were implemented to address those issues. The response from the farmers and the WUGs, however, was not enthusiastic. This was mainly due to the embedded culture and traditions of maintaining security of land ownership and control by self-management. It was also due to several inherent institutional structures that limited the formation of WUGs based on irrigation command areas as it was meant to be. The WUGs was also an administrative arrangement between the farmers and the system management and therefore did not have any legal instrument to ensure compliance by members and enforcement by the system managers. Consequently, these programs and interests of the WUGs also faded.

The farmers, however, continued planting paddy and the Cropping Intensity (CI) remained high at nearly 200% in the Granaries, the large irrigation schemes. This means that nearly all of the paddy areas were planted during both the seasons in the year, every year. This sustained interest was due in part to Government subsidy programs and another due to the changes in farmers' farm management approach and the paddy production industry.

The paddy production was now less labour intensive with direct seeding and mechanisation. This had transformed the farmers from having to 'toil the soil' to becoming 'Farm Managers' instead. Farmers became more independent as individuals and less dependent on the community for labour intensive activities as in the past. Instead, there were now 'service providers' for mechanised land preparations and harvestings and even for direct seeding and pesticide and fertiliser applications. Farmers needed only to appoint and manage these service providers and inspect the fields periodically. These periodic visits also resulted in water wastages from the farms, especially over the period in between those visits.

Figure 9. Direct seeding

At present there are no special regulations to ensure coordination and conduct of these service providers. There are now concerns of the emerging threats on irrigation sustainability as these service providers appear to be in control over the farmers in terms of the timing service deliveries. Cartels by the service providers are emerging and farmers are more and more coerced to accept their terms and conditions without any alternative. The impacts on irrigation are wastages of delivery waters when fields are not ready and disruptions in irrigation schedules when harvesting is delayed. There are now efforts to rationalise this service provider industry to protect the farmers and sustain irrigation.

The Asian Financial Crisis that occurred in 1997 affected Malaysia severely. Investments in irrigation were severely cut back. Nonetheless, irrigation persevered and with continuous 'soft' programs in the form of capacity building and performance assessments. One of the important lessons learned from the crisis was that agriculture was more economically resilient compared to other economic sectors that were more sensitive to external factors. This led the Government to implement policies to strengthen the agriculture including paddy production and supported by the policy to reduce food imports as well. At the same time, questions on the economic and financial viability of paddy production resurfaced in the light of the country's vision for a developed economy. These in a way further held back plans for new investments in irrigation. Instead, the focus continued on efforts for higher systems efficiencies as well as increasing yields to 10 tons/ha (the '10 tons/project) in the 8 Granaries, the large irrigation schemes.

2004 - 2015: irrigation revitalisation

The year 2004 saw another milestone in irrigation and also the water management sector in the country. This was when the Government water related institutions were restructured to separate water resources from end-user management. The DID, having gained experience over the past 72 years in water resources, floods and coastal management was moved from the Ministry of Agriculture (MOA) to the newly formed Ministry of Natural Resources and Environment (NRE) and continued with those primary functions. The irrigation and agricultural drainage function of DID was transferred to the newly formed Division of Irrigation and Agricultural Drainage (BPSP - *Bahagian Pengairan dan Saliran Pertanian*) of the renamed Ministry of Agriculture and Agro-Based Industry (MOA). The DID continued providing the staffs for the BPSP. Irrigation scheme operations remained under the purview of the respective State DID. There was no change under this restructuring exercise to the two MADA and KADA organisations managing their respective Granaries. The management institutions of the remaining 6 Granaries were changed to become the respective Integrated Agriculture Development Area (IADA).

In the following 10 years after restructuring, there were emerging concerns on the declining state of irrigation services. In the restructuring, the NWMTC remained under the DID and its role has now been changed to capacity building programs related to the department's functions. This effectively removed an institution that specialised in water management training for irrigation managers and farmers. In addition, the issues of the continuity of irrigation managers and technicians and retention and enrichment of irrigation knowledge and experience remained. This was because the schemes operated by DID State and the management at the BPSP level were by staffs seconded from the DID. These staffs were subjected to transfers back to the DID and to be replaced by new ones. Those transferred would not have the opportunity to apply and spread the knowledge gained in irrigation since irrigation was not under the DID's purview. The incoming staffs would have to pick up new knowledge and skills. This was disruptive to the continuity and level of services in the schemes. The irrigation manager-farmer bonds established over many years before was also weakened in the process.

In 2008, the country was jolted with the virtual rice shortage, due to 'price spikes' in the international rice market. The impact was of a very short duration (less than a month) in certain areas of the central region of Peninsular Malaysia. Although the situation passed and recovered rapidly, it prompted the Government to seriously review the country's position on food security.

Following this, the SSL for rice was revised to be at more than 70%. In 2013, the Government announced an additional four (4) new Granaries namely Pekan (10,937 ha) and Rompin (6,137 ha) on the Peninsular, Kota Belud (3,357 ha) in Sabah and Batang Lupar (4,300 ha) Granaries in Sarawak. Thus, the total number of Granaries were 12, covering a whopping area of 230,275 ha.

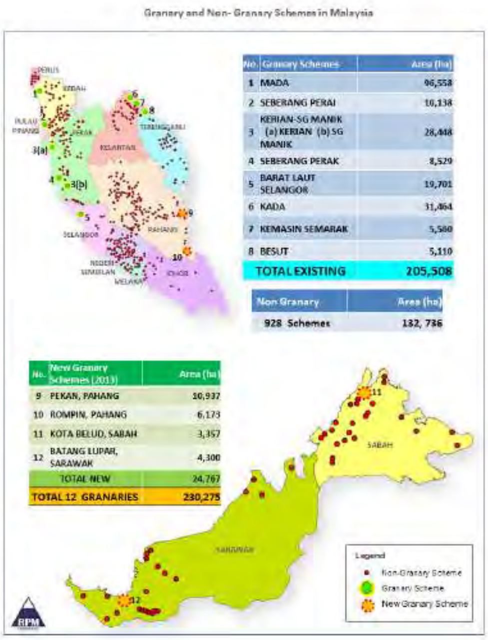

Figure 10. Granary and non-granary schemes in Malaysia

The sustainability of the Granaries was also reinforced under the National Physical Plan No.2 (NPP2) formulated in 2010 under the Town and Country Planning Act 1976. The NPP was a framework, reviewed every 5 years, for sustainable and integrated land use planning that required adherence of the Federal and States in the Peninsular Malaysia. The 8 matured Granaries were recognised in the NPP2 and it was expected that the newly formed Granaries would be incorporated in NPP3 currently under formulation. The National Agro-Food Policy 2011-2020 continues the emphasis on food security, sustainable development, commercial farming and modernisation. 'Agriculture is Business' is the tag line and efforts continue to encourage paddy farmers to transform from individual farming to commercial enterprises.

In 2012, the National Water Resources Policy was formulated and this recognised the need for improved and sustained water resources development and management in the country.

In 2012 too, the Government introduced the Economic Transformation Programme (ETP) that set out the plan for the country to achieve a high income and developed nation status. Twelve (12) National Key Economic Areas (NKEA) were identified and Agriculture was one of them. Within Agriculture, irrigation was set to be transformed to meet the targets of the ETP, that is, principally to increase the Gross National Income (GNI) from RM 23,700 (USD 6,700) in 2009 to RM 48,000 (USD 15,000) by 2020.

To overcome the inertia of the ETP, model fast-tracked projects known as Entry Point Projects (EPP) were implemented for the respective sectors. For Agriculture (Paddy), there were two EPPs namely, tertiary intensification and farmers' exit plan (EPP 10) for the MADA Granary and irrigation system development and improvements (EPP 11) for the remaining 11 Granaries.

EPP 10 will see the installation of tertiary irrigation facilities in 61,500 ha or about 65% of the total MADA Granary, not yet installed with the system. The farmers exit plan was an affirmative plan to encourage aging farmers as well as individual farmers to withdraw as self-farm operators and instead allow for Single Purpose Vehicles (SPV) of which they can be shareholders to operate larger farm areas on a commercial basis.

EPP 11 aimed for the installation of new irrigation systems for the 4 new Granaries and systems upgrading for efficiency improvements of existing infrastructures in the other matured Granaries (excluding MADA). The farmers' exit plan implemented under EPP 10 in MADA was also replicated in these Granaries.

In 2014, a program to revitalise the WUGs was launched. Apart from the need to continue efforts in water savings by the farmers, these WUGs were also to function to provide opportunities to be SPVs for commercial farming and for non-farm income generation within the irrigation sector as well as outside as in line with the ETP principle of inclusivity for GNI increment.

As the country rapidly approaches a developed nation status, new issues are emerging and imposing challenges to irrigation sustainability. Available unregulated water resource is declining rapidly. Water demands from the Water Supply Sector is increasing and emerging water dependent industries are also expanding and becoming significant. The exclusivity of irrigation facilities initially installed for its own use are gradually breached to satisfy demands of other sectors. For example, the extensive MADA system has now to be multifunctional to meet the needs of Water Supply Sector and for flood management. The Bukit Merah reservoir for Kerian Granary now has to be operated incorporating functions of water supply, aquaculture, flood management and tourism.

Water quality is also becoming an issue now and irrigation will need to respond to this in terms of improved returned water quality to the system as well as water reuse. The MADA Granary has begun water reuse in the system and now 8% of the total water for paddy planting here is from the irrigation water reuse systems.

Irrigation is still the biggest user of water for human activities. It is now under pressure to reduce this through Water Demand Management such that by 2050 paddy irrigation water demand would reduce to 40% from 56% of the total water demand in 2010 in the country. This is a formidable target and special efforts and investments will be needed to increase efficiency levels to 70 - 75% and on-farm water savings.

To achieve this target and also for irrigation sustainability, the MOA is formulating plans for establishing a Centre of Excellence (CoE) for Irrigation Management Modernisation. This CoE is expected to undertake research and development as well as capacity building programs with the cooperation of local and international universities and related organisations.

CONCLUSIONS

Irrigation for paddy development in Malaysia has been successfully sustained through the past 83 years since 1932, to meet the challenges brought by the changes from a predominantly agriculture based to a declining agriculture sector in a diversified economy. Irrigation has sustained planting twice a year every year for more than 30 years in the Granaries. Yields that seemed to remain stagnant at 5 tons/ha for many years have now shown significant increments. The MADA Granary recently reported an average of 6 tons/ ha. More farmers reporting yields of 8 to 10 tons/ha here and in the other Granaries. Overall irrigation has helped achieve the SSL targets of more than 70% and now with the Granaries contributing to more than 70% of the national production.

At present the indications are that irrigation will continue to be sustained with food security for an SSL of more than 70% as the main driver and adequately supported by the policies such as the National Agrofood Policy, Granary Policy, the National Physical Plans and the Economic Transformation Plans. Challenges will continue in the future, particularly from increasing demands of water by other sectors, the need for improved water quality and the environment and the impacts of climate change. As a profession, the sector will be challenged to continue to attract and retain talents in irrigation if this sector is to survive and flourish. Special plans will have to be developed to achieve this.

In summary, this brief history has highlighted the following key elements for irrigation sustainability in Malaysia:

- adequate water resources;
- relevant and consistent policies that contribute to irrigation sustainability;
- full and continuous Government support;
- a dedicated and specialised teams and organisations;
- long term system manager-farmer relationships;
- laws and regulations;
- science, technology, innovation, knowledge and skills;
- farmers (public) participation;
- economies of scale.

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CHAPTER – 8

Historical Water Sustainability: Lessons to Learn from Japanese Experiences

Nobumasa Hatcho [a] and Yutaka Matsuno [b]

Sustainability is often discussed with three major perspectives; economic, social, and environmental, and maintaining a good balance of these three factors will contribute to achieving the sustainability of any system. This condition would also apply to water development and management in agriculture. Rice irrigation system has been operated and maintained in Japan over the last 2500 years without suffering from major breakdowns, supporting the food production and livelihood of its population.

In this chapter, historical agricultural water development and management in Japan has been analysed, taking account of economic, social, and environmental factors. In achieving economic sustainability, or productivity and stability, technological innovation always plays important roles. However, technology can only be a necessary condition for achieving productivity in terms of food production. Without proper governance to manage and maintain the system, it may not lead to sustainable development. Similarly, the fruits of development should be shared among the stakeholders of development to ensure necessary participation for operation and maintenance of a system and investment for future rehabilitation and modernization. Certain mechanism of benefit sharing should be in place to motivate people to participate and cooperate.

With successful development, population is likely to increase and with resource constraints to follow. The mechanism of sharing limited resources and conserving these resources will be an important governance mechanism for sustainable management. However, conservation alone would be able to support increasing population. Production frontier needs to be expanded through technological innovation without resorting further exploitation of limiting resources, particularly land and water.

It has been a challenge to pursue all the three factors and maintain their balance. Historical experiences of Japan will be examined, and the wisdom of people to overcome these challenges has been analysed.

INTRODUCTION

Paddy field provides an excellent and sustainable method of farming suited to the Asia monsoon region because it prevents damages from continuous cropping, salt accumulation, floods, and/or soil erosion, and supplies nutrients of natural origin through irrigation water and rainfall. This farming method has supported large number of population and the development of the region with its high productivity. Even within the region, diversified characteristics of farming could be observed such as: i) weir irrigated area in the mountainous valley of the continent or alluvial fan/plain; ii) reservoir irrigated paddy fields; iii) groundwater irrigation by pumping; iv) floating rice cultivation in the delta of the continent or low-lying coastal marsh of the islands, utilizing flood water; v) rain-fed paddy field in the plains or plateau of the continent. Japanese farming based on paddy field farming has similar characteristics commonly observed in Asia, and has developed over the last 2500 years. The evolution of paddy field area, yield and population of Japan is shown in Figure 1. Development of paddy fields and rice production had long been the foundation of Japanese society and economy, and one of the most important policy issues. Therefore, it has been

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the struggle of obtaining sufficient food (rice) over the entire period of a history, except for the period after 1960s when the food import started to be liberalized and the rate of food self-sufficiency started to decline. The decline of paddy field area after the 1970s could be seen in Figure 1.

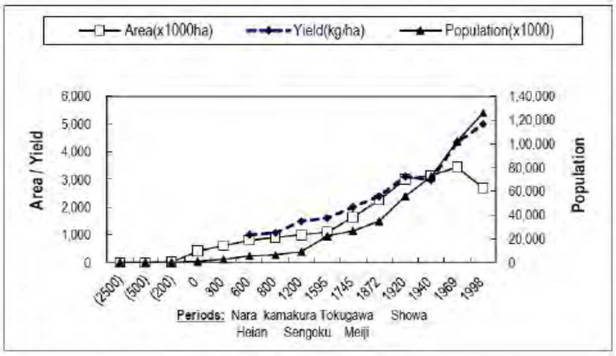

Figure 1. Historical development of paddy area, yield and population (Sources: Tomiyama, 1993; Nagata, 1994; Yamazaki, 1996)

Paddy field engineering has evolved in pace with the expansion of paddy field area and associated technologies. Rice cultivation started in Japan about 2500 years ago, applying the cultivation technology imported directly from China or via Korea. Then at the beginning of the 7th century, a great technological innovation was realized with the import and advancement of land and water management technology as well as the development of systematic organization and management of these activities. Since then, these technologies and cultivation practices have been adopted to the local conditions of Japan. Until about the 16th century, there had been no major expansion of paddy field area. Water resources development in small and medium sized rivers had almost been completed, and the technologies to develop major rivers and deltaic plains were not available. With the accumulation of knowledge and technology in mining and castle building as well as administering people during the civil war period in the 14th to 16th century, flood control works and development of deltaic plains of major rivers were implemented, which largely expanded the rice cultivation area and production capacity after the 17th century as it is shown in Figure 1.

Sustainable development and management of land and water resources from the start of rice cultivation until the start of modernization in the 19th century has been analysed from economic, environment and social points of view.

ECONOMIC FACTORS

Technological innovation and benefit sharing

Technological innovation

Technological innovations for increasing the productivity of food production were inevitable to satisfy the needs of population and accumulate the wealth to accelerate development. How could these innovations be realized in Japan? The paddy cultivation technology brought into western Japan around 4th-5th century BC used the small-scale irrigation systems based on a weir in the alluvial plain, which was adapted to local conditions and moved to the eastern Japan in a relatively short period. Quick transmission of technology showed high productivity and viability of imported technology.

The major technological breakthrough was realized in the 7th century through the application of sophisticated survey and construction techniques and the mobilization of large number of labours and tools. Systematic application of imported technology through the migrants from Korea, based on the grand design of integrating traditional small irrigation schemes, enabled the technological leap of the ancient period. Such major intervention was only possible with the initiative of a state, which was formed in the central part of Japan at the beginning of the 7th century. Proactive involvement of a state in the development works came as a necessity for consolidating the form of a state into a stable government. Some of the major works in those periods were; Furuichi Oomizo (large canal with a width of 8～20 m, depth of 4～8 m and the length of about 10 Km), and Sayama pond (Around 625 a pond area of 26 ha and storage volume of 0.8 Million m^3), Manno pond (701-703), and others. Historical evolution of reservoir/dam construction is shown in Figures 2 and 3, and the number of small reservoirs increased significantly between 400 and 700, when the technology was imported and applied systematically by a newly formed state. Design capacity of the time was not high enough and records of repeated damages and repairs remained for ponds like Manno or Sayama. During the repair of Manno pond in 852, it is said that about 20,000 labourers were mobilized with a cost of 240 tons of rice equivalent. By experiencing damages and repairs, the technological skills and capacities improved, which were accumulated to enable further development.

At the initial stage of development, many of the works were carried out by immigrants, but over the years, government sent many scholars and priests to China to learn her advanced knowledge and technologies, who mastered and returned to Japan to apply it in building many irrigation systems and structures. Famous priests among those were Kukai and Gyoki, who rehabilitated flood damaged Manno (821) and Sayama (731) ponds, respectively.

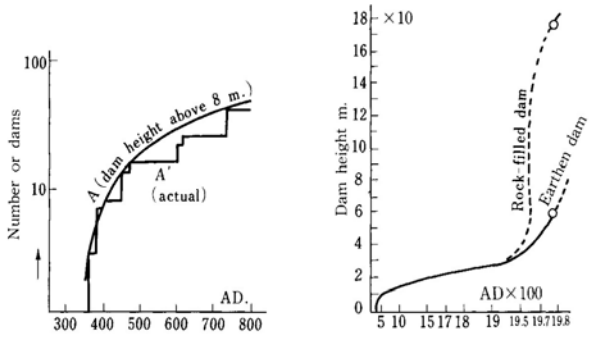

Figure 2. Evolution of the number and the height of small dams and reservoirs (Source: Yukawa, 1981)

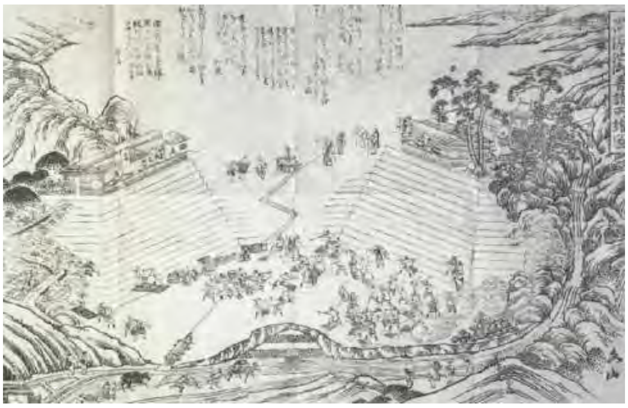

Figure 3. Construction of Manno Reservoir (Source: The New Study Group on History of Agricultural Land Development in Japan, 2004)

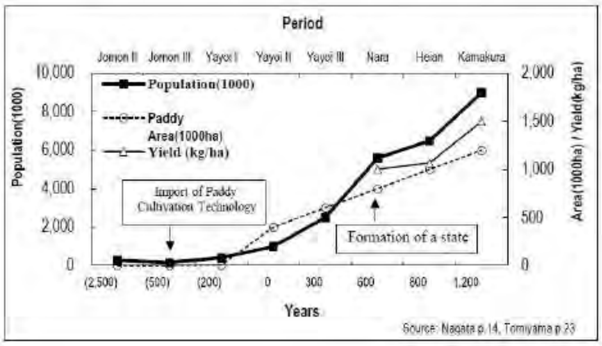

Figure 4. Paddy field area and yield in ancient Japan

With such technological breakthrough, the production increased rapidly, so does the population as is shown in Figure 4. In addition to the application of imported new technologies, there had been experiences of managing land and water in the preceding periods of small-scale irrigation schemes, which enabled the great leap of the time.

Benefit sharing

In the initial stage of a state formation, public land and people were the basic principle of the newly established state. Under this system, farmers were required to pay various kinds of taxes to the government, and the life of farmers in those days was very difficult with heavy tax burdens. Average yield was low of about 1-1.3 ton/ha and allocated land size was 0.24 ha for a male adult and 2/3 of a male for a female adult, out of which farmers had to pay local production tax of 67.5 kg of rice, central government tax of 22.5 kg of rice equivalent, and local products such as cloth or others of 71 kg of rice equivalent. In addition, farmers had to contribute labour such as transportation tax to the capital, the military training (one person from every family), and various services and works in the capital (one person out of 25 families for one year). With heavy tax burdens, some farmers failed to pay the tax and abandoned their allocated land and became landless. The abandoning of the government allocated land caused the degradation of property, which also diminished the government's tax revenue.

Production increase with technological breakthrough was important, but unless the benefits of the development were properly shared with farmers, it would be difficult to sustainably manage the system. Similar situation prevailed in encouraging the participation of farmers in management. Clear signs of benefits should be there to provide enough incentive for farmers to better manage the system and increase production. Without guaranteeing certain prospects of improving their livelihood by participation and organizing themselves to undertake management responsibilities, sustainable management of local resources would be difficult to realize.

It was heavy tax burdens in Nara period that brought about the collapse of central control system of land and water. Incentive was not only the availability of water or the price of water, but overall economic environment and farmers' living conditions surrounding irrigated agriculture that needed to be improved. Many of the environmental problems related to land and water resources were caused by inappropriate uses of these resources by users who could not see any prospects of improving their livelihood or could only survive with unsustainable uses.

Adaptation and localization of imported technology

Initial technology or system for developing land and water in Japan came from China or through Korea, but gradually imported technology was adapted to local conditions and the knowledge spread to various sectors of the country. In particular, at the end of 8th century, the power of Chinese Dynasty gradually declined and the communication between China and Japan was decreased in frequency, resulting in eventual abolition of Kento-Shi (Japanese Envoy to the Government of China) in 894. With the closure of official communication with China, Japan had become practically isolated and internalization of the culture, knowledge and technologies progressed from this time on.

Large expansion of paddy areas was not possible with the level of technology to control floods in large delta areas, the production increase had to be achieved by rehabilitating degraded and abandoned lands as well as intensifying cultivation. It is important to note that 20-40% of paddy fields existed at the beginning of 10th century was not cultivated due to frequent damages by floods and drought. All these paddy fields that were not utilized were put into cultivation by the improvements in water delivery and management as well as construction of small reservoirs.

Flood prevention efforts were also made to protect the land from damages, though still very gradual and small in size. As flood prevention progressed, farmers who were living mainly along the foot hills or on higher ground started to move to lower flat land and building their dwellings closer to the land they cultivated. When paddy was cultivated in marshes or wetlands as in ancient times, the water required to grow it was almost always available and its particular management was not needed, consequently there was not much cooperation among farmers. However, when they started to cultivate areas protected from floods and/ or somewhat higher grounds, while living in primitive rural villages, they encountered difficulties in securing water to grow paddy in their fields.

Although strongly needed, water facilities were normally beyond the capacity of individual farmers. Here, cooperation in construction and management of facilities for irrigation and flood protection took shape just for their stable harvests and survival, resulting in the birth of communal water use and management system. Reclamation of paddy fields was promoted in 12th and 13th centuries by mainly using the water in smaller and medium size tributaries of major rivers and streams. However, the progress of opening up of new land for cultivation and the development in irrigation in this period was very modest and slow. In addition to constructing small reservoirs, improvements were made in small weirs, water delivery facilities such as canals, conduit, aqueducts as well as water wheel for pumping. Available water was highly utilized by rotation method, particularly in areas with water shortages and relatively small rainfall.

At about the 14th century, the power of government appointed local officers became so strong that they actually administered and owned the province or the manor where they had been assigned or stationed to. They grouped the local warriors and small landowners as their subordinates and became the federal lord at the provincial level. Provincial lords had started to compete and fight with each other for controlling better lands. To strengthen the economic power, provincial and estate level warriors had invested in developing new lands, controlling floods, and rehabilitated degraded and abandoned lands. The integration of political, economic and military power by feudal lords led to the integrated management and development of land and water resources. As such, warriors started to master the engineering technology by engaging in development works. In addition, persistent fighting with neighbouring lords led to the construction of castles and moats, which accelerated the development of engineering capacity.

One of the famous lords in engaging in flood protection work was Shingen Takeda (1521-1573), who rearranged the joining point of the Midai River to the Kamanashi River to prevent turbulent flow at the point by having the Midai flow hit the rock cliff on the opposite bank. Then, he fixed the river channel by building discontinuous embankment diagonally laid out, called Shingen-levee (embankment). The Shingen levees were so laid that the embankment made the flow more downstream and away from the river channel leading to more space left for flooding. This space thus created, served as the retarding basin to absorb backward flows in the river (Figure 5). The river front side of the embankment was paved with rock and trees and bamboos were planted on the embankment to increase the strength. In addition, successive protection levees (Levees No. 1, 2,…) were stretched to the river channel to prevent flood waters to hit the main embankment directly. By employing embankment that conforms to the principle of nature and applying rational method of flow energy reduction, the flood protection in the area was realized. Furthermore, nearby villagers were relocated in this area to carry out maintenance and rehabilitation works of the constructed system, who were exempted from tax and other duties of the farmers.

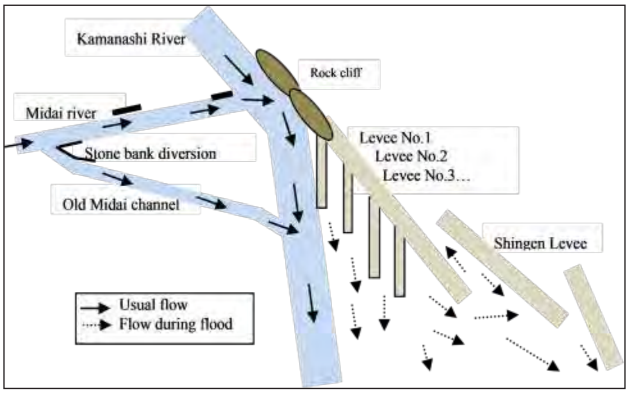

Figure 5. Layout of Shingen levee and flood protection work (Source: The New Study Group on History of Agricultural Land Development in Japan, 2004)

Many lords in this period followed the suit, and the technology spread widely in the country. At the beginning, planning, design and implementation were the jobs of engineering bureaucrats of the state or lords. But in the latter period, resident warriors and upper-class farmers mastered the technology and implemented irrigation and flood control as well as reclamation works. By involving farmers in the construction and rehabilitation works, the capacity of farmers to manage the system improved and the applied technology became more locally adapted.

After the fighting among

Reconstruction of Tawara Weir and Canal System

Original Tawara weir was made of bamboo gabion, constructed in the early 17th century. The weir deteriorated very heavily, and modernization was undertaken in the late 17th century by the leadership of the county head, Nagamasa Tsuda, who was also an excellent engineer and designer. The rehabilitated weir was made of large stones, quarried from the back of the mountain. The weir body had the length of 570 m to cross the river of 220 m at an angle, with the bottom width of 30 m, and the length of riprap extended to 60-110 m. After 300 years, when the weir was modernized in late 1980s, the total volume of stone removed from the weir amounted to about 254,000 m3, which required 40,000 dump trucks of 11 ton loading capacity. In view of the fact that all works were basically carried out by human labour in those days, the work was such an enormous achievement. After the modernization, the system irrigates about 5,700 ha of paddy fields and 1,300 ha of upland fields.

Figure 6. Imaginary drawing of the construction scene of Tawara Weir and Irrigation System (Source: History of Irrigation in Japan, Japanese National Committee of the International Commission on Irrigation and Drainage, 1984)

lords was over, local farmer leaders even engaged in development works to enhance the production of their village and the livelihood of villagers. Extension of technology and know-how from the elite and ruling class to local level could have been possible through the encouragement of improving reading and writing skills even to the merchant or farmers. Human capital development in the form of education supported such changes.

Figure 7. Surveying by using the lantern light (Source: History of Irrigation in Japan, Japanese National Committee of the International Commission on Irrigation and Drainage, 1984)

Table 1. The process of technology transmission in Japan

	Technology import	Local adaptation/ internalization	Extension to wider groups
Stakeholders	Immigrants, Priests, scholars	Bureaucrats, Resident warriors, Upper class farmers	Local farmer leaders, farmer groups
Process/cause	Immigration Official envoy	National isolation, Closure of a country	Involvement farmers, Spread of education

In Japan, people absorbed technologies imported from China through immigrants in ancient times, and internalized and improved them during the period of national isolation, particularly during the Tokugawa period (17th to 19th century). As a result, the development of local and farmer level technologies was promoted and special groups to apply them emerged under the prevailed education level among the common people.

Throughout the development and management of resources in Japan, elite engineers or government technocrats did not monopolize technology. Rather, it was extended to local people and adapted to local environments, which in turn induced innovations and allowed establishing long-term sustainability and local management of resources.

ENVIRONMENTAL FACTORS

Forest conservation and regulation

Struggling to survive in mountainous country like Japan, people started to learn the impacts of forest degradation and the importance of forest conservation. After logging for capital and temple construction at the beginning of the state formation, prohibition of forest clearing had been issued many times at about 800.

Over the years, the importance of maintaining forest for fostering water resources, preventing flood and preserving natural environment was recognized among local leaders and shared by farmers. To sustain the paddy field production without heavy external inputs, it was understood that forest area of about 5-10 times as large as the cultivated field was required to obtain the supply of green manure from the forest and secure necessary amount of water for cultivating the paddy field. The system of communal forest started to emerge in the medieval period (14-16th century), which allowed the use of forest resources in paddy fields.

After the period of war and confrontation in the 16th century, the country was finally unified under one federal lord (Tokugawa Shogun) at the beginning of the 17th century, and the Edo period by Tokugawa Shogun lasted until the mid-19th century. Under the Shogun, each federal lord encouraged the development of his domain by expanding the agricultural land area and controlling flood and developing irrigation systems. As a result, the population in Japan increased rapidly from about 12 Million in 1600 to 31 Million in 1721 as it is shown in Figure 4.

With population increase and farmland development as well as the construction of temples and towns at the beginning of Edo period, the exploitation of forest and deforestation resulted in Japan. As such, competition for forest areas/resource became very intense. In the process of resolving competition and confrontation, the custom of using forest as a common source was established and prevailed nationwide. However, landlords set the forest regulation of clarifying the borders between the forest of the lord and of the community. Regulations were laid down such that specified detailed use of rights could be practiced, where the product could be harvested, number and day or class of people entering the forest, or the size of equipment to harvest the log could be recorded. Some landlords, sometimes, restrained development of new paddy fields because they feared that excessive use of forest would cause adverse impacts to downstream farmlands.

In addition, after the mid-17th century with rising demands, the regulation of harvesting/production did not have enough effects in conserving the forest and protecting downstream area and farmlands, and then Shogun and landlord regulated the distribution and consumption of forest products. For example, even the size of wood for housing was regulated and defined specifically by Shogun/landlord according to the status of a person in warrior class or village.

After experiencing regulation setting and conflict resolution under limited forest resources and increasing demand, the policy of the government shifted to progressive forestation after 18th century. Through the progress of forestation technology with wider participation from agriculturist, private forester, landlords, the forestation and the system of benefit sharing among stakeholders were established and the conflicts among ruling class (Shogun and landlord) and local forest users in the village were resolved.

Cycle oriented management of resources

During the Edo period when resource limitation became evident in Japan, farmers skilfully managed local resources by joining the natural resources of paddy fields, dry fields, commons (grassland, forest), rivers, and the surrounding mountains. Forest was very important for their living as a source of manure/fertilizer, fuel and building materials. It was the complex system of production, consumption, and recycling, combining available resources, and was based on material cycle. To enable cycle-oriented system, understanding of the material flow in a basin perspective became very important. Farmers, through their experiences, understood the importance of forest and grassland for enhancing the nutrient levels in paddy fields, increasing the availability of water from rivers, and controlling floods. Thus, community rules for preserving these resources were strictly enforced.

Edo period was highly cycle oriented because of the isolation policy of the government, where the use of renewable energy resources such as forest, muscle power of livestock or humans, wind or water was inevitable. Feudal lords and farmers were very much concerned with the sustenance and maintenance of reproductive capacity, and available resources were fully managed and utilized, leading to a sustainable development. Local resources base was managed without destroying the cycle system inherent from the nature. To allow this, the circular structure of land use system was realized, being settlement in the centre, and farmland for production, communal forest for living materials and manure/fertilizer source, and surrounding forest farther away (Figure 6).

This structure can only be maintained when each constituting element fully functions. To maintain the balance of nutrients in the farmland, a forest area of nearly 10 times as big as the farmland was needed, thus enforcement of strict management and restrictions for the use was needed together with an appropriate management of surrounding forests. For example, restrictions of use for certain area or period, prohibition of logging, or even a total ban were enforced for the forest management. In addition to these restrictions, management approach had shifted from exploitation of forestry to cultivation of forestry over the period of the 17th and 18th century.

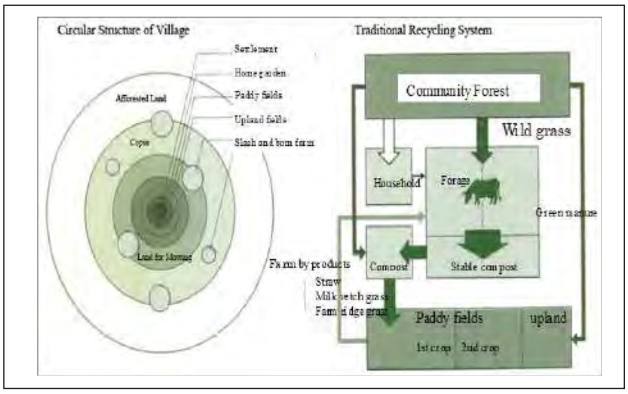

Figure 8. Traditional village layout and recycling system (Source: The New Study Group on History of Agricultural Land Development in Japan, 2004)

Thus, the overall maintenance of land use structure, encompassing organically connected land use types, considered to improve and maintain the production and living, and people improved the capacity to grasp overall structure of the system. In addition to the material cycle, water cycle of the basin area was strongly recognized for the preservation of water use, water circulation within the basin (coming from the mountains, to farmlands and used/reused several times), and then finally its flow to the ocean.

In addition, harmonious relationship between the urban and rural area through the material cycle had been maintained during Tokugawa period, which is shown in Figure 7. Farmers from the neighbourhood of the capital Edo (present Tokyo) had to rely on fertilizers such as oil cake, powdered fish, and herring from Edo Bay. But it was not sufficient, so farmers paid to collect human waste from houses in Edo, which was then used as fertilizer. Highly cycle oriented system was already in use during the Edo period. In other words, such system was necessary to maintain the production level under limited resources availability. As such those who abused resources or violated community rules had to face severe punishment such as death or ostracism in the village.

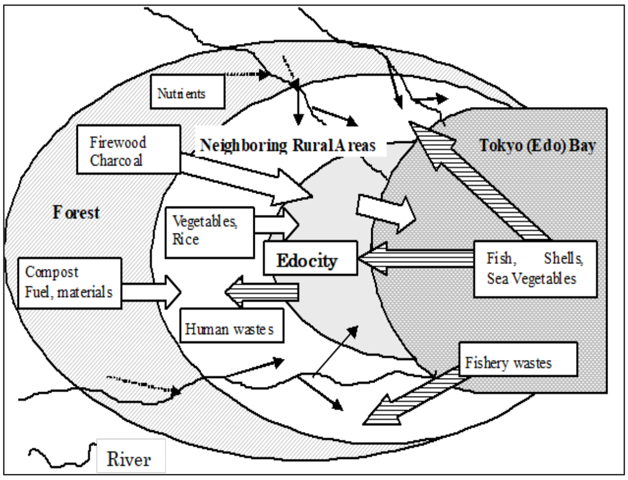

Figure 9. Cycle oriented system of Edo City

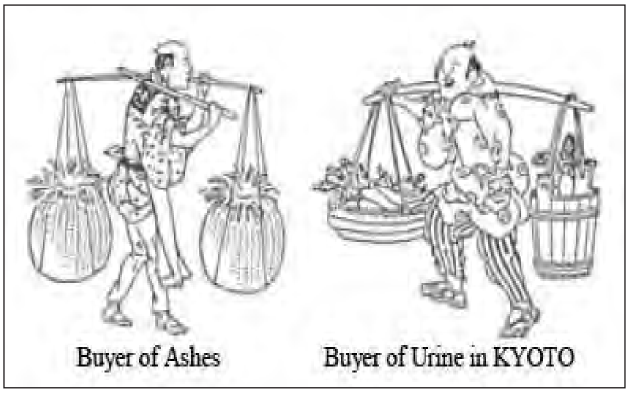

Figure 10 Buyers of recyclable resources (source: The New Study Group on History of Agricultural Land Development in Japan, 2004)

Rural areas supplied farm products to cities for their functioning, and the organic waste of cities was received and utilized in the rural area for food production. Human waste in particular was traded as important fertilizer, and used clothes, scrap wood and ash or garbage were also traded and circulated. Figure 8 shows the drawing of buyers of these wastes in Edo period.

SOCIAL FACTORS

Autonomous and participatory management of local resources

In the medieval period (from 9th to 15th century), communal system of managing local resources, including forest, land and water, had been established in the local area. The technology of the time did not allow further expansion of the agricultural land area in the flood plains of the large rivers. Thus, the production increase was achieved through the intensification of farming by introducing transplanting, whole plant harvesting and double cropping. Transplanting through cooperative and communal works replaced direct seeding for higher yields, and harvesting of only ears was changed to whole plant cutting because of the ease of transporting, and straws after thrashing were used for straw carpets and feed for animals. The intensification of land use and farming such as transplanting, harvesting, thrashing, or management of irrigation system induced the change in working system from basically family based one to more cooperative and communal type.

The village self-government became even stronger and autonomous water management by villages and/or by their federations intensified at the terminal level of irrigation systems. The autonomous water and forest management system, thus, formed at the terminal and village level, had continuously been strengthened and institutionalized in rural communities. Villagers managed irrigation systems, conserved forests, and worked together for communal activities, which became the norm and rules of utilizing communal facilities and resources. Cooperation and mutual help among the members of the village based on the rule became the principles of village management. The same principles of self-help and management in villages expanded to larger developments that gradually were implemented in alluvial plains and other places. This was the foundation of autonomous rules. Basically, the same system of management is still being adopted even in modern Japan.

Community cooperative functions included not only the supports for production, but also the various phases of rural living. These were the function of managing rural spaces such as: management and construction of rural roads, use and management of community forest, and management of community cemetery; living support functions such as: care and support for the aged or the poor, mutual aid financing arrangement, mutual help for funerals, etc., and mutual defence against disaster; and preservation function of community culture such as: the maintenance of shrine and festivals, transmission of the mode of life or customs, coordination of human and family relations, and the maintenance of values and norms.

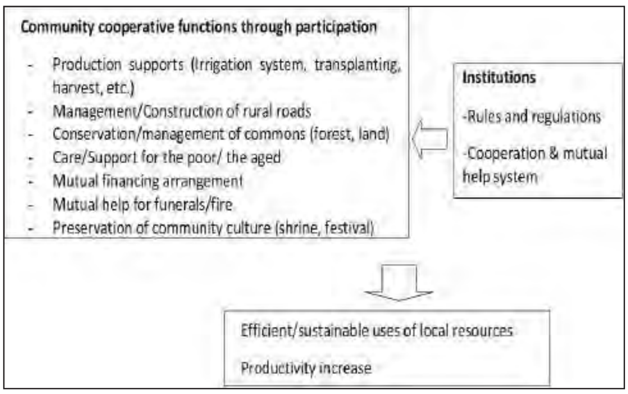

Figure 11. Interactions of community cooperative functions and sustainable development

These functions not only were important for the supports of living and food production, but also provided regulating mechanism of rural society. To maintain production and living, by mostly homogeneous small farmers in rural community, cooperation in the rural community by each individual household, was inevitable. This system of farming in collaboration, eventually led to the formulation of basic pattern of rural communities in Japan. In addition to farming in cooperation, farmers built their irrigation and drainage facilities together, operated, repaired and managed them by themselves in an autonomous way. In addition, very strong mechanism of regulation existed even to exclude those who did not follow the rule of the community by not providing labour to the communal works. Figure 9 shows the photo of scent box for controlling irrigation rotation by the burning time of the scent.

Figure 12. Scent box for irrigation rotation (source: Sayamaike Land Improvement District, 2001)

With the participation of local resource users, the resource limitation was overcome by promoting efficient uses of local resources and regulating selfish and abused uses.

Customs developed through repeated conflicts

As the development advanced, disputes on land and water resources became unavoidable within and among villages. However, the accumulation of experiences with similar disputes gradually brought about the consensus to consolidate them upon rules for land and water sharing to avoid repetition of conflicts. As such, the basic pattern of resources management for water or land/forest resources was gradually formulated at the village level first. Canal groups and/or water groups organized in respective villages were orderly incorporated in a larger association formed by uniting individual groups.

As the conflicts on forest and wilds use rights intensified in and among villages, the control of land use to harvest grass and leaves was also made stricter in villages. That is, the period of use was limited, the tools and method of grass cutting specified and the total volume of grass to be harvested was fixed. Trading of harvested grass to people of other villages and others was also prohibited. The entrance to forest or grassland was opened on a specific day determined and informed by the village officials. They harvested grass all together, once in early May and two times in late May for base spread before transplanting, in late June for fertilizer grass and up to early September for stable spreading.

In the process of institutionalizing the customary practices into rules of local resource uses, sustainability of rural communities became the mode of action. Awareness and behaviour of people living in rural communities were refined into the established 'standard norm of communities'. As such, farmland was the private property as well as the one to inherit from ancestors to descendants, and its preservation was the norm. Preservation meant to improve the land and deserting cultivation was considered to be the shame. In addition, community made strong intervention in the sale of farmland or using it as collateral.

Similar to forest resources, water resources in Japan came to almost a limit at the mid of 18th century, when most of river water had been developed. Under such constraints, water conflicts persisted among villages, in particular during drought years. The feudal lord and the Shogun in those days prohibited the fighting between and among villages over water and ordered people to resolve the conflict by court decision. If fighting resulted, those who were involved in fighting were severely punished, in many cases by death penalty. The feudal government in 1776 stipulated on the resolution of water conflict as: 'When the consensus is difficult to get, local governor or government official will be dispatched to inspect the site and countermeasure will be formulated. The countermeasure will be on trial for certain period of 3-5years, during which period water could be abundant or scarce, and make a final judgment by learning from this trial period' (Watanabe, 2014).

Education and human capital development

Human capital development in the form of education supported the technological innovations from a wider sector of society. Sharing the knowledge and knowhow led to the engagement of development works by priest, warriors or even farmers themselves. Temple schools or 'Terakoya', started in the early 16th century, taught primary literacy and calculation to common people, including merchant and farmers. Terakoya spread widely in the early 18th century all over Japan, and numbered 16,000 in mid-18th century.

With accumulated experiences and knowledge, farmers sometimes became experts in certain engineering works. For example, after the mid-Edo period (18th century), earthwork groups called 'Kurokuwa', (named after their special equipment 'black hoe' used for construction works), emerged as a specialized contractor and they worked in many parts of Japan during off-seasons of farming. As they were strong in earthwork on flatland, they were extensively employed in new paddy field development and marsh reclamation.

Together with Korokuwa, a specialized blacksmith group was formed in the Chita area to supply their special equipment. Furthermore, ship building or shrine building carpenters sometimes made wooden sluice gates, and masons of Buddha statues made masonry works for water use facilities. Thus, artisans with their highly developed skill levels contributed to the development of water facilities, which were also applied to daily living.

Such capacity building and education among farmers induced the development of grass-root techniques and knowhow, leading to the publication of books on farming technology by progressive and innovative farmers. These books were used for accumulating and extending techniques, know-how and experiences to a wider population. One of the most famous books was called Nogyo Zensho (Comprehensive guidebook of agriculture) by Miyazaki Yasusada as early as 1697, and the photo of which is shown in Figure 10.

Figure 13. Photo of Nogyo Zensho byMiyazaki Yasusada (Source: The New Study Group on History of Agricultural Land Development in Japan, 2004)

Similarly, the accumulation and spread of technical skills and knowhow promoted the creativity of local farmers. Many of the water development works had been initiated and constructed by local progressive farmers or merchants. Some leader farmers devoted themselves in developing irrigation systems for the betterment of their village. In particular, the tax during Edo period was imposed on a village basis, thus it was a common responsibility and benefits for villagers to increase production at a village level.

Literacy and calculation were the first step of education, and the spread of it led to the accumulation of human capital, which laid a foundation for technological innovations and production increases. Without taking account of such foundation, the extension of technology to a wider sector of society would be difficult, and development initiatives will not be sustained.

CONCLUSION

Historical experiences of Japan in managing the land and water sustainably have been presented and discussed, taking account of three major factors of sustainability: economic, environmental and social factors. The increase in productivity and production by technological innovation and development should be equitably shared among stakeholders, in particular sufficient incentive should be provided for resource users (farmers) for proper and sustainable management of resources.

Furthermore, it seems important to understand the cyclic nature of resources, water and physical cycle, and how to maintain the balance of resource uses. Accordingly, the appropriate management should be carried out on a wider scale, such as basin level, so that certain balance, no excess nor shortage, can be established in the system. In addition, local resources should be fully utilized without causing the damage to the system it relies on. To promote such approaches of resource use, participation and initiative of local people, particularly farmers, who have an access and responsibility for the resource they are using, are important. Certain rules and customs should be established among resource users for sharing limited resources. The interactions of economic, environment, and social factors and related components are summarized in Figure 11. Technological innovation enhanced the resource use efficiency, and if the resultant production increase was equally shared, it would enhance the participation of resource users. In addition, in the face of limited resource availability and population pressure, regulations needed to be in place, which regulated the abuse and promoted conservation, which in turn increased the resource availability.

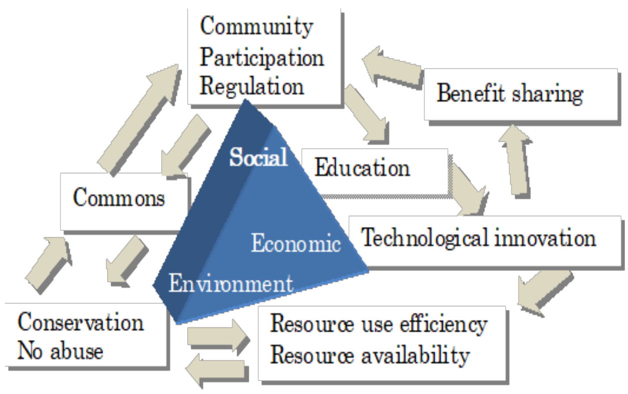

Figure 14. Interactions of three factors for sustainable development

Japan has a long history of community-based management of resources. Such user-oriented approach of resource management proved to be quite successful in maintaining and managing local resources in a sustainable manner. The success of Japan in sustaining paddy irrigated agriculture and managing local resources could be attributed to the above-mentioned factors, however, rapid modernization of the system led to the deterioration of it in a short period. We need to learn again from the past experiences and identify how we can resolve the problems we are facing today.

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CHAPTER – 9

Creative Sustainability in the Context of History

Kamran Emami [a]

INTRODUCTION

The 21st century would be very distinct from the other centuries in thousands of years of history of the mankind. According to Dr. James Martin, IT entrepreneur and founder of the 21st century School at the University of Oxford, 'we are at an extraordinary crossroads of human history. Our actions, or failures to act, during the next 20 years, will determine the fate of the Earth and human civilization for centuries to come. This is a make-or-break century'.

The 20th century was the century of explosive population growth, resulting in unprecedented impacts. In contrast, for the first time in human history, the 21st century is likely to see the end of world population growth (Figure 1). With the current trend of sophistication of technologies, it may be envisioned that by the end of the 21st century, even the poorest human beings would enjoy the basic desires of life. Nonetheless, reaching this status may involve unimaginable human sufferings. Based on a UNICEF report entitled '*The state of the world's children 2005, childhood under threat*', for nearly half of the two Billion children in the real world, childhood is starkly and brutally different from the ideal we all aspire to. Poverty denies children their dignity, endangers their lives and limits their potential. Conflict and violence rob them of a secure family life; betray their trust and their hope. HIV/AIDS kills their parents, their teachers, their doctors and nurses. It also kills them. A summary of horrible statistics given in the report is presented in Table 1. This is the situation in 2005. If the current trend of resources and demands continues, in the coming years, we would face unprecedented disasters similar to the tsunami of 2004 in south Asia. According to above discussions, the influential groups should recognize that the next few decades could be critical for the wellbeing of human race and adopt appropriate measures to 'make poverty history' with very limited resources and in a very short time in the context of severe constrictions imposed. The challenges are immense but the eventual potentials of human being are unimaginable at the same time.

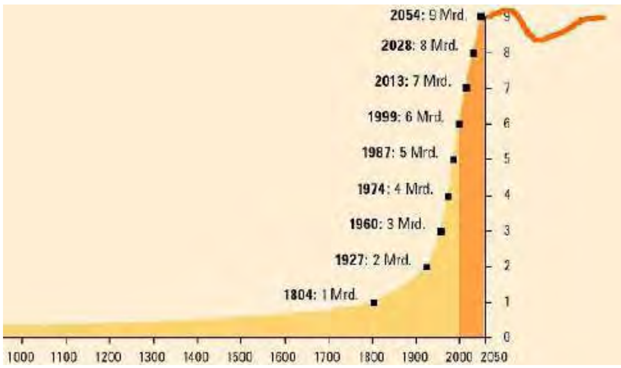

Figure 1. World population from 1000 BC to 2300 BC

WATER-RELATED CHALLENGES IN 21ST CENTURY

Based on IPCC WGII Fourth Assessment Report on climate change in 2007, climate change would be one of the key challenges of mankind in the next decades. Key findings of the report include:

- 75-250 Million people across Africa could face water shortages by 2020;
- more heavy rain events are very likely and more areas are likely to be hit by drought;
- crop yields could increase by 20% in East and Southeast Asia, but decrease by up to 30% in Central and South Asia;

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Table 1. A summary of UNICEF report (2005) on the state of the world's children

Number of children in the world:	2.2 Billion
Number of children living in poverty:	1.0 Billion
Number of children in developing countries who live without adequate shelter	640 Million
Number of children who have no access to safe water: one in five	400 Million
Number of children who have no access to health services	270 Million
Number of children who are out of school	121 Million
• total number of children younger than five living in France, Germany, Greece, and Italy: • total number of children worldwide who died in 2003 before they were five	10.6 Million 10.6 Million
Daily toll of children in the world who die before their fifth birthday:	29,158
The number of children who die each day because they lack access to safe drinking water and adequate sanitation:	3,900

- agriculture fed by rainfall could drop by 50% in some African countries by 2020;
- 20-30% of all plant and animal species at increased risk of extinction if temperatures rise between 1.5-2.5C;
- glaciers and snow cover expected to decline, reducing water availability in countries supplied by melt water.

The report stated that the observed increase in the global average temperature was 'very likely' due to man-made greenhouse gas emissions. The scientific work reviewed by IPCC scientists included more than 29,000 pieces of data on observed changes in physical and biological aspects of the natural world. Eighty-nine percent of these, it believed, are consistent with a warming world. People living in poverty would be worst affected by the effects of climate change. The finding of the report underlined how important it was for every country to adapt to the climate change that is already under way. The great challenges of 21st century are shown in Figure 2.

Figure 2. The great challenges of 21st century

A HISTORICAL INNOVATION IN FLOOD MANAGEMENT

Figure 3 presents 73 historical dams located in Iran. As the Figure clearly indicates, the most important characteristic of Iranian historical dams is its remarkable height. Twenty historical dams higher than 15 m have been identified in Iran as shown in the Figure. This was a world record in dam engineering. Spain with 10 and Solvakia with 9 historical dams higher than 15 m ranked second and third, respectively (Schintter, 1994).

The construction of three arch dams in the 13th century in Iran (Kebar, Kurit and Abbasi) was the first application of this type of dam engineering since Romans and Iranian constructed 3 true arch dams 2000 years ago (Schnitter, 1994). Abbasi flood-retarding dam also known as Abbasi arch was constructed 600 years ago near Tabas, in Northeast Iran. The dam is located 20 Km Northeast of Tabas. Tabas has a long history. The surface water from the surrounding mountains flows towards the city. It seems that this natural advantage was the main reason for the development of Tabas. In 13th century, the people living in Tabas, near the Great Dash Kavir and Kavir Lut desert (Figure 3), constructed ambitious water transfer projects for management of limited but vital water resources of the region. Due to the primitive technologies of the 13th century, the visionary people had to rely on their intuition, imagination, creativeness, hard work and courage to accomplish astounding achievements in water engineering. One of the mentioned water transfer systems consisted of 60 m high arch dam, which was the highest dam in world for 550 years till early 20th century, a Qanat and a 20 Km long channel. The system regulated and transferred water from the Kurit dam site to Kurit village for irrigation. Considering the dimensions of the project, i.e., the length of the transfers system (26 Km) and the height of the dam (60 m), it is evident that the construction of the project required astonishing qualifications and capabilities in the 13th century (Emami, Hematian, 2005). The achievements of the region in flood management were equally important.

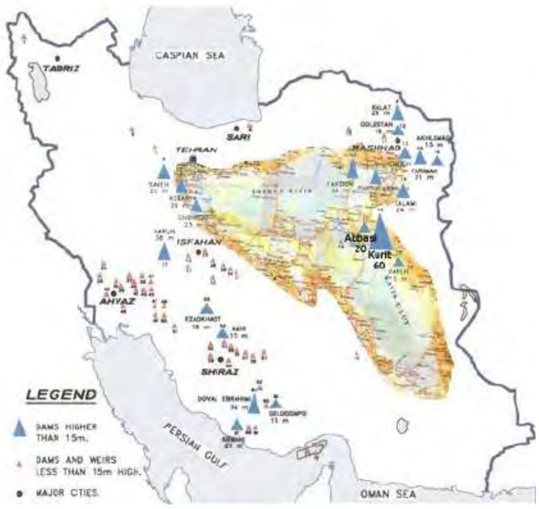


Figure 3. The historical weirs and dams of Iran (the deserts around Tabas are highlighted)

The Abbasi flood-retarding dam was an illustrating example of water wisdom of the builders. The dam has protected the city of Tabas from floods of Nahrain River for 600 years. To avert construction of diversion tunnel, Iranian used to construct the dams on a brick arch in narrow canyons. The lower part the dam was constructed during the dry season. This creative scheme had been used in many historical dams in Iran (Figure 4). At Abbasi dam site, the lower part was not constructed, so during floods, the outflow from the dam was automatically regulated (Figure 4). The scheme was so elaborate that most of the engineers visiting the site believed that the dam was incomplete or it had suffered a wash-out because of the alluvium foundation (Schnitter, 1994). This was the first time that based on site visits by dam and flood experts and communications with the nearby villagers, the dam was called a flood-retarding dam. The dam site was located 100 m upstream of water springs that accounted for a considerable part of the base flow of the river. Consequently, it was unlikely that the main function of the dam was water storage, otherwise they would have constructed the dam downstream of the springs. A historical document indicated that the main function of the dam was to control the floods. Based on this document they did not construct the lower part of the dam in view of probable failure of the structures and risk to downstream. Although the area of the basin was just 200 Km^2, the floods had large peaks as shown in Table 2.

RETARDING BASIN FOR FLOOD CONTROL

There were two basic types of flood-mitigation reservoirs - storage reservoirs and retarding basins - differing only in the type of outlet works provided. The discharge from a storage reservoir was regulated by gates and valves operated on the basis of the judgment of the project engineer. Storage reservoirs for flood mitigation differed from conservation reservoirs only in the need for a large sluiceway capacity to permit rapid drawdown in advance of or after a flood.

A retarding basin was provided with fixed, un-gated outlets that automatically regulate the outflow in accordance with the volume of the water in storage. The outlet usually consisted of a large spillway or one or more un-gated sluiceways. The Pinay retarding basin in France consisted of two wing dams, partially closing the river, but with a gap between them for discharge, and the type of outlet selected depended on the storage characteristics of the reservoir and the nature of the flood problem. Generally, the un-gated sluiceway, functioning as an orifice, was preferred because its discharge equation [$Q = C_d A(2gh)^{1/2}$] resulted in relatively greater throttling of flow when the reservoir was nearly full than would a spillway operating as a weir . A simple spillway was normally undesirable because storage below the crest of the spillway could not be used. However, a spillway for emergency discharge of a flood exceeding the design magnitude of the outlets was necessary in any case.
As a flood occurred, reservoir filled and the discharge increased until the flood had passed and the inflow had become equal to the outflow. After this time, water was automatically withdrawn from the reservoir until the stored water was completely discharged (Figure 6). An outstanding example of the use of retarding basins in the United States is the reservoir of the Miami

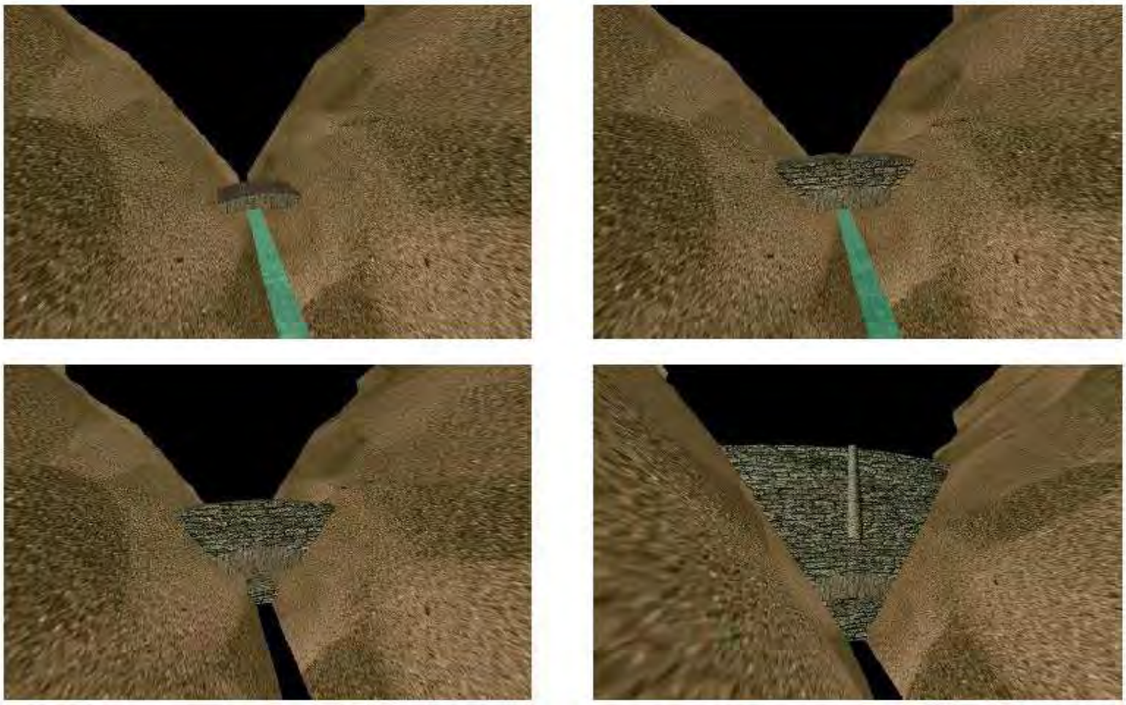


Figure 4. Construction of the dam on a brick arch to manage floods during construction

Table 2. The flood peaks at Abbasi dam site

Return period (year)	5	10	20	50	100	1000	10000	PMF
Flood peak (m^3/s)	49	92	161	286	375	632		993

Figure 5. 25 m high Abbasi flood-retarding dam

Conservancy District in Ohio. Retarding basins were selected for this project because the small streams rise so rapidly that it would be difficult to operate storage reservoirs effectively. Moreover, the retarding basin assures the drawdown of the reservoir after a flood and prevents use of the reservoir for conservation purposes at the expense of flood control.

The planning of a system of retarding basins must assure that the basins will not make a flood worse by synchronizing the increased flow during drawdown with flood peaks from tributaries. When the entire drainage area is small, such an event is unlikely. However, separate tributaries within a large basin may be subjected to independent storms and the probability of synchronizing is greater. Hence retarding basins are preferable for relatively small streams and storage reservoirs are preferable for large streams.

THE ADVANTAGES OF THE PRESENT ALTERNATIVE

To control the floods of the river, there were other alternatives involving storage structure at Abbasi dam site. One of the alternatives was a dam with overflowing outlet (overflow alternative). Undoubtedly the alternative of creative builders (bottom outlet alternative) had great advantages in comparison with the overflow alternative as follows:

Initial reservoir elevation

In overflow alternative, reservoir may be partially full at the beginning of the flood. Consequently, the routing of the peak of incoming flood in this alternative would be less than the bottom outlet alternative. Similarly retarding of the flood peak would be less in this case. Surprisingly the alternative constructed matches closely with modern criteria for retarding dams as motioned above.

Sedimentation

The bottom outlet alternative enjoys considerable advantage in terms of sustainability and sedimentation. A survey of the reservoir clearly indicated that there was virtually no sedimentation in the reservoir after 600 years of operation. As the Abbasi dam has been stable in many extreme events such as the Great earthquake of 1978 with maximum horizontal acceleration of 0.75g, it is virtually a sustainable dam. Very few dams in world enjoy such an advantage. On the other hand, the maximum useful life of the overflow alternative would have been 50 to 100 years. Fortunately, Abbasi dam is the only historical dam in Iran that has not been threatened by construction of a modern dam. It is hoped that many generations would have the privilege of visiting this outstanding human heritage than would be a source of inspiration for many engineers for centuries to come.

Risk to the downstream

As it was mentioned, Tabas is located downstream of the dam near the river. Accordingly, the failure of the dam would have disastrous consequences for the city. In the overflow alternative, the total time that dam was full or nearly full was much more than the other alternative. So, the total risk to the downstream was much less in the bottom outlet alternative. A historical document indicated that they did not construct the lower part of the dam in view of probable failure of the structures.

Overtopping frequency

Evidently the frequency of overtopping was much lower for the bottom outlet alternative. Figures 4 and 6 clearly indicate that the dam structure was intact after 600 years. With increased overtopping frequency and duration, the probable damages to dam would have been more severe.

Passage of people

In the overflow alternative, the passage of villagers was blocked because there was virtually no other way in the gorge. Still the bottom outlet alternative had allowed the passage of villagers.

Throttling of flood peak

For retarding dams, the un-gated sluiceway functioning as an orifice was preferred because its discharge equation resulted in a relatively throttling of flow when the reservoir was nearly full than would a spillway operating as a weir. The deep understanding of dam and flood hydraulics by ancient Iranian were very surprising, but it should be remembered that their survival depended on efficient water resources and flood management.

In addition to the above discussion, the overtopping resistance of the masonry arch dam and application of arch, which was a superior structural element, should not be overlooked (ASCE Task Committee, 1995).

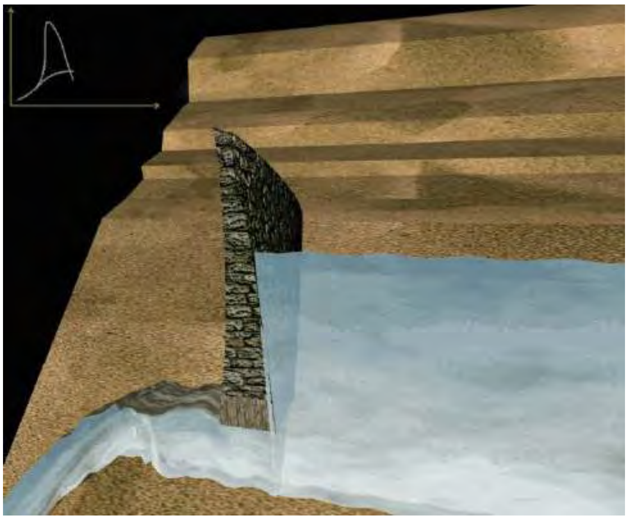


Figure 6. Flood Attenuation in Abbasi retarding dam

Figure 7. A view of the arch of Abbasi dam from underneath

ROLE OF CREATIVITY IN FLOOD MANAGEMENT

Creativity is the means to advance civilization into the future. The Abbasi dam is a symbol of creativity and can be considered as a technical jump. In the view of flood and drought challenges of 21^{st} century, many technical jumps are vitally needed. Accordingly, creativity should be promoted in flood management projects, so that appropriate solution can be tailored to the particular site-specific conditions. Large flood projects are always unique and therefore engineers should 'invent' unique solutions for them.

According to a survey conducted in the United States (Park, 1999):

- 75% of the people are neither eager to present new ideas nor they can develop a new idea;
- 12% can present new ideas but they do not develop them;
- 12% can develop a new idea if they are given one;
- 1% can present new ideas and develop them.

According to the results of the survey, we cannot rely on a tiny part of the population for creativity and innovation. We should try to promote creativity by the synergy of teamwork. In this context, the Value Methodology is a proven management technique that can greatly help the flood engineers in 21st century because in flood projects, finding the correct combination of various structural and non-structural measures has always been a great challenge. In this context, the water wisdom and achievements of past generations can inspire the water engineers and scientists.

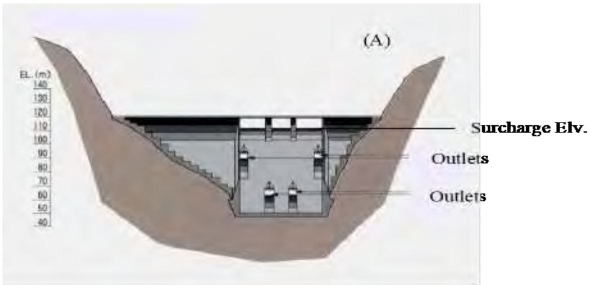
A SIMILAR CREATIVE SCHEME FOR HARMONY WITH FLOODWATERS IN JAPAN

The flood-retarding scheme of Abbasi dam had been used for solving flood control and environmental conflicts in Muko River in Japan (Hata, 2005). One of the biggest issues in the discussion on dams was the interception of biological continuity by a dam. On the other hand, it was necessary to keep the discharge less than the flow capacity of downstream. To satisfy both the conditions, the following measures could be suggested. The Muko River in the Hyogo prefecture runs through the highly developed urban areas and also crosses the Japanese main road and railway, and flows into the Seto Inland Sea.

The river authority of Hyogo prefecture planned, in 1983, to construct flood control dam in the valley at the middle stream to protect this important urban area. However, as the place was famous for the beauty of the valley and was known as a scenic area, people who loved the place had been against the plan for more than 20 years. The re-examination of the river plan including the design flood from the Zero Base had started in the Muko River Basin Committee where the author was also a member of the committee. The Prefecture River Authority proposed a type of dam with orifices like a retarding basin without control gates at the outlets as shown in Figure 8 (A).

Under a certain value of the design flood, comprehensive flood management may be possible without dam construction. However, an agreement must be arrived between the two groups of people having different opinions on dams, when there is no choice but the dam construction. The following type of a dam may be a solution in these circumstances.

The objective of these flood control dams was to decrease the discharge rate less than the flow capacity of the downstream. On the other hand, the main problem of a dam was the interception of biological continuity as mentioned above. Therefore, a solution of this problem would be to enlarge and open the outlet of a dam along the riverbed, and preserve the continuity of the river flow (Figure 8(B)). If the orifice was enlarged to the size that maximum discharge rate became the flow capacity of the downstream, it would make it possible to keep the continuity of sediment and the migration of fishes through the dam. The structure may be similar to the historical Abbasi dam (Emami, *et al*., 2005) in Iran. It was important to keep the continuity of flow especially for the dam aimed for flood control. It might also be necessary for a newly planned small-scale dam for irrigation to empty it once a year similar to emptying the irrigation pond. Though it was not an effective water use of a dam, it would make more nature-oriented water use of the river.



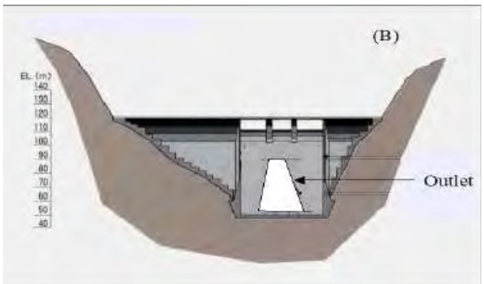


Figure 8. Modification of flood control dam (A: Planned dam by Hyogo Prefecture B: Modified one)

As the stored water in the dam was quickly discharged after controlling the discharge rate, the damage to the plants could be avoided. By designing the shape of the orifice, the dam could be harmonized with the surroundings as a well-designed bridge fitting the landscape. It might be important to design a large aperture of orifice and the shape of it, according to the calculated discharge, to conserve ecological and sediment continuity and to decrease the damage to the landscape. The delay of runoff by the storage in the dam gave the time for warning and evacuation even in the case of exceeding the designed flood when overflow of the dam crest occurred and the danger of overtopping the downstream levee impended.

SUMMARY AND CONCLUSIONS

There was no single universal remedy against water-related extremes and it was necessary to use a site-specific mix of measures, including structural and non-structural ones. This called for more emphasis on creativity and innovations. This chapter tried to demonstrate that creativity is the key in coping with the flood related challenges in the 21st century and major technical jumps and innovations are essential; Abbasi retarding dam symbolized creativity and sustainability and could be regarded as a technical jump and a success story of creativity. Through creativity and persistence, the visionary builders of the structure succeeded in construction of an effective, safe, low cost and sustainable dam that had successfully achieved the main function of the project for the last 600 years. It is likely that the dam would attenuate the floods of Nahrain River for many centuries to come. The successful use of flood retarding scheme of Abbasi dam in the MuKo river dam is another illustration of the vital role of creativity in solving the conflicts of flood management and environmental values;

Striking a balance between the needs of this generations with those of the next generations is a challenging task in view of uncertainties of hydro systems and urgencies of flood protection in many different regions. Many success stories in flood management demonstrated that Creative synergy of teams of experts is the key to sustainability, safe and low-cost flood management schemes. The Abbassi dam is a great symbol of safe and sustainable scheme fulfilling its main objectives for 600 years.

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CHAPTER – 10

The Grand Canal of Vercelli and Novara in Italy

(Later the Cavour Canal)

Antonio Linoli [a]

In the mid-19th century, a modest surveyor and farmer in the countryside of Vercelli and Novara (Piedmont) in Italy, insufficiently served by various canals, studied the course of a Grand Canal which, by diverting the waters on the left of the Po River, would permit the cultivation especially of rice in the plains lying between the course of the canal and the Po River. The first war of independence between the Kingdom of Savoy (of which Piedmont was a part) and Austria blocked any initiative, but several years later the initial project was considered by the government, enlarging it and adding necessary modifications.

This memoir illustrated the various planning and construction phases, together with the successes and shortcomings which characterised a work destined to have such a profound effect upon the agricultural and socio-economic aspects of the region. It was an 82 Km long canal with an initial flow of 110 m^3/s destined to serve an area, already partly served by other water resources, with a gross area of 300,000 ha. Thanks to the perfect organisation of the construction sites where work was realised in only three years, from 1863 to 1866, resulting in the largest canal ever built in Italy until then (another even larger work was be realised only in 1955).

This memoir also illustrated the planning problems caused by so-called 'experts' as well as the hesitations of a political class in taking as rapidly as possible the necessary decisions for the exploitation of the irrigation potential of the Grand Canal, fortunately remedied by private initiatives.

Thanks to the Grand Canal (now the Cavour)due to which the provinces of Vercelli and Novara are today the major rice producers in Italy. The waters diverted by gravity from the Po river, apart from agricultural production and the reintroduction of any excess water into the water courses or the reciprocal integration with other irrigation networks, in the the East Sesia sector produced electrical energy through 40 small hydros installed in the secondary canals by exploiting the difference in level between the canal and the Po river, and with another 23 hydros being planned. Today the hydro-electrical energy produced is equal to 130 Million Kwh/per year.

INTRODUCTION

The Cavour Canal, almost 83 Km long, was built to divert 110 m^3/s from the Po river near to Chivasso (province of Turin) and – after irrigating Vercelli, Novara and Lomellina countrysides, all situated on the left bank of the Po in the western Po valley – flowed out into the Ticino river in the territory of the commune of Galliate (province of Novara).

At the time of its construction, the area to be served by the canal (extending to 300,000 ha for circa canal) was either insufficiently irrigated or not at all by the canals which diverted their water from some local torrents. The Vercelli area had guaranteed irrigation during the summer by waters of the Dora Baltea through the diversions of the Ivrea Waterway, the Rotto and the Cigliano Canals. The territory of Novara and the Lomellina were without water due to the very low water levels in the Sesia during the summer, which left the Busca, Mora and Sartirana irrigation ditches without an adequate supply.

While the Cavour Canal took 3 years to build (from 1863 to 1866), it will be seen later that many more years were needed first for the studies and later to get the water into the fields.

a ITAL-ICID, translation Virginia Valentini

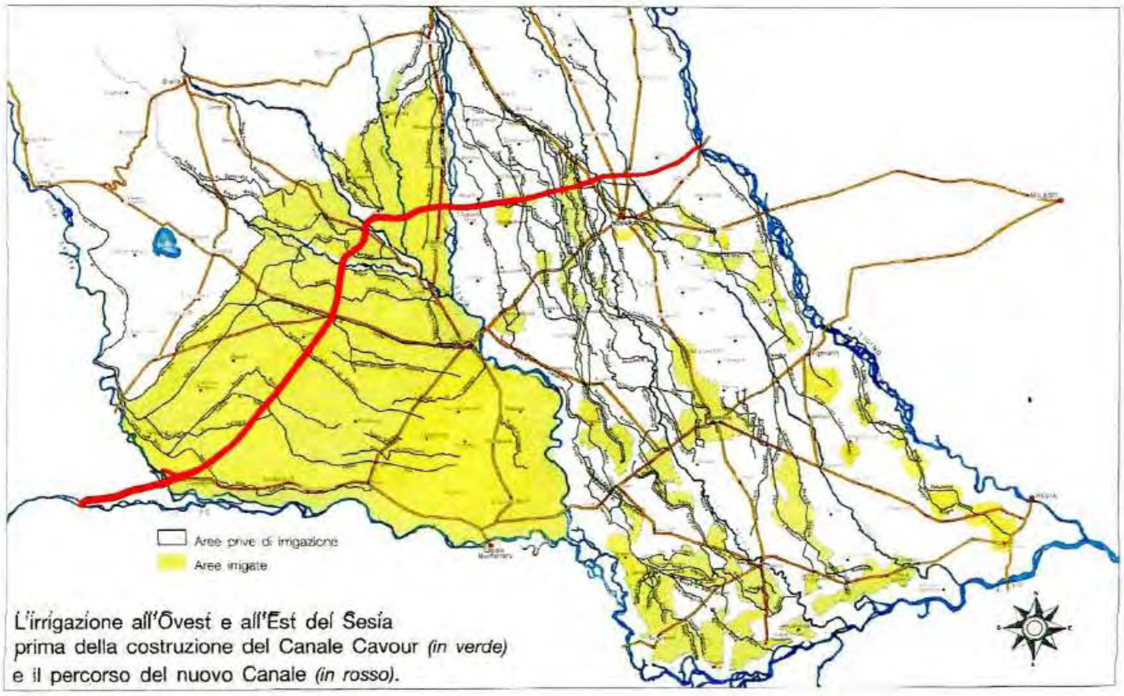

Figure 1. Irrigation to the west and east of the Sesia prior to the construction of the Cavour Canal (in yellow-green) and the course of the future canal (in red) (Baratti Claudia, 2011/2012)

THE FIRST STUDIES

Francesco Rossi: A pioneer

Born at the end of 1794, Francesco Rossi, after deserting his studies as a surveyor, worked for 16 years as law officer of the estate belonging to the Marchese Michele Benso at Leri (a small hamlet of Trino Vercellese). When, with time, count Camillo di Cavour, the Marchese's son, abandoning his frivolous life in Turin, took over the running of the estate (measuring over 700 ha) from his father, Rossi – probably due to some misunderstanding with the new manager – left the post and leased some land to become a farmer himself.

First as a law officer and then as a farmer, he understood the problems of irrigation of the lower Novarese and the Lomellina and, with a good knowledge of the area, was convinced of the existence of a drop in level between the Po and the Sesia which, by diverting water from the Po, would have allowed a vast area to be irrigated by gravity; and in fact – with the aid of his knowledge as a land-surveyor – for five years, he studied a possible course for a new irrigation canal. So, between 1842 and 1846, he was able to draw up a project with the following characteristics:

- length of the canal circa 70 Km with diversion of water slightly further downstream from the the confluence of the Dora Baltea with the Po;
- width of canal 24 m;
- 24.80 m drop in level of canal from start to finish;
- estimated cost of work: 14.9 Million Lira.

The project, presented to the competent authorities, was a great success and at the General Agrarian Congress of 1846 was praised, obtaining the congratulations of king Carlo Alberto as well.

Unfortunately, with the defeat of the Piedmontese army at Novara, the king – who had also promised to award Rossi a prize – went into exile, while our land-surveyor farmer was reduced to abject poverty also due to the Austrians confiscating a large amount of rice worth over 18,000 lira of the day.

Rossi tried in vain to find backing for his project and, in the end, in 1851 turned to Count Camillo Cavour, then just a simple deputy, who looked at the course but on learning that the canal would have crossed his property cutting it into two, ended the meeting with the following words *'your canal will never be built'.* Not only, but two years later, in 1853, with Count Cavour having, in the meantime, become Finance Minister, in a speech to the Chamber gave technical and economic reasons (the work was too costly) for the unfeasibility of Rossi's project; but since increasing irrigation in the area was a good idea, ordered Carlo Noè[1] to study an alternative course.

1 Carlo Noè, civil engineer and director of the of the Workshop of the State-owned canals, a few years later would be one of the protagonists of the second war of independence by blocking the advance of the Austrian army by flooding the Vercelli countryside.

Mr. Carlo Noè's project

The Financial Administration of the Kingdom of Sardinia had already, in 1844, given civil engineers Noè and Fagnani the task of studying the possibility of realizing a waterway from the Po to facilitate transport of goods in the Vercellese and the Novarese using links between the Po and local rivers. Mr. Noè had had the opportunity of seeing Rossi's study which he found very interesting, suggesting various modifications, such as moving the diversion of the canal from the Po River, from downstream to upstream of the outlet with the Dora Baltea, so as to avoid any hydraulic disruption due to the influx of the waters of the tributary of the Po.

When several years later Mr. Noè was given the task of studying a new course for the future irrigation canal, he greatly benefited from the studies carried out in the past and by the knowledge already acquired and therefore, practically chose the course of Francesco Rossi, moving it further up. Figure 1 shows the courses of the two planners [2]. The new course would still originate from the Po, near Chivasso, about fifteen kilometres upstream from the Crescentino, the point chosen by Rossi, even though this would mean crossing the Dora Baltea. Moving the intake meant, moreover, making water available higher up and therefore the possibility of controlling a greater area of potentially irrigable land; furthermore the new course would allow the use of waters of the Mora, Busca and Biraga drainage ditches which, diverted further upstream from the Sesia, could be distributed for irrigating the Novara highlands, while the stretches of these ditches downstream from the new canal could be used for conveying waters towards the Lower Novarese and the Lomellina.

The total length of the course, with its outlet still planned into the Ticino, would have been 85 Km; the total difference in water level between both ends of the course would have been 30 m; Ing. Noè calculated the total cost as 35.3 Million Lira.

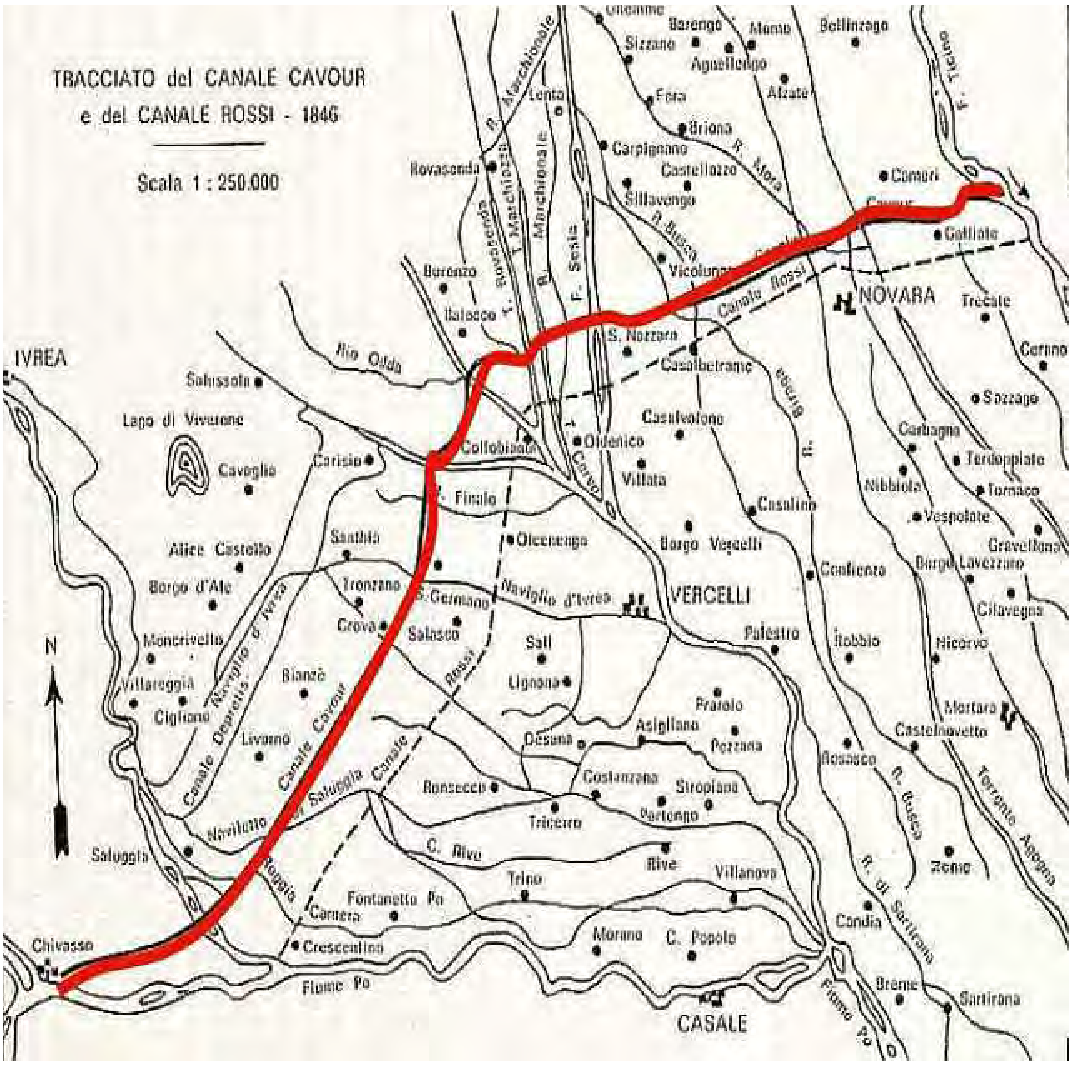

Figure 2. The area served by the Cavour Canal with the Rossi and Noè' (in red) courses

2 And, incidentally, Mr. Noè's course no longer crosses the estate of Count Cavour, but – in fact – dominates it completely enabling it to be irrigated entirely.

THE REALISATION OF THE CANAL

The second war of independence halted any further initiatives and only by Act 776 of 25 August 1862 the construction of the canal could finally be approved [3].

The company for the construction of the Grand Canal

Already before the promulgation of the act which constituted the realisation of what would become the Cavour Canal [4], the Ministry of Agriculture, Industry and Trade (Minister Pepoli) and the Ministry of Finance (Minister Sella) on 9 May 1862 had signed an agreement with some English and French financiers for the realisation of the canal. On the basis of this agreement, the contracting parties agreed to:

- constitute a limited liability company for the construction and running of a canal of 110 m^3/s to be diverted from the Po river, for the irrigation of the Novara and Lomellina countrysides and also to substitute irrigation of the Vercellese by means of the waters of the aforesaid river with those of the Dora Baltea; all according to the project of Ing. Noè;
- to start works within six months of the promulgation of the act of approval of the agreement itself, to be completed within four years from the start [5].

The Company would be committed to find the sum of 80 Million Lira for executing the programme on the basis of the following estimated costs:

- for the construction of the new canal (in a lump sum) including interest for the duration of the works[6] L. 53,400,000;
- for the payment to the Finance Administration of the price for the sale of the existing state-owned canals L. 20,300,000;
- for the acquisition of canals or privately-owned water rights and for the creation of new canals

	L	6,300,000
Total	L.	80,000,000

The Italian state would guarantee the Company the sum spent for the realisation of the canal and other items with an annual interest of 6% and a quota of ammortization over 50 years of L. 0.3444 for every 100 lira effectively spent. And finally the Company could sell the water from the new canal to the consumers, as well as that of the existing canals of the Dora Baltea and the Sesia for fifty years starting from the year in which the new canal entered into service. At the end of the fifty-year period, the entire canal network would revert to State ownership.

Approved by the Chamber of Deputies and by the Senate, the project to realise the Cavour Canal became law, and on 1st September 1862 the *Compagnia Generale dei Canali d'irrigazione italiani* was created (known from hereon as the *Compagnia*), commissioned with the realisation of the work and the contract drawn up with one of its founding members, Frenchman Henry Bonnaire, known as the *General Director.* On the same day, Bonnaire assigned the construction of the work to the *Impresa Scanzi, Bernasconi and Co.* of Milan. All was well (or maybe) and the works could start and be finished within the estimated time limit but, as will be seen later, two clouds were soon to appear on the horizon: on the one hand financial problems and on the other the fact that an extremely important water conduit was conceived and built instead of – as would have been more logical – an integrated system of carrying and distributing water, causing difficulties to emerge over the years immediately following, with the Cavour Canal becoming defined as a plant without branches, which *'before growing all its branches, cannot bear all its fruit'.* [7] When it started working, a third problem emerged, that is the insufficient flow effectively available, of which more will be said later.

The final project

The total length of the canal was 82.23 Km, built in 37 straight lines with 36 bends [8]. The canal runs in a channel for over 76 Km with little more than 6 Km raised. The average gradient was 0.25%. The width of the canal's bed was 40 m, then – by stretches – it

3 The report accompanying the project of law stated that *'this canal must serve the irrigation of an area situated on its right of about 110,000 ha of land in the Novarese and Lomellina countrysides which lack everything, and to bring assistance to about 6,000 ha of those parts of these countrysides which are not adequately provided. The canal is also able to bring the benefit of irrigation to an area of 11,000 ha in the plain between Casale and Valenza which is devoid of it, and if necessary to cross the Ticino, where it ends up, to bring assistance to a large dry area of the Lombardy plain above the Great Waterway of Milan'.*

4 The statesman who worked so hard for the *Grand Canal* died of malarial fever on 6 June 1861 aged 51, a few months before the proclamation of Italian Unification, leaving the realisation of this very important water work suspended, but it was thanks to the tenacity of Quintino Sella, Minister of Finance, that Parliament approved its construction naming the work after Cavour.

5 Claudia Baratti: The construction of the Cavour Canal: the Pharaonic enterprise on the morrow of Italian Unification in 'East Sesia' year LVI-LVII, December 2011-January 2012 no. 116, page 24.

6 To be noted how in just a few years the cost of the canal alone rose from circa 15 Million lira (considered too expensive at the time) to over 53 Million lira: without doubt the greater length and size played its part as well as a drop in the value of the lira. But, as will be seen later, other important private interests.

7 Sergio Baratti: 'The difficult early years of the Cavour canal' page. 7

8 The canal crosses the communal land of Chiasso and Verolengo (province of Turin); of Saluggia, Lamporo, Livorno Ferraris, Bianzè, Tronzano Vercellese, Crova, San Germano Vercellese, Santhià, Casanova, Elvo, Formigliana, Balocco, Villarboit, Albano Vercellese and Greggio (province of Vercelli); of Recetto, Biandrate, Vicolungo, San Pietro Mosezzo, Novara, Cameri and Galliate (province of Novara)

became gradually reduced narrowing down to 7.5 m in the final tract before flowing into the Ticino. In the tracts built of earth, the lateral banks of the canal had 45° slope; while in the tracts built in masonry, the banks had a 1/10 slope. The canal was also flanked on both sides and along its entire length by two 2.85 m wide service roads.

Apart from the structure for the diversion from the Po, other numerous important constructions were planned along the course and, in particular, 4 canal-bridges placed, respectively, on the Dora Baltea little more than 10 Km from the inlet, on the Cervo, the Roasenda and the Marchiazza, and then 4 multiple pipe culverts underpassing the following water courses: the Elvio, Sesia, Agogna, Terdoppio [9].

A great number of minor constructions were planned in the project:

- single, double, and triple straight trenches 17
- single, double, triple, and quadruple culverts 182
- canal-bridges and other hydraulic bridges 45
- road bridges of various sorts 74
- railway bridges 2
- guardians houses along the canals 19
- all types of external buildings and various constructions 141

For a total of 480 works, however, during the course of the work were reduced to little more than 300 [10].

The construction for diverting the waters of the Po was particularly important: this was situated on the left bank of the river, about 400 m downstream from the bridge of the Turin-Casale main road. The length of the construction for the mouth equals the width of the canal (circa 40 m), 8 m wide and was divided into 21 outlets, 1.50 m wide, repeated in two superimposed layers for a total height of 7.50 m. Each outlet had three sluice-gates (two for normal service and a subsidiary one for maintenance and repair works) which were maneouvred from a 4 m-high tunnel situated above the openings [11]. The tract facing the building up to the river and the first stretch downstream both had their beds and their lateral walls protected in masonry.

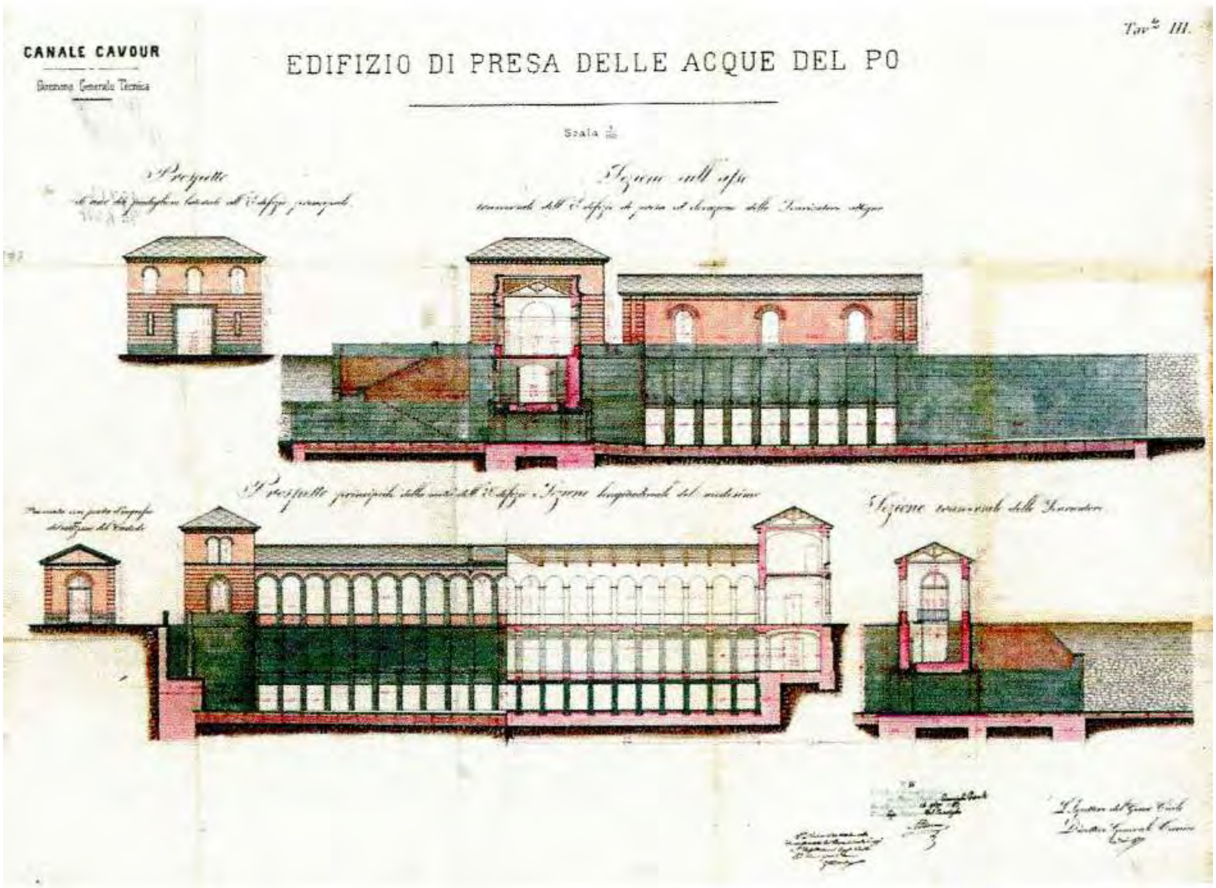

Figure 3. Entrance building of the waters of the Po into the Cavour Canal: elevations and sections. Historical Archives of the Waters and Irriguous Lands 'Historical Archives of the Cavour Canals', drawing no. 2171 (source: Baratti Claudia, 2011/2012).

9 The dimensions of these constructions can be found in the memoir by Sergio Baratta: The construction of the Cavour Canal, pages. 213-214

10 For greater details on the various types of works planned see Sergio Baratta: The construction of the Cavour Canal, pags. 214-215

11 Originally and for many years sluice-gates were operated manually; today they are all electrified.

The works

The work began officially on 1 June 1863, but in fact the real works started only during the following winter, as it was necessary first to proceed with a series of preliminary activities such as staking-out the course, the elaboration of all the details of the working plans, the drawing up of a preliminary plan for land expropriation: this last procedure was long and complex due to existing legal regulations.

Then a plan needed to be drawn up in order to guarantee new transit roads corresponding with the interruptions which the works would cause, both to the roads as well as the existing irrigation canals and water courses. And the company had to prepare the building yards along the entire course to accelerate the realisation of the work and to arrange for supplies of building materials in advance.

To guarantee that the work was carried out correctly, Mr. Carlo Noè was rightly named Manager and Designer of the work, organizing the General Technical Management. The management was divided up into four *Inspectorates,* one for each of the 4 trunks into which the canal was divided [12]; with each *Inspectorate* having two *Departments. Regulations for the Service of external personnel applying to the construction of the Cavour Canal* were also compiled, whereby technical personnel was divided into *'superior'* (inspectors, departmental engineers, deputy engineers, assistant engineers) and *'subordinate'* (assistant-surveyors and assistants).

An *Inspector* was in charge of each *Inspectorate*, with a deputy-engineer and an assistant engineer beneath him. The *Inspectors* had to carry out a multitude of tasks which went from the surveillance of the construction of the canal to carefully checking that the instructions of the General Technical Management were carried out, both as to the modality of the realisation as well as the choice of materials, and that was from the studies regarding the management of the new canal to assisting with the paperwork relating to expropriation of the land, from carefully verifying the layout to providing a sufficient supply of material and labour force for the amount of work in progress.

Each *Department* (two for each *Inspectorate)* was directed by a *Departmental Engineer*, responsible for the surveyors and work force. The *Departments* were responsible for overseeing the work and for surveying the plans and the profiles, checking and testing all the materials, visiting the brick yards every week and for sacking, whenever necessary, any personal assistant or worker who proved incapable or disobedient.

Figure 4. Entrance building of the waters of the Po into the Cavour Canal with the work almost complete (from a contemporary print)

12 The Inspectorates were divided up as follows: the first from the Po to the Dora Baltea, the second from the Dora Baltea to the Cervo, the third from the Cervo to the Sesia and the last from the Sesia to the Ticino.

It should be noted that the construction company hired many engineers for directing the work of the various construction sites, mostly from the Lombardy Railway Company and therefore, particularly expert in the construction of large longitudinal infrastructures.

Work was obstructed by the presence of rich groundwater tables which necessitated the bailing out of the excavations, particularly for building the foundations: for example in the summer of 1864, and for the minor works only, 30 moveable machines were at work with a total of 190 HP, 18 horse-powered water pumps, 1200 labourers manoeuvring 7 to 9 m long 120 Archimedean screws and 30 pumps of all sorts (turbines, chain pumps, etc.) [13].

28,000 m of railtrack was laid for moving the earth and transporting material and 5 locomotives with 300 wagons were used. 76 brick-kilns were installed (67 wood burning and 9 coal burning) in which 2,246 workers were employed for making bricks. In fact 120 Million bricks, as well as 8,000 m^3 of freestone, 59,000 m^3 of rough stone block and the production of 50,000 tons of lime were needed to realise the work. There was a great use of labourers: in all the construction sites circa 14,000 men were employed every day between workers and labourers at a cost of 3 Million Lira per month.

On 12 April 1866, less than three years from the laying of the first stone, the canal was inaugurated with great pomp [14] and for its time it was the most important water conduit realised in Italy [15]: *'the astonishing speed with which the canal was realised was due above all to the careful planning by state engineer Carlo Noè, extending to the smallest construction details, and also to the skills of the engineers directing the works, and their great experience in the realisation of large longitudinal works such as the railways* [16]*.*

THE FLOW AVAILABLE

A serious problem was discovered once the main canal started working. The flow for the concession of the Cavour Canal was laid down by law in 1862 as 110 m^3/s. Years before the designer of the work, Mr. Carlo Noè, in order to discover the maximum flow that could be diverted from the river in times of low water turned to Senator Elia Lombardini, one of the top experts in fluvial hydraulics of his day who had already carried out many studies on the Po [17]. Because there were no water-flow gauges, not only at Chivasso but even further up and downstream of the diversion point, Lombardini attempted a hazardous (but unfortunately erroneous) comparison between the situation at the Lagoscuro station (almost at the end of the final stretch of the Po), where the flow and size of the catchment basin were known, with the situation at the point of the future diversion of Chivasso, of which only the total area filled by the Po was known.

Lombardini came to the following conclusions:

- during the month in summer when the water was at its lowest (August) the average flow was 208 m^3/s,
- during the lowest-water period in summer, the flow would have been an average of 118 m^3/s, and so the projected flow in concession was fixed at 110 m^3/s.

But very soon Lombardini's calculations proved to be completely wrong: in fact between July and August, that is during the period of the greatest need for water,

13 See also vol. VI chap. 57.2 on pumps used for dewatering.

14 In 1955 the construction of the Emiliano Romagnolo was begun: 133 Km long (but still not completely finished by the start of the 21st century due to some diversions), putting the Cavour Canal in second place for importance.

15 Author's note: to carry out such a work today, despite the technological progess of the last 150 years, 3 years would be insufficient and would now last several decades: complicated bureacratic procedure, evaluation of environmental impact, opposition from communal and provincial administrations in order to obtain interventions in favour of the commune or province which had nothing to do with the work (but increase, often notably, the total cost of the work), opposition, often out of place but sometimes violent, of the various environmental associations and local populations (see the problems with Lyon-Turin TAV), infiltration by the mafia, increase in the global cost of the work, all sorts of strikes, interventions by the magistracy for irregularities, sometimes formal, in the depositing of excavated material, etc. etc.

16 Sergio Baratti: The difficult early years of the Cavour Canal in 'East Sesia: periodical of the East Sesia – Novara Association ', year LV, June-July 2010, no. 115, page 7

17 Graduating in Bologna in 1813 he held various posts in the Governmental Engineer corps, first in Cremona and then in Milan at the Hydraulic Inspectorate. In 1848 he was nominated Director General of Public Works, Senator of the Italian Kingdom in 1860, and died in 1879. He published around fifty texts and articles. The following is a list published up until 1860 (titles left in Italian): Intorno al sistema idraulico del Po e ai principali cangiamenti che ha subito ed alle più importanti opere o proposte per il suo regolamento (1840), Cenni idrografici sulla Lombardia in Notizie naturali e civili su la Lombardia (1844), Memorie originali: Della natura dei laghi e delle opere intese a regolarne l'afflusso (1845), Importanza degli studi sulla statistica dei fiumi e cenni intorno a quelli intrapresi (1846), Notizie sulle piene dei fiumi della Lombardia (1846), Della natura dei laghi e delle opere intese a regolamentarne l'afflusso (1846), Dei cangiamenti a cui soggiacque l'idraulica condizione del Po nel territorio di Ferrara (1852), Sull'omonimia de' fiumi dell'Italia settentrionale e di quelli della Francia…. (1852), Della sistemazione dei laghi di Mantova per liberare la città dalle inondazioni e per migliorarne l'aria e la navigazione (1854)Sulle piene de' fiumi e laghi della Lombardia avvenute nel giugno 1855 ed in particolare su quella del lago di Como: considerazioni (1855), Notizia sulla straordinaria piena del Po avvenuta il 23 ottobre 1857 (1857), Dei progetti intesi a provvedere alle deficienze di acque irrigue nel cremonese (1858), Sulle piene e sulle inondazioni avvenute nella Francia in questi ultimi tempie sui provvedimenti proposti per apporvi rimedio, con note finali intorno ai vari punti d'Idrologia (1858), Dell'origine e del progresso della scienza idraulica nel Milanese ed in altre parti d'Italia: osservazioni storico-critiche (1860), Sul regime delle acque del progettato canale marittimo di Suez e dei laghi amari interposti (1860)

there were low water periods lasting up to as long as a month and a half and with a flow which could fall to 40 m^3/s (and in 1882 it fell to as low as 28 m^3/s for a fortnight) [18]. Evidently the surveyor Rossi, who knew the area well, had envisaged the diversion downstream from the Dora [19] and not upstream as Ing. Noè was obliged to do in order to pander to Cavour who was completely contrary to the canal crossing his property. In order to remedy this grave lack of water in the canal in 1868, a diversion canal from the Dora was built, with the intake situated on the left bank near Saluggia (around 3 Km upstream from the confluence with the Po), which flowed into the Cavour Canal. The estimated extra flow was 70 m^3/s, causing a disaster: in fact from the first year in function, the turbid waters of the Dora caused the entire secondary canal to silt up by 50 cm reducing the flow. Since, despite everything, the Cavour Canal still lacked thirty cubic metres per second, it was necessary to make use of the water resources of the Cigliano Canal (known also as the Depretis) to channel about 80 m^3/s, in excess of the effective needs of the land it served, also diverted from the Dora, but much further upstream than the ill-chosen diversion of 1868.

THE FINANCIAL PROBLEMS OF THE *'COMPAGNIA'*

In the meantime, due to multiple factors, financial difficulties had arisen causing the *Compagnia* to be declared bankrupt by a sentence of 17 July 1867. Firstly, the difficulty in raising the capital needed for the works: the *'Compagnia'* had to raise 25 Million Lira by issuing shares of 500 Lira and the remaining 55 Million by bonds at an interest rate of 6% (not so attractive for foreigner investors). Even in Italy, placing these bonds was not easy. *'Through the Prefectures the population of the Novarese, Vercellese and the Lomellina were encouraged to participate in the initiative by underwriting the Company bonds; with great sacrifice, made worse by the economic crisis and a persistent drought, the Provinces, Communes, Non-profit making institutions, as well as private individuals underwrote almost seven Million bonds'* [20].

Despite the frequent delays by the Concessionaires in paying the Construction company, the principal canal had been realised; however, the 6.3 Million Lira provided for in the agreement and intended for the realisation of the branch canals and/or the acquisition of existing private canals for guaranteeing consignment of the water to the land were still lacking.

A scarcity of financial resources, delayed paying creditors and other motives caused the *Compagnia* to go bankrupt. During the trial it was shown how:

- the unit costs presented by Ing. Noè in his calculations of 1853 were much greater than those in 1867,
- the Construction company paid a kick-back to the concessionaires of 9 Million Lira in order to win the contract,
- the Construction company made a profit of more than 13 Million Lira, which minus the kick-back, left them with a notable profit.

Nevertheless the Commission of the House of Deputies approved the balance sheet of the works justifying everything *'with the difference between the prices of 1853 and those of 1862'.* However, the official receivers came to an agreement with creditors, which permitted the creation of a new Irrigation Canal Company, which could – from 1 November 1869 - resumed work for the realisation of the branch canals.

SECONDARY OR BRANCH CANALS

The doubts of the Government and Parliament:

With the Cavour Canal terminated, it was for the time being unusable due to the absence of secondary canals to bring water for land irrigation. In reality, the 25 August 1862 Act, approving the concession for the construction of the Cavour Canal prescribed the following: *'At the Government's request, and in accordance with its decision, the Company (concessionaire) must carry out the construction of the collection and branch canals, also beyond the right bank of the Po near Casale, on the basis and assurance, and in the interest of the main work. In the same manner, the Company must acquire irrigation ditches, springs, aqueducts and water rights'* [21]
.
To this end, a cost of 6,300,000 Lira was estimated, so long as the works and acquisitions were first approved by Parliament: nevertheless Government and Parliament were unable to come to an agreement on the plan for the secondary irrigation network and the method of distribution.

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18 The Royal Commission for the studies of the hydraulic regime of the Po also illustrates (on pags. 57-59 of its First publication from October 1910 to December 1913 – Parma, 1914) the criticality of the flow of the Po at Chivasso. For example from 8 to 10 September 1911 the diverted flow (drying up the river) was 60.3 m3/s. The same for 11 September 1912. Worse still on 28 July 1913 when only 48 m3/s could be diverted; from 18 July until 2 September the divertible flow and therefore diverted was always less than 60 m3/s apart from some days in August when the flow fluctuated between 60 and 70 m3/s.

19 Characterised, on the contrary to the situation of the Po at the section of Chivasso, by strong summer floods (due to melting snow) and low water in the winter.

20 Sergio Baratti: The Construction of the Cavour Canal, from the memoir presented at the itinerant Assembly on 13 June 1998 in Novara

21 Ibid

At this point, it would seem opportune to report what Sergio Baratti, former Director General of the *Associazione Irrigua Est Sesia* (East Sesia Irrigation Association) and expert on the history of the Cavour Canal, had to say. *'In 1870 Mr. Carlo Negroni (lawyer) from Novara – in a memoir about the distribution of the waters of the Cavour Canal, given to the 'Agrarian Committee of Novara' – expressed his protests as follows. «Sad to say! It is eight years since the concession of the Cavour Canal: it is four years that the Canal is functioning: another diversion was opened to supply it with the waters of the Dora: and the Government still does not know what system to use for distributing this great body of water. In the meantime the Italian exchequer (which as we all know is thriving) pays from three to four Million annually for the guarantee promised to the Concessionary company: and no benefit is derived from these waters to relieve this burden, and this immense wealth is dissipated in a deplorable way'* [22]. And Baratti commented: *'So the great irrigation initiative connected with the realisation of the Cavour Canal, carried out up to now so admirably, committed a terrible error, unfortunately destined to repeat itself in many other similar ventures, up to our own day; the error of underestimating the difficulties, the time and the costs which the realisation of an irrigation distribution network entails, especially when - even before the great irrigation works - the most suitable solutions for the characteristics of the areas to be irrigated and the methods for carrying them out are not properly researched and defined, with the inevitable consequence of seriously delaying the complete and productive use of the works themselves'* [23 & 24].

In fact in 1865, the Government had already elaborated a plan, which then ran aground, which planned to utilize existing torrents and irrigation ditches for distributing the water. Then, in 1868, two top-level officials of the Administration (the Chief Engineers of the Civil Engineers of Ferrara and Ravenna) were instructed to study the problem. These two men, faced with the constrasting interests of the farmers demanding water and the owners of the lands who were opposed to the expropriations for the realisation of the canals, decided that, apart from some small interventions, it was better to let things sort themselves out in time, thus succeeding in pleasing nobody.

In 1868, the Superior Council of Public Works expressed the opinion that three new branch canals should be realised [25]: an idea that was voted down for economic reasons. In 1870, a Commission was nominated [26] which adopted a mixed solution to build a new branch with sub-branches and using some of the already-existing irrigation ditches. This solution was also voted down. Mr. Negroni, in a note sent to the Concessionary company, the Government and Parliament, wrote among other things: *'Don't nominate any more Commissions. You've already nominated too many, with the results that can be seen. The second Commission opposed the ideas of the first: the third that of the second: and so on and so forth, that's what happened and will happen again; because it couldn't have happened any other way. In the meantime the waters of the canal have been distributed on paper, but never on the ground.*

Action required individuals, not Commissions. When there was a Director General of the Waters and State Canals at the Ministry, I doubt whether the reports were as learned and elegant as those made by the Commissions. But I know this for a fact, that then the waters were not left idle in the rivers, nor thrown away into drains; but flowed through the countryside, bringing fertility. There was much less discussion, but much more was done, and much better' [27].

The realisation of the first branch canals:

Faced with the doubts and perplexities of the political authorities, under the pressure of the interest of private individuals, something was done although not without difficulty. The branches which started functioning before 1870 were as follow:

- from *Cavo Montebello*, realised by the *Compagnia Generale dei Canali d'Irrigazione Italiani.* It began functioning in the spring of 1868 for the irrigation of circa 5,400 ha spread over nine municipalities located east of the Sesia river; the 4.4 Km-long canal originates in the municipality of Recetto and, at its end, flows into the Sesiella Canal. The flow diverted from the Cavour Canal was in the order of 6.5 m^3/s;
- from the so-called *Cavo Belletti,* realised by four municipalities in the territory of Novara, right of the Ticino (Galliate, Romentino, Trecate and Cerana). The canal, which originated in the Galliate territory to the right of the Cavour Canal at the height of number 80821, was little more than 14 Km long and was terminated in the summer of 1868. The flow initially diverted from the Cavour was 7.5 m^3/s, ⅔ of which destined for the irrigation of circa 5,000 ha. In 1893, the Irrigation Consortium of the four municipalities, owner and manager of the *Cavo*

22 East Sesia – Periodical of the East Sesia Irrigation Association – Year LV – June-July 2010, no. 115 , pag. 8

23 ibid

24 Author's note: Words that ring true, particularly today, which could be applied to any intervention in the public works sector.

25 One between Sesia and Agogna, a second between Agogna and Terdoppio and a third between Terdoppio and Ticino.

26 It was called the Brioschi commission after its president.

27 Sergio Baratti: The difficult early years of the Cavour canal in Est Sesia – Periodical of the East Sesia Irrigation Association – Year LV – June-July 2010, no. 115, pag. 17

Belletti, ceded it for free to the State Exchequer which got it restructured and widened, lengthening the course by circa 4.5 Km. The flow was raised to 22 m^3/s and the canal, so restructured, was named the *Diramatore Vigevano;*

- grants were made for improving the transportation of water to the *Roggia Rizzo-Biraga* and the *Cavo dell'Ospedale*.

The Quintino Sella Canal

The Quintino Sella Canal (known also as a branch) was realised from 1870 to 1874, upon the initiative of the *Compagnia* for irrigation purposes, as part of the water carried by the Cavour Canal. With its sub-branches Mortara and Pavia, it served the area downstream from the Cavour Canal up to the Po and included between the Agogna and the Ticino to the east.

The Quintino Sella Canal originated close to Veveri (Novara), was about 24 Km long and diverted a flow of 30 m^3/ s from the Cavour Canal, which was gradually reduced to 21 m^3/s at its end at the height of the Cilavegna-Sant'Anna diversion chamber. Work was carried out very rapidly and costed 1.6 Million Lira (of the day) compared with the much greater estimate of 2.7 Million Lira.

'The course of the branch canal was drawn up so that, passing through the south-east of the city of Novara, there were leaping weirs capable of developing a great amount of industrial power; in fact 20 weirs were built along its course for a total drop in level of 28.5 m' [28].

The two, Pavia and Mortara sub-branch canals originated from the Cilavegna-Sant'Anna diversion chamber as mentioned above.

The *Compagnia* began the construction of the Pavia sub-branch canal in 1872 and the first trunk was quickly terminated. The construction of the second and third trunks were started by the administrations and the municipalities involved, but the works were then redeemed and completed by the *Compagnia*, while the realisation of the 4th and final trunk was put in the charge of the *Compagnia* with the Groppello Irrigation Consortium contributing to the costs. The original plan assigned a flow of 15 m^3/s to the first trunk of the sub-branch canal, as this trunk had to serve as drain for the Quintino Sella branch into the Terdoppio torrent. The river-side dwellers of the torrent opposed the plan, so the original flow of the sub-branch canal was reduced to 7 m^3/s, thus altering the canal's dimensions.

The plan for the 1st trunk of the Mortara sub-branch canal (13.527 Km) was approved by the Governing Council of Public Works at the end of November 1872 and its realisation was terminated by the *Compagnia* in 1873. A second trunk of 1,778 m was planned and constructed by the *Compagnia* at the expense of the municipalities and the irrigation consortia involved, unfortunately giving rise to numerous disputes among the various parties. These problems were, however, resolved and the Mortara sub-branch canal gave rise to numerous irrigation canals:

- Canalino Canal (2,927 m);
- San Giorgio Canal (3,830 m);
- Ottobiano Canal (582 m);
- Curti Canal (6,594 m);
- Curti-Malaspina Canal (also known as the Morto Canal (626 m);
- Cattanea canals (3 canals for a total of 9,420 m).

THE WATERS OF THE CAVOUR CANAL TODAY

Today the waters of the Cavour Canal have numerous uses: first of all, the irrigation of the rice fields and water meadows, but also for replenishing the water table used for irrigation further downstream and finally for producing energy. Before proceeding further, brief mention should be made of the importance of rice-growing to the economies of the provinces of Vercelli and Novara, both served by the Cavour Canal.

Rice production in Italy

In 2013, 216,018 ha were used for cultivating rice in Italy, 95% of which in Piedmont and Lombardy and the rest in other regions. In the same year, a total of 1.4 Million tons of paddy rice (*risone)* was grown with an average yield of 6.56 tons/ha. The net production of polished rice was 862,000 tons, equal to 61% of gross production. These figures were very modest compared to the extent of the rice-growing areas and the yields in Far East countries; but they were important when considering that Italy was the most important producer in Europe and a rice-exporting country.

Rice consumption per capita was 5-6 Kg/year absorbing 300-350,000 tons of the produce, allowing for about 500,000 tons of polished rice [29] to be exported to Europe and other countries.

The principal rice-growing regions were Piedmont with 113,789 ha and Lombardy with 87,393 ha, in particular the Piedmont provinces of Vercelli and Novara, with respectively 68,204 and 32,385 ha cultivated with rice and the Lomellina in the Lombardy province of Pavia with 58,058 ha with a total of 158,647 ha (data 2013).

28 Sergio Baratti: 'The difficult early years of the Cavour canal' East Sesia Review, Year LV, no. 115, pag. 19

29 In effect, since Italy imports about 60,000 tons/per year of oriental varieties of rice not grown in our own country, the volume of exportation increases accordingly.

Irrigation

The irrigation of this area was managed by the West Sesia Irrigation Association and the East Sesia Irrigation Association, with the Sesia river as the border line between the activities of the two Associations. The Cavour Canal (together with a few smaller canals) affected the territories of the two Associations and, in 1997, in order to improve management and maintenance, the *Co-utenza Canale Cavour* was created with the participation of both associations.
Over the years, the irrigation network has continued to develop with the restoration of old canals, the tapping of new sources and the construction of new adduction canals and a particularly ramified distribution network. Limiting oneself to the East Sesia area, where rice is grown on little more than 90,000 ha (added to which some thousands of hectares destined for other types of cultivation, including water meadows – see further on), during the peak period of demand the total amount of water available – between sources inside and outside the district - is around 262 m^3/s, 60 of which (equalling the 23% available) are taken from the Cavour Canal.

Reutilisation of the irrigation waters

The water used for irrigating the individual basins, pours out through drainer ditches when these are emptied to be reutilised further downstream; part of the water poured into the basins filters into the subsoil and feeds the water table which rises to the surface further downstream, causing *'risorgive'* (resurgences). These, also known as *'fontanili',* are contact water springs which rise to the surface at the edge of two formations, an impermeable layer lying beneath a permeable one. This is the situation in the Padan plain to the left of the Po River, where there is a more or less continuous line of resurgences corresponding with the border between the upper and lower Padan plain. The water temperature of the resurgences maintains an almost constant temperature of + 10 °C thus permitting the production of green forage even in wintertime, thanks to the sheet of water passing over the meadow preventing the plants from freezing even when the water temperature is very low (*marcita* – water meadow).

Energy production

The gradient of the Cavour Canal is much lower compared with that of the river Po, so that as the canal flows along, the distance between it and the river increases: near to Novara the distance is about 50 Km. The irrigated area of East Sesia is served by several branches, the principal one being the Quintino Sella branch, all typified by their cutting perpendicularly through the contour lines. Due to the steepness of the terrain, these branches have numerous falls to prevent the water from flowing too fast, which could cause serious damage to artefacts and canal linings. Already in the early years of the 20th century, some of these falls were used to produce energy for local factories. With the nationalisation of electric energy production in 1961 and the closure of many small factories, these small hydro-electric power stations were abandoned. From 1982, with a series of changes in events (political, economic and environmental), there has been a revival of mini-hydroelectric power stations. The East Sesia Association has, therefore, carried out various feasibility studies pinpointing to over 200 falls existing along the branch canals with a flow of 10-25 m^3/s, and these power stations can be realised without affecting the main priority for irrigation. In fact, the realisation of these stations caused no removal of water, required no building of reservoirs and only caused a minimal environmental impact or damage to the local eco-system, but in exchange the proceeds from the sale of energy allowed for a reduction in the running and maintenance costs of the irrigation plant paid for by the consumers.

There are 40 hydroelectric power stations currently operating on the East Sesia irrigation network (including three on the *Co-utenza Canali Cavour*) with a unit power varying from 100 to 5400 kW, for a total power of over 26,000 kW, while 39 more stations are in the planning stage or under construction.

Cooling down industrial plants

Since the cooling down of industrial plants consumed no water, in order to reduce the pumping of underground aquifers, around thirty industries in the East Sesia District have been connected to the irrigation network, with the added advantage that the hot water, once returned, mingles with the rest warming it up, thereby favouring the growth of the crops.

CONCLUSIONS

So, the above description shows the importance, even more so today than when it was built, of the Cavour Canal, the existence of which, together with the exploitation of other irrigation resources, is essential to the economy of the area and the development of ancillary industries. In fact, there are numerous plants for processing rice (42 in the Vercelli province alone) as well as industries for manufacturing machines specifically for work in the rice fields, for sowing and the various interventions connected with rice.

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CHAPTER – 11

History and Sustainability of Water in Indonesia

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GENERAL OVERVIEW

The historical overview of water resources development in Indonesia had at least been conducted since the Ancient Kingdoms of Mulawarman at the 5th century followed by the flourishing era during the Buddhist and Hindu Era of the 7th to 9th century. During which, the development and institutional arrangement were mainly based on the 'executive order of the king', referred to as 'dawuhan' or command, without any formal institutional arrangements. However, the introduction of water resources technology was only started in the middle of the 18th century through the implementation of the Dutch Colonial Government Policy. During which, most water resources projects, with parallel development of institutional arrangements, were conducted on experimental basis by virtue of trial-and-error approach. This was due to inadequate experiences, with limited knowledge about actual site conditions, and the absence of hydrological as well as climatological data. Subsequent effort in historical process was the establishment of the Ministry of Public Works referred to in Dutch Language as 'Department van Burgelijke Openbare Werken (B.O.W.)' was only possible in 1854, which was responsible for development of public infrastructures on water resources. The establishment was encountered by problems for recruiting competent personnel due to the lack of experiences and technical skills as well as continuous suffering of institutional constraints in water resources development and management till after the Country's Independence, 1940's to 1950's. In an attempt to scrutinize the institutional constraints stated above, an effort had been made to list up the past problems and constraints along with the Indonesian history of water resources, institutional arrangements as well as trend of sustainability. However, the effort is mainly addressing the general water resources institutional arrangements, and not specifically on the framework of development in flat coastal areas, which is relatively new to Indonesia.

As far as the historical evidence of water resources development and management in Indonesia is concerned, there are three main starting points that could provide evidences of water resources development and management in Indonesia. The first artefact was denoted by the stone inscribed of construction of hydraulic structure, known as the Harinjing stone inscription which was found at the village of Kepung, Sub District of Pare, within the catchment area of Brantas River, East Java Province. The stone inscription stated that the structure was constructed in the year of 726 Caka Calendar or at 808. The second evidence of construction of hydraulic structure was dated back to 843 of Caka Calendar, or 921. The third evidence in term of stone inscription was dated back to 849 of Caka Calendar of 927 (Angoedi, 1984).

The overall improvement process of water resources development and management and the subsequent institutional arrangements were undertaken gradually through four phases: First, accumulation of the long terms community experiences for more than thousand years started with the development of rain-fed agriculture, followed by water resources technology of water diversion from rivers; Second, coexistence between community based development and management and the government based approaches, took place for over one century (from 1848 till 1970s); Third, full government based implementation on O&M of Water resources infrastructures; Fourth, restructuring of water resources and irrigation development and management

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following decentralization and government autonomy. Parallel with irrigation transfer policy, the government also started to scrutinize the policy on water resources development and management.

From the water resources history in Indonesia, there were several lessons learnt from the experimental phase of irrigation and water resources development policy. These, among others, were: (1) The importance of undertaking experimental and trial efforts to learn about the applicability and effectiveness of policy instrument; (2) The importance evaluating the implementation of the underlying trial or experiment before proceeding to the subsequent phases using larger investments; (3) In line with the expansion of investments, it was highly important to pay special attention to follow up institutional arrangements for infrastructural O&M, before the policies were widely implemented at the next phase. Therefore, the subsequent Phase could be considered as the overall establishment phase of both infrastructures as well as institutional arrangements.

Followed by about five decade's studies, there existed a strong political commitment for implementing the water resources development policy, with the emergence of the First Generation for development of public irrigation at the large scale during 1850-1950. The expansion of public irrigation under the First-Generation development was also supported by the fast development of technology within the middle of 19th century to enable the development of water resources infrastructures at the large scale. In response to the successful physical development of the First Generation, the Second-Generation development emerged to continue more extensive development efforts. This was initiated by the development of large reservoirs in Citarum River of West Java Province, started in the 1950's, followed by several major infrastructural developments in Brantas River of East Java Province, started in the 1960's.

Today, Indonesia is entering the Third Generation of the developmental process, which are becoming more complex, because it requires a comprehensive insight on development and management, which are not only required to integrate the water resources management but also urged to integrate the use of water for all sectors, for maintaining the harmony amongst ecosystem services, regulatory services, cultural services and other support service systems. One of challenges that should be anticipated is the urgency to escape from the old paradigm and move towards new paradigm of integrated water resources development, involving all development sectors, community and stakeholders in all the decision-making process of WRDM on integrated basis. Being the case, experiences indicated that institutional setting must be carried out parallel with the entire process of infrastructural development of Water Resources Management, including the provision of all the required government regulations, and regulatory instruments for the appropriate implementation of Integrated Water Resources Development and Management.

GEOGRAPHY

Indonesia, the largest archipelago in the world consists of five main islands, Sumatra (473,606 km2), Java (132,187 Km2), Kalimantan (539,460 Km2), Sulawesi (189,216 Km2), Papua (Irian Jaya) at 421,981 Km2, and some 30 smaller archipelagos, totalling at about 17,508 islands and isles, of which about 6,000 are inhibited (Figure 1). The archipelago stretches between 6o8' north latitude and 11o65' east longitude; and between 94o45' and 141o 65' east longitude, having a total area of 5,193,150 Km2 – of which 2,027,087 Km2 of land territory and sea territory at 3,1666,163 Km2. The Indonesia's land area is mostly covered with thick tropical rain forest where fertile soils are continuously replenished by volcanic eruptions, particularly on Java Island, where 15 active volcanoes out of 112 volcanoes are located.

Figure 1. Indonesia

Climate

The climate and weather of Indonesia is characterized by two tropical seasons, which vary with the equatorial air circulation (The Walker Circulation) and the meridian air circulation (The Hadley Circulation). The displacement of the later follows the north-south movement of the sun and its relative position, in particular from the continents of Asia and Australia, at certain periods of the year. These factors contribute to the displacement and intensity of the Inter-Tropical Convergence Zone (ITCZ), which is an equatorial trough with low pressure that produces rain. Thus, the west and east monsoons, or the rainy and dry seasons, are a prevalent feature of the tropical climate. The climate in general is characterized by equatorial tropical monsoon-type climate changes every six months. The dry season occurs from June to September, and the rainy season from December to March. The temperature varies in accordance with the season having the average at the coastal plains at about 28oC, inland and mountain areas at about 26oC and at the high land territories at about 23oC. The relative humidity, like many tropical regions is generally high, between 70 and 90%, with a minimum of about 73% and a maximum of about 87%. In general, the climate changes every six months. The dry season (June to September) is influenced by the Australian continental air masses; while the rainy season (December to March) is the result of the Asian and Pacific Ocean air masses. The air contains vapour, which precipitates and produces rain in the country. Tropical areas have rains almost the whole year round. However, the climate of Central Maluku and the East Coast of South Sulawesi is an exception. Here, the rainy season is from June to September and the dry season from December to March. The transitional periods between the two seasons are April to May and October to November.

Water Resources

The overall accessible water resources potential of Indonesia is estimated at about 2,530 Km3, (about 1,850,000 m3/year) scattered over river basins throughout the archipelago, of which about 2% (96m3/capita/year) is currently utilized for agriculture at about 76%, domestic at about 11.5%, and industries at about 13,5%. These water resources are scattered throughout the country flowing through about 5,886 rivers and tributaries with the overall length of about 18,000 Km. The major rivers are also used for substantial inland transportation such as the Musi, Batanghari, Indragiri, and Kampar Rivers in Sumatra; the Kapuas, Barito, Mahakam, and Rajang Rivers in Kalimantan; the Mamberamo and Digul Rivers in Papua. On Java Island, rivers are dominantly utilized for irrigation, such as the Bengawan Solo, Citarum, Ciliwung and Brantas Rivers. A number of islands are dotted with scenic lakes, like the Toba, Maninjau and Singkarak Lakes in Sumatra; the Tempe, Towuti, Sidenreng, Poso, Limboto, Tondano, and Matana lakes in Sulawesi; and the Paniai and Sentani lakes in Papua (Irian Jaya). Beside these, a total of 33.4 Million ha of lowlands (consisting of 20.1 Million ha of tidal lowlands, and 13.3 Million ha of inland swamps.

OVERVIEW OF WATER HISTORY

The historical survey of water resources development in Indonesia had at least been conducted since the Ancient Kingdoms of Mulawarman at the 5th century followed by the flourishing era during the Buddhist and Hindu Era of the 7th to 9th century. During which, the development and institutional arrangement were mainly based on the 'executive order of the king', referred to as 'dawuhan' or command, without any formal institutional arrangements.

The introduction of water resources technology was only started in the middle of the 18th century through the implementation of the Dutch Colonial Government Policy. During which, most water resources projects with parallel development of institutional arrangements, were conducted on experimental basis by virtue of trial-and-error approach. This was due to inadequate experiences, with limited knowledge about actual site conditions, and the absence of hydrological as well as climatological data.

The establishment of the Ministry of Public Works referred to in Dutch Language as 'Department van Burgelijke Openbare Werken (B.O.W.)' was only possible in 1854, which was responsible for development of public infrastructures on water resources. The establishment was encountered by problems for recruiting competent personnel's due to the lack of experiences and technical skills. The above endeavours had been practically terminated during the Second World War till the revival of development programs a few years after the Country's Independence, 1940's to 1950's.

From this point on, the government of Indonesia has been taking all the necessary endeavours on institutional arrangement including the establishment of the government institutions at all levels. This included the review of the previously initiated 'Water Regulation' such as Presidential Instruction No. 1/1969 on Water Resources Management, Law No. 11/1974 on Water Resources Development, and most recently Law No.7/2004 on Water Resources, and its related Government Regulations. The latest law prescribed the urgency to establish Water Resources Council at the Central, Provincial, Regency, and/or at the River Basin levels, as effective coordinating instruments toward Integrated Water Resources Management.

In an attempt to scrutinize the institutional constraints stated above, an effort had been made to list up the past problems and constraints along with the Indonesian history of water resources institutional arrangements as well as trend of sustainability, for discussing future challenges and develop sustainable and cost-effective approaches. The discussion, however, is mainly addressing the general water resources institutional arrangements, and not specifically on the framework of development in flat coastal areas, which is relatively new to Indonesia.

HISTORY OF WATER UTILIZATION IN INDONESIA

Ancient historical evidence

Before the discovery of water resources artefacts some scholars argued that the Indonesian Archipelago had been naturally structured in terms of groups of tropical islands and isles with large number of local communities. Therefore, the infrastructural developments were not urgently demanded, and only small scattered water resources infrastructures were provided to support water requirements of the people. Therefore, infrastructural development of water resources at that period was only at the small scattered areas without the demand management and only provided with small scattered infrastructures. In addition, the abundance of water resources availability in the Indonesian Archipelago caused the water resources infrastructures to be not specially developed. Given this assumption, it was quite obvious that the water resources development proceeded with simple water resources infrastructures for thousands of years. And hence, the historical infrastructures in terms of structural artefacts have never been found to give concrete evidence to the future generation.

Evidence from artefacts at the ancient temples

With regards of water resources development for traditional agricultural practice, a number of evidences had been found in Indonesia inherited from the ancestors, both in terms of hardware, software as well as institutional arrangements. From the perspective of irrigated agriculture, these ancient practices were mostly inappropriate in the modern era such as rice terrace technology in Bali, Lombok, Java, Sumatra, Sulawesi and some other local irrigated agricultural systems.

In line with the above matters, the water resources and irrigated agricultural technology in Indonesia had long been implemented within the entire archipelago. It has been apparent, therefore, that the Indonesian Ancestors had already been intended to communicate their skill and experience in water resources and irrigated agricultural technology through stone grafting records at the walls of the temples on Java Islands.
A number of such messages on water resources management and conservation had been conveyed from old generation to the new generation through stone engraving at the wall of the temples. These include water conservation, irrigated agricultural implementation, as well as utilization of water for health, live activities as well as environmental preservation. These messages were quite clear and mostly were self-explanatory even some of them were still relevant with modern technology, though the messages had not been stated in exact period of historical time. As a matter of fact, all of the stone engraving were perfectly made so it would continuously give messages to their future descendants from generation to generations, and some of them were still consistent with water resources conservation technology till the modern time, despite that the temples were mostly constructed between the 7th and 9th century.

Based on the complete explanations that were given through the stone engravings we could assume that the water conservation and sustainable technological aspects must have been known and implemented far before the construction of the temples per-se'. It means that water resources development and management had also been mastered by Indonesian ancestors far before the construction of the temples. Despite that the period had not been clearly and exactly stated at the stone reliefs, it could then be concluded that water resources conservation must had been implemented in Ancient Indonesia before the 1st century.

For illustration, there were many evidences of the ancient messages from the previous generations in terms of stone engraving at the wall of the temples on Java as well as on the Outer Islands. There were a number of stone reliefs engraved at the wall of the temples which explained implicitly about agricultural technology, both for the case of utilization of rain water and utilization of technology. The implicit in animate messages from the ancestor could be traced back from the initial stage when agricultural technology had not been implemented till up to the application of water resources technology for conservation of ecosystem. A stone relief from Borobudur Temple for instance, clearly illustrated the community livelihood through wild life hunting, crop cultivation, fruits gatherings, fishing and so on (Figure 2). From this figure, it was clearly understood that how the ancient people applied tools, arrows for hunting and fishing, transplanting of banana and other fruit trees for supporting their food supplies.

Despite the fact that the relief did not give information about the exact period of community livelihood, nor the period when agricultural technology was started to be implemented, it was very clear from the stone relief of Borobudur Temple (which in fact built up between the 7th and 9th century), that the ancient agricultural practices had already been utilizing cattle power (a pair of cow/bulls) for ploughing to conduct land preparation, which in fact are very similar with equipment that are presently utilized in many agricultural communities in Indonesia. Even the type of plough is still popularly used at the modern era in Indonesia (Figure 3). From this relief, it is not yet clear whether the agricultural technique had been already implemented by applying

Figure 2. A Stone relief that illustrates the livelihood of pre-agricultural community life; hunting, fishing fruits gathering, etc. (Relief from Borobudur Temple Registered under the O Series of Karmawibangga No. 118)

irrigation technology or only for cultivating their crop by depending upon the rain water (rain-fed agriculture). However, from this example, it was logically clear that however simple the agricultural practices at that that period, they must have been applying for water supply technique to support the plant growth.

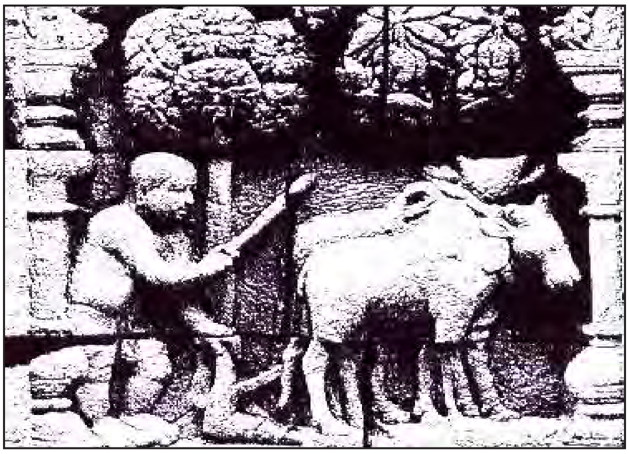
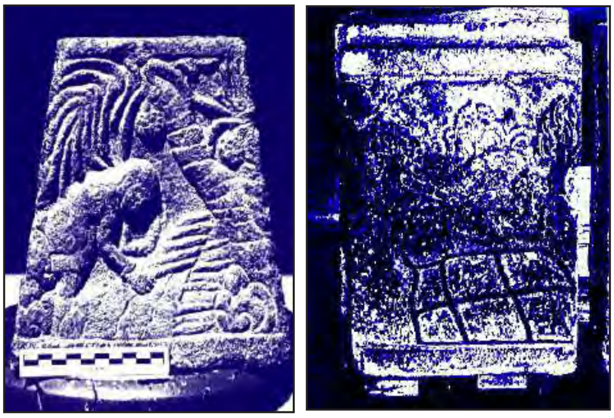


Figure 3. Stone relief at the wall of Borobudur Temple illustrates the application of cattle power ploughing for land preparation, which in fact the method of application and type plough tool are still utilized for conducting land preparation today (Gany, Feb 2006)

From many reliefs that were located at the base foundation of Borobudur Temple, (the reliefs are now covered by soil embankment after restoration), there were found many stone reliefs about the livelihood and way of life of the ancient generation which did not differ from the underlying practices of the successive generations in the Modern Era. – The author has been permitted by the Research and Conservation Station of Borobudur Temple to reproduce their pictures from their archives, others pictures were directly taken by the author at the site.

The ancestor's message regarding cultures and rice cultivation, for instance, from two reliefs at Trowulan Area, East Java Province, were very clear and self-explanatory showing rice transplantation and dyke arrangement for lowland bonded paddy fields (Figure 4a). From these reliefs, it was clear that for rice cultivation, the farmer must conduct rice seedling preparation which differed from upland paddy where seeds were sown by broadcasting. Thus, it was very obvious that the paddy transplantation illustrated in the reliefs must have been utilizing water medium for softening the paddy field to allow paddy transplantation. However, simple the water techniques were used for plant consumption. They understood the way to provide water for supporting the crops growth. From Figure 4b, (relief at Trowulan Museum), the message was even more obvious about the bird's eye view of bonded rice fields which indicated that they must had been practicing irrigation technique, however simple it was (for instance by making canal for gathering water during rainy season for subsequent distribution to the rice plots). Paddy cultivations were recorded as the earliest agricultural practice in Asia, including Indonesia, and paddy was one of the aquatic plants which consumed more water than other plants. Upland paddy cultivation or gogo for example, were planted by direct seeding, while lowland paddy had to apply for wet seed bed preparation within the period of two weeks prior to seedling transplantation, (as clearly demonstrated by the stone reliefs from Trowulan Museum.)



(a) **(b)**

Figure 4. (a) A Relief from Trowulan Temple in East Java illustrates the farmer transplants lowland paddy cultivation. ource: Reserch station for Study and Conservation of Borobudur Temple; Wiwit Kasiati, 2000. (b) A relief of Trowulan Temple illustrates the bird eye view of bonded lowland paddy field at a village. Source: Research station for Study and Conservation of Borobudur Temple; Wiwit Kasiati, 2000.

In an attempt to find evidence on history of water for supporting the above assumption, a relief from the basic foundation of Borobudur Temple (Karmawibangga) – which is presently covered by soil embankment after inventory recording at the completion of reconstruction, revealed a number of related information. Figure 5 depicted the technique of irrigated agriculture, despite that the relief does not show any information about the year of its implementation and how the technique was applied. As a matter of fact, the relief illustrated the way of the farmer at the ancient time conducting the pest control such as rats and birds that were attacking the paddy at the maturity stage, also the way of controlling pest such as rats that were damaging the harvest. The reliefs were also showing application of watch dog for controlling the related pests. The reliefs also showed the information about anticipation of the farmers to prepare for storage after harvesting, post-harvest crop maintenance and so on. If we have a special look at the quality of reliefs that illustrated the above processes, it was quite amazing to find out that the ancient civilization was very skilful to make illustrations at the walls of the temples, in the form of stone carving which were quite awesome about the way they illustrated their experiences on irrigated agricultural implementation, for conveying information to the future generation.

Figure 5. A relief from the main foundation of Borobudur, Karmawibangga (Series O No.65), illustrates the way of the farmer to conduct pest control, including application of watch dog for controlling the related pests. These include some information about anticipation of the farmer to prepare crop storage (barn) after harvesting, post-harvest crop maintenance and so on

Other relief (Ib. 41 Relief Jataka/ Avadana) illustrated a diorama where a farmer was carrying out bunches of paddies after harvesting, in which a group of people at the foreground being at the gathering or party, chatting at the joyful condition with plenty of harvested products and hunting objects (birds and cattle at his back), while enjoying agricultural harvesting (Figure 6).

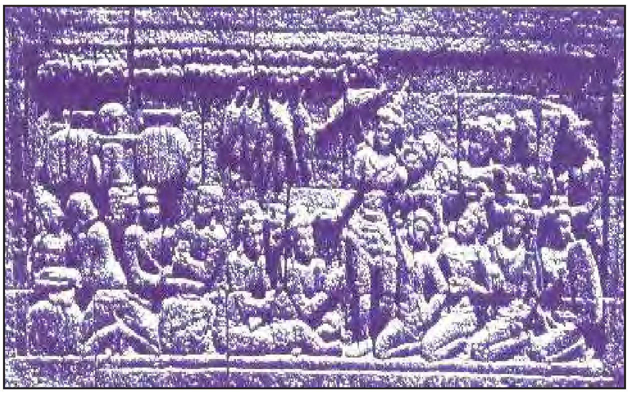


Figure 6. A relief of the Wall of Borobudur temple illustrating a man carrying crop products, at the harvesting period, with foreground of people enjoying agricultural product after harvesting.

Water for life and effort for conservation

Regarding water utilization for supporting life and livelihood, another relief at Prambanan Temple (Figure 7a), indicated the message of water utilization for supporting livelihood of the people, where people were utilizing water for cooking their daily foods necessities, boiling water while the other people standing at the front sites cleaned fishes that would be cooked. From Figure 7b clearly illustrated that a woman is serving drinking water at certain occasion. This relief clearly illustrated as to how water in a special container was poured out to a cup – the form and function were fairly similar with kitchen appliances that are currently used at the modern era today.

(a)

(b)

Figure 7. (a) Illustrates the ancient water utilization for daily cooking, boiling water, and a person at the foreground using water for cleaning fish before cooking. (b) illustrates the ancient people enjoy water for drinking, while a woman seen at the diorama is pouring drink to the cup of a guest at a certain occasion. (Source: Research Station for Study and conservation of Borobudur)

Despite that the pictures did not clearly denote whether the people were using water technology for taking the optimum advantage of water, illustrations linked with other similar artefacts, at Prambanan Temple, gave a general indication that the water utilization during that period was familiar to people and they were aware of application of water technology, for instance, techniques for providing water as well as water conservation.

From several reliefs displayed at Prambanan Temple, the diorama clearly displayed the ancient technique of water utilization, including effort for environmental protection through ecosystem water conservation, not limited to the human life, but also for ecosystem protection and conservation of the existing flora and fauna. Figures 8a, and 8b, the pictures were taken from the wall of Prambanan Temple Central Java, clearly illustrated the ancient water conservation techniques for maintaining ecosystem balance and environmental protection. Both pictures clearly illustrated the message of the ancient people that the forest and environmental water ecosystem must be properly maintained and conserved for supporting the life of people, flora and fauna as well as environmental ecosystem on sustainable basis.

(a)

(b)

Figure 8. (a) A picture from the wall of Prambanan Temple shows the message that water conservation technique has already been practiced by the ancient generation for protection of forest ecosystem. (b) A picture from Prambanan Temple illustrates the water conservation technique for human, flora, fauna and ecosystem (Source, Gany, at Prambanan Yogyakarta, Feb. 2006)

With an assumption that the above stone reliefs at the ancient temples – which were made at the Era of Buddhist and Hindu on Java Island, between 7th and 9th century, it could be clearly concluded that the history of water utilization and conservation as for human, and environmental ecosystem as well as for sustainable agriculture must had been implemented long before the construction of the temples per se'. However, such ancient message could not be utilized to determine the exact time of the history, as to when the Indonesian Ancestors commenced the water resources development and conservation.

Subsequent Historical Evidence

The historical survey of water resources development in Indonesia had at least been conducted since the Ancient Kingdoms of Mulawarman at the 5th century followed by the Flourishing Era during the Buddhist and Hindu Era at the 7th to 9th century. During which, the development and institutional arrangements were mainly based on the 'executive order of the king', referred to as 'dawuhan' or command. This was normally conducted by the community leaders who were specially appointed by the king to coordinate the construction and the subsequent operation as well as maintenance of Water Resources Infrastructures for irrigated agriculture and flood protection, by means of voluntary mutual-aid approach by the community referred to as 'gotong-royong' system. The community organizations undertook the on-demand operation and maintenance of the constructed water resources infrastructures by means of mutual consensus without any formal regulatory or institutional arrangement.

As far as the historical evidence of water resources development and management in Indonesia is concerned, there are three main starting points that could provide evidences of water resources development and management in Indonesia. The first artefact was denoted by the stone inscribed of construction of hydraulic structure, known as the Harinjing stone inscription which was found at the village of Kepung, Sub District of Pare, within the catchment area of Brantas River, East Java Province. The stone inscription stated that the structure was constructed in the year of 726 Caka Calendar or at 808. The second evidence of construction of hydraulic structure was dated back to 843 of Caka Calendar, or 921. The third evidence in term of stone inscription was dated back to 849 of Caka Calendar of 927 (Angoedi, 1984) (Figure 9). For giving illustration of the construction method of the hydraulic structures, a diorama that had been placed at the original location of the stone inscription for commemoration, can be seen in Figure 10.

Figure 9. Duplicate of the Harinjing Stone inscription at the original location near Jombang Sub District of Pare at the village of Siman Krajan, the original artefact is placed at the National Museum in Jakarta under the Registration No. N. D.173

Figure 10. Diorama had been made at the original location of the ancient hydraulic structure embankment of Harinjing artefact, for commemoration of manual construction technique of hydraulic structure by means of mutual aid of the local community members

From the evidence of the uncovered stone inscriptions, it can be seen that during the establishment of the river embankment, there were three tributaries of the Barantas River which frequently suffered from flood incidents as well as sabo sediment current from the Mount Kelud Volcano. From the stone inscriptions, it was also recorded that the Harinjing Dyke of Brantas Tributaries suffered frequent damages, and at this moment there remained only two large boulders of the original dykes' structure which can still be seen at the original location of Harinjing River Dyke.

Other evidence from the Gurit stone inscription gave historical notes, written in Sanskrit, about hydraulic structures of the time, were also found in the vicinity of the previous evidence. From this stone inscription it was clear that the hydraulic structure was constructed in the year of 907. The stone inscription also noted that in 823, the Ancient Kingdom of Mataram under the rule of Pikatan King, supported the development of water resources for agricultural activities in the Island of Ancient Java.

Most recently, the evidence of water utilization in Indonesia had been discovered in 1990 from excavation in the Village of Trowulan, East Java, where a canal made of large brick arrangement with the size of 1.00m x 1.00m is suspected to be used as irrigation water channel in combination with drainage for the ancient agricultural area in that particular location (excavation is still continued at the time this picture was taken). In line with other artefacts, it is estimated that the brick channel was constructed during the era of Majapahit Kingdom between the year of 1293 and 1500 (Figure 11).

Figure 11. The ruin of irrigation channel made of brick layer with the size of 1.00 m x 1.00 m was excavated in Trowulan Village, East Java in 1990, estimated to be constructed during the Era of Majapahit Kingdom between the year of 1293 and 1500 (Gany, 3rd December 2014).

As far as the history of water resources infrastructures that have been discovered in Indonesia is concerned, it has been recorded from the Tugu Stone Inscription that the oldest hydraulic structure in the history of Indonesia is the Chandra Baga water channel in the vicinity of Cilincing River near Jakarta.

The stone inscription was discovered at the village of Tugu, the upstream of Cilincing River. For the purpose of historical protection, the Tugu Stone Inscription has been stored at the National Museum in Jakarta under the registered number D.124 (Angoedi, 1984) (Figure 12).

Figure 12. The Tugu Stone Inscription which was discovered at the Tugu Village at the upstream of Cilincing River, the original artefact is now kept for protection at The National Museum under the registration Number D.124. (Angoedi, 1984)

Based on the interpretations of the ancient script by Prof. Dr. R. Ng. Purbatjaraka, it was observed that the King Purnawaman gave command to his technical staff to excavate Chandrabaga Channel along Chandra Bhaga Palace next to the Bekasi River. In the meantime, based on geo-morphological interpretation it is estimated that the Chandra Bhaga location, is at the Cakung River of today. This stone inscription stated that since the 5th century, the lowland plain where Jakarta is located now, has been frequently suffered from flood incidences. From the above evidence, it has been obvious that the oldest hydraulic structure in the history of water resources development in Indonesia has been shifted from the previously known Harinjing Dyke (804) to the Chandra Bhaga Water Channel (500) at the Cakung River.

Simple irrigation system

With regards to the context of water resources artefact of historical evidence in terms of ancient infrastructural development and management, some scholars argued that Indonesia, which is located at the tropical region, the ancient artefacts on water resources development could not remain as historical evidence, because such simple water resources infrastructures could not last for long due to the susceptibility of the simple material due to deterioration process in the tropical climate. Therefore, it was the reason as to why ancient artefacts of simple and small infrastructures, especially the structures which consisted of organic material could not stay as historical evidence. If this argument is correct, the historical evidence on water resources infrastructures in Indonesia, which is located at tropical archipelago, could not be discovered. And hence the historical evidence of ancient water resources development and management are hardly traceable in ancient Indonesian archipelago. However, this argument is not fully significant to take into consideration for supporting the absence of historical evidence on ancient water resources infrastructures in Indonesia.

The history of water resources development in Indonesia has been mostly associated with irrigated agriculture, including the water allocation for crop, cattle, and fisheries, gardening, horticulture, fruits and other food crops. Today, despite that irrigation water consumption (about 75%) is still dominated by paddy, as the major food crop of ancient heritage for centuries, it has been indicated that other water requirements for human life, such as for urban settlements, industries, needs to be considered for environmental sustainability. Despite the long-term historical development of water utilization, the introduction of water resources technology started in the middle of the 18th century through the implementation of the Dutch Colonial Government Policy that had been directly involved with the efforts to improve irrigation infra-structures for supporting the 'Cultuur Stelsel' or 'Compulsory Agricultural Policy'.

During the period, most water resources projects were either executed on 'experimental' basis and/or with 'trial-and-error' approach, together with the efforts on institutional arrangements to allow the implementation of the demand driven of water resources infrastructural development. This included the scrutiny of the role of central government, provinces, districts, and rural communities as well as non-governmental organisations (NGO). The construction aspects were directly managed by the Local Authority, supervised by limited number of Dutch engineers, with limited knowledge about actual tropical site conditions, and the absence of hydrological as well as climatology data records.

The establishment of the Ministry of Public Works or in Dutch referred to as 'Department van Burgelijke Openbare Werken (B.O.W.)' was only conducted in 1854, which was responsible for development of public infrastructures of water resources. The establishment was encountered by problems of recruiting competent personnel's due to the lack of university and technical high school graduates. For this reason, the first engineering faculty was only established in Bandung, West Java in 1924. It took many years before the Dutch Colonial Government gave full development endeavour for construction of irrigation infrastructures. More significant commitments were only apparent when the Colonial Government established the Afdeling Irrigatie or Irrigation Division of the Department BOW in 1889, or 35 years after the establishment of the Ministry of Public Works in 1854.

From this point on, the government of Indonesia had been taking all the necessary follow up endeavours on institutional arrangements including the establishment of the government institutions at the provinces as well as at the districts level. This included the follow up of the limited scope of water law, that was previously initiated by the Colonial Government such as Presidential Instruction No. 1/1969 on Water Management, Law No. 11/1974 on Water Resources Development, and most recently Law No.7/2004 on Water Resources, and its related Government Regulations. The latest law prescribed the urgency to establish Water Resources Council at the Central, Provincial, Regency/ Municipality, and at the River Basin level as the coordinating mechanism for water resources policy amongst the government, non-government, and the stakeholders.

In an attempt to follow the Johannesburg declaration, Article 26 of Plan of Implementation of the World Summit on Sustainable Development (WSSD), Johannesburg, 2002, and for having 'IWRM Plan and Strategy on Water Efficiency' to cope with ecosystem challenges such as drought, flood, and conflicts on water uses allocation, Indonesia had conducted a number of efforts having special focus on water resources policy reform, including legal and institutional reforms. The water resources policy reforms had been scrutinized through adjustment with the dynamic shift of focus from time to time. This included the immediate demands for improving infrastructural efficiency, bureaucratic reforms, and institutional arrangements for improving the working relationship amongst the stakeholders on water resources utilization. This chapter has been prepared to list up the past problems and constraints along the Indonesian history of water resources institutional arrangements, for discussing future challenges and develop sustainable and cost-effective approaches. The chapter, however, is mainly addressing the general institutional arrangement, and not specifically on the framework of development in flat coastal areas, which is relatively new to Indonesia.

HISTORY OF TECHNICAL AND INSTITUTIONAL ARRANGEMENTS

As mentioned earlier, as far as irrigation and water resources history of Indonesia is concerned, there are three major milestones that could provide evidences to uncover the historical background of the early irrigation development and management practices in Indonesia. The Harinjing stone inscriptions to be found at the Kepung village, Pare District, within the Brantas River Basin, are dated back to the year of 726 of Caka Calendar, or 808. The second inscription dated back to the year of 843 Caka Calendar, or 921, and the third stone inscription dated back to the year of 849 Caka Calendar, or 727 (Angoedi, 1984).

The third stone inscription mentioned that a community leader named Bogawanta Bori from the village of Culunggi had been bestowed by the King Warok Dyah Manarah with a special privilege in terms of exemption of property taxes for his outstanding accomplishment to build the Harinjing River Dyke for water diversion, and flood prevention for agriculture as well as human settlement in the tributary of the Brantas River Basin.

The oldest water resources structure in Indonesia

From previous illustration, the first water resources infrastructure in Indonesia was constructed at the Tugu Village near the Cilincing River in the 5th century; this evidence unveiled the Tugu stone inscription in the Tugu Village near Cilincing River, Northern Jakarta (Angoedi, 1984). The historical evidence as translated later on by Prof. Dr. R. Ng. Purbatjaraka revealed that the King of Purnawaman declared his ‘executive order’ to excavate a short-cut channel at River Candra Bhaga for allowing the river flow directly to the sea, along the downstream site of the palace of Candara Bhaga, near Jakarta. This was evidently the flood control structure for preventing the ancient Jakarta and its agricultural vicinities from occasional flooding. This evidence also proved that since the 5th century, flood and drainage problems had encountered the ancient city of Jakarta. Thus, it revealed that so far, the Chandra Bhaga channel was the first water resources infrastructure in Indonesia, which was mainly undertaken through the ‘executive order’ of King Purnawarman.

The first rehabilitation work on water resources system

For rehabilitation of water resources infrastructures, a stone inscription unearthed from the ruin of the Harinjing Weir of Brantas River, stated that the Harinjing Weir, which was erected in the year of 804, had undertaken an unprecedented rehabilitation work on irrigation structure in 1350. The construction work for the weir was said to be a permanent structure for unlimited time horizon, however, the weir had been reportedly flushed away several times due to catastrophic occurrences.

From the ancient experience on irrigation rehabilitation, it became obvious that the hydraulic infrastructures for irrigation and other related purposes would need rehabilitative works on top of the routine Operation and Maintenance (O&M). As a matter of fact, it is quite admiring that the ancient work of Harinjing Irrigation Weir of the Kali Brantas River had evidently been long lasted for at least 546 years before the first rehabilitation works, under the executive order of the king, without any evidence about the existence of institutional arrangement.

Ancient indication of irrigation technical staff

Similarly, during the Hindu Era, construction of medium and large irrigation schemes was executed through the executive order of the King. For the construction of the ‘dawuhan’, the King authorized irrigation technical staffs to act for and on behalf of the King. According to the same ancient stone inscriptions, the assigned technician in practice, did not involve himself directly with construction execution. Instead, the royal irrigation technicians authorized the local technical staff from the village to execute the works, and subsequently responsible for conducting O&M as well as water allocation from the constructed weirs. Again, this ancient evidence did not specify any record of institutional arrangements.

Institutional arrangements - the case of Subak in Bali

Despite the absence of information about the exact date of the first establishment of Subak as an ancient organization for managing irrigation systems, in Bali Island, the local people had been implementing this distinct irrigation based agricultural practices from generation to generation for centuries till present. With regards to the interaction between Subak organizations and other ancient irrigation-based organizations, many researchers were in puzzled to learn the fact that no single evidence ever existed to show of any kind of organization similar to Subak’s in Indonesia.

To the extent of this argument, the pro side could at least give some rationale for similar democratic principle as they all have similar processes for irrigation management implementation. Similarities in these organizations existed in the way that they organized themselves in role sharing, organizational or institutional set up with more or less similar utilization of irrigation based agricultural tools and facilities. In fact, there are actually several other types of water users in Indonesia, who could not be incorporated into one single democratic based water user association like Subak System in Bali. For the case of Subak in Bali, there were some reasons to believe that this irrigation-based organization had at least been existed with its institutional arrangement since three centuries before the Era of Majapahit Kingdom on Java Island.

The ‘Pranatamangsa’ indigenous irrigated agricultural calendar

It had long been discovered that ‘Pranatamangsa’ as the ancient practice of Javanese Heritage on Irrigated Agriculture, had been a strong evidence of the sustainable ancient irrigated agriculture and is still adapted now, with some adjustments, with the most recent implementation condition. Despite the fact that no exact evidence about the history of the Pranatamangsa has ever been discovered, this traditional agricultural calendar was known to have been practiced by ancient Javanese farmers long before the Hindu Era in the Indonesian Archipelago. Aartsen (1953) believes that the lowland agricultural pattern for paddy had been practiced in Indonesia for over 2,000 years, and yet it is still comprehended by many rural traditional Javanese farmers today.

As the matter of fact, the Pranatamangsa had been widely used to guide the agricultural activities since the ‘Old Mataram Kingdom’, during the ‘Pajang’ Era, and during the ‘Islamic Mataram’ period (Fruin, 1922). Learning from the nature of the Pranatamangsa, Fruin further believed that such a well-sequenced procedure could not have emerged by itself. Thus, the invention must have been based upon very long and sophisticated observations. Whoever might be the inventors, they must have been expert in the art of observation, regardless of its having been developed so long ago.

The basic techniques of the Pranatamangsa were actually incorporated with the ‘simplicity’ principles. Simple enough that every farmer could easily adopt the technique without involving sophisticated learning processes. The complexity of the technique became obvious as they were comprehended from the implications of school of thoughts of today such as agricultural environment, cosmography, bioclimatology, socio-cultural circumstances and others. The Pranatamangsa agricultural calendars respectful even today because the application principles continue accommodating the environmental circumstances of agricultural activities.

One of the unique aspects that made the system sustainable, was that the complications of natural phenomena were bound together in such a way that it was easy to comprehend even by the illiterate farmers. Every aspect of agricultural patterns was deliberately connected with the natural characteristics. The agricultural patterns were seemingly developed to be able to accommodate the natural phenomena after a series of scrupulous observations. Most importantly, the application principle always capable of accommodating harmonious relationship between human, cosmic, nature and reality (Daldjoeni, 1979), without much concern about the nature of the underlying relationships per-se’.

The basic principle of the Pranatamangsa agricultural calendar was that one-year (365 days) was sub divided into four main-seasons: (1) Katiga, (2) Labuh, (3) Rendheng and (4) Mareng. Each main-season was further divided into three more seasons or ‘Mangsa’, which resulted in 12 distinct seasons (Figure 13, the general outline of the Pranatamangsa Agricultural Calendar). It was said (Handamangkara, 1964), however, that the original concept prescribed only 10 seasons a year, and the remaining 64 days were considered to be the resting days of the year, within which the farmers were prohibited from undertaking any farming activities (bera resting period). This was meant to let the soil rest between the harvest time and the next planting season. To further enable, the farmer recognized the resting period, the 64 days was further divided into two distinct seasons: (1) Desta, and (2) Sandhi, instead of the 11th and the 12th seasons. These terms were derived from Hindu months, Jaista and, Asadha, which literally meant, ‘to occupy the same period’ (See Figure 13 of the Pranatamangsa principles).

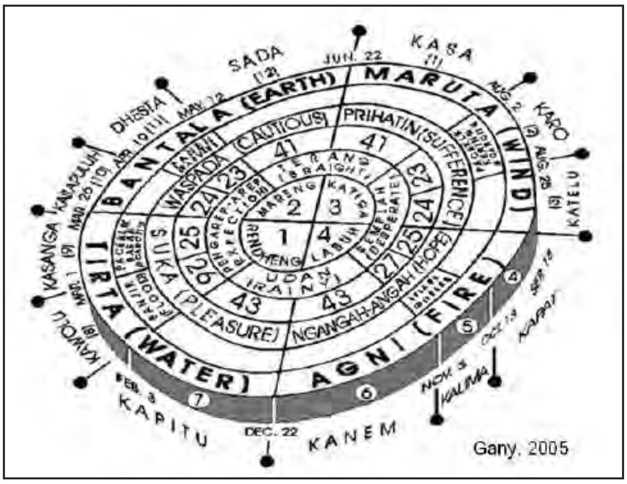


Figure 13. The basic feature of the Pranatamangsa Agricultural Calendar

Socio-cultural dimension

One of the crucial aspects of implementing the sustainable agricultural practices in the society was related to the difficulty to formulate regulation that could meet the demands of the farming circumstances as well as the society as a whole without causing any inconveniences. As a matter of fact, it was always difficult to establish good regulation that could apply to the poorly educated members of the farming community as the most farming situation in the rural areas of Indonesia.

There were some traditional regulations, which appeared logical and technically sound. But in most cases, the farmers just took them for granted. Therefore, it was almost certain that the role of the Pranatamangsa was more effective, if it was geared towards encouraging the socio-cultural participation in the traditional agricultural community. Thus, the implementation of the modern innovation in the traditional society should first of all convince the farmer that their participation in the activities was worthwhile. Despite that today's farmers are no longer fully practicing in the traditional agricultural activities as that of their ancestors did, the socio-cultural functions of the Pranatamangsa or other traditional agricultural heritages remain very important to consider by any change agents if the agricultural development efforts should be sustainable.

FRAMEWORKS OF WATER RESOURCES MANAGEMENT

It has been stated previously that Indonesia has quite a long-term experience and heritages on water utilization since the ancient time. For instance, the use of water for irrigated paddy in Java has been existed since about 1600 years BC, despite the simple infrastructures and the institutional settings. The functioning was only based on mutual consensus. Appropriate irrigation system in Java Island was estimated to exist since the 1st century. The system was mostly were consisted of simple small-scale structures which was within the capacity of the local community to construct, O&M on sustainable basis for centuries.

The development of large-scale water resources and irrigation infrastructures were only attempted, during the middle of the 19th century, for alleviating poverty problem due to the extreme droughts in Demak Regency, Central Java Zone. The subsequent developments were followed with institutional arrangements, especially for sustaining the O&M as well as utilization of the developed infrastructures. During the initial phase of development, the development programs were also not supported by substantial innovations in hydraulic technology. This was indicated by the ability to reconstruct the simple irrigation structures that were previously initiated by the local communities with an overall total of about 300,000 ha. These experimental efforts of 50 years were considered adequate by the colonial government as the basis for policy instruments for expanding the follow up developmental policy referred to as 'Ethieshe Politiek' or ethical policy.

Based upon the above policy, the first part of the 20th century was identified as the period for infrastructural development for irrigation and water resources which were conducted at a large scale by the Government. The first period was between 1900 and 1925, which consisted of development of infrastructures and institutional arrangement, although some institutional arrangements for O&M have already been initiated since early 1871. Despite that the decentralization of government authority on Java Islands had started since 1926 to 1930, and the irrigation management had been decentralized to the provincial government, the laws that regulate irrigation and water resources (Algemeen Water Regelement) were enacted in 1936 through 'Staatsblad 1936 No. 489' which was later on followed by provincial water resources and irrigation regulation (Provinciale Water Regelement).

There were several lessons learnt from the experimental phase of irrigation and water resources development policy. These, among others, were: (1) The importance of undertaking experimental and trial efforts to learn about the applicability and effectiveness of policy instrument; (2) The importance to evaluating the implementation of the underlying trial or experiment, before proceeding to the subsequent phases using larger investments; (3) In line with the expansion of investments, it was highly important to pay special attention to follow up institutional arrangements for infrastructural O&M, before the policies were widely implemented at the next phase. Therefore, the subsequent Phase could be considered as the overall establishment phase of both infrastructures as well as institutional arrangements.

Given the fact that the increasing demands of water resources and irrigation, led to a dichotomy between the government based infrastructural management and the community-based management that was examined. There were at least four developmental phases that were scrutinized in terms of the strengths and weaknesses of the two types of infrastructural management frameworks (Pasandaran, 2003).

First Phase: This phase dealt with Irrigation and water resources infrastructures developed by the community. Accumulation of the long terms of community experiences, perhaps more than thousand years – (Estimated by Van Zetten Vander Meer 1979, the development since the 16th century BC) – started with the development of rain-fed agriculture, followed by water resources technology of water diversion.

Second Phase: This phase dealt with coexistence between community-based development and management and the government-based approaches.

Since the 19th century, large scale developments of irrigation infrastructures were conducted by the Colonial Government. This phase had occurred for over one century (from 1848 till 1970s). At the same time, the community based simple irrigation schemes continued.

Third Phase: this phase dealt with full government-based implementation of O&M of Water resources infrastructures. For achieving self-sufficiency in rice production, during the 1970's to 1980's, the government conducted mass irrigation implementation. In addition, the government also assisted the development and management of community-based irrigation systems.

Fourth Phase: This phase dealt with reformation of water resources and irrigation development and management following decentralization and the government autonomy. This phase was initiated by presidential instruction No. 3/1999 and Government Regulation No.77/2001, which was intended to transfer the O&M of irrigation infrastructures to the water users' association. Parallel with this effort, the government also started to scrutinize the draft of the policy on WRDM. During which, the constraint also existed between the need to encourage opportunity of private sector for conducting O&M on the one hand, and the efforts that affecting this phase, which discouraged the role of private sector to conduct O&M of water resources infrastructures.

INSTITUTIONAL REFORM OF WATER RESOURCES MANAGEMENT

For the Fourth Phase of policy reform, there were at least three interrelated determinant factors of water resources management that were taken into account. These were legal aspects in terms of law and government regulation, local wisdom that had been practiced by local people, and technological development.

In conjunction with the institutional reform, definition of water resources management from the perspective of institutional arrangement was the authority to make decision in the water resources utilization (Schlager and Ostorm, 1999). Therefore, water resources management was a kind of water right that could be in the form of cumulative means. This was for instance consisted of the right to access water, water use right, exclusive right or the right to determine who is deserved or did not deserve to access water, transfer right or the right to sell or transfer resources. The right to access water uses was merely for operational level, while others for collective water right.

In Indonesia, since the economic depression in 1997, the capacity of the government to finance the O&M of water resources infrastructures became decreasing. This was due to the increasing number of community-based irrigation infrastructures that were becoming a burden on the government. The problem had been apparent when the government intervention to rehabilitate and improve the O&M, by virtue of centralistic decision-making approach, was substantially increasing the government burden. This approach had apparently been increasing the dependency attitude of the water users on O&M, including dependency attitude on the financial responsibility.

In an attempt to prevent the water users from perpetuating dependency attitude, it was important to consider the dynamic evolutionary structure of the community as social capital. This included, for instance, open mindedness, transparency, participatory attitude, as well mutual trust – which were among the important part of social capital, as the determinant aspects of successful governance of water resources development and management.

Integrated policy on water resources development

Based on the long-term experience, it has been observed that one of the obvious constraints in the implementation of integrated policy was the difficulty to convince the bureaucratic structures to adopt and implement the integrated policy, despite the increasing awareness of the importance of integrated approach in water resources development and management which has become apparent amongst the bureaucracy. To this extent, the awareness of the importance of policy on integrated approach had been transformed into political commitment to the international forums. Nevertheless, during the implementation, the policy could not be immediately adopted, because many of the political commitments were not met such as the practical needs of the bureaucracy.

Based upon the experiences from the past, there were several factors that demanded the need to create new policies. For example, the impacts of drought that caused famine and deaths in Demak Regency, Central Java Zone in 1848 which had inspired the colonial government to formulate new policies. After about five decades of studies, in 1901 the government declared the new policies referred to as the ethical policies, having three policy instruments which were; Irrigation, Education and Emigration.

As a result of the strong political commitment for implementing the policy, there emerged the First Generation of developmental work of public irrigation at a large scale. This generation had been existed for about a century (Table 1), starting from the policy of large-scale trial for over 50 years, implementation of colonial government ethical policy till the enactment of the First Water Law (Algemene Water Reglement – AWR) on trial and error basis. The characteristic of this effort was centralistic formation of irrigation and water resources bureaucracy and decentralization

Table 1. The first generation of water resources development (1850-1950)

Year	Government policy	Triggering factor	Characteristic
(1)	(2)	(3)	(4)
1858	Large scale trial for infrastructural development	• famine incident • existing development of hydraulic technology	It took about 50 years effort for development trial
1901	Ethical Policy of the Colonial Government	• underlying political pressure in the Netherlands	Expansion of Large-Scale Irrigation Development
1936	Enactment of the First Water Law *(Algemene Water Reglement – AWR)*	• trial on institutional setting	• centralistic formation of irrigation and water resources bureaucracy • decentralization of irrigation management to Provincial level
Source: Translated with some modifications from Effendi Pasandaran, 2008			

of irrigation management to Provincial level. The expansion of public irrigation under the first generation was also supported by the fast development of technology within the middle of 19th century to enable the development of water resources infrastructures at the large scale.

From the above explanation, it is obvious that the second half of the 19th century could be considered as the trial phase of infrastructural development in Indonesia, which was later accepted as the large-scale development. In an effort to improve the operation and management of irrigation and water resources system, after problem identifications within the last decade of the 20th century, the first Water Law (Algemene Water Reglement) was enacted in 1936, but only applied on Java and Madura Islands. This effort was followed by Decentralization Policy on O&M and Management of Irrigation to the Provincial Government through a special government regulation refers to in Dutch as Provinciale Water Reglement (PWR). However, the policy of water resources development and management remained at the central government.

In terms of physical development, the First-Generation development had been considered to be successful, within the relatively short time, to expand irrigation areas from about 1 Million hectares at the beginning of the 20th century to about 3.5 Million ha in 1949 (Burger, 1975). However, the problems remained apparently on the O&M and management of irrigation systems. Despite the underlying O&M problems, these developmental efforts had taught lessons that could be implemented to improve the subsequent infrastructural developments. Thus, parallel with the subsequent developments, the government kept implementing experimental and trial efforts, particularly on policy instruments, and improvement of institutional arrangements. Further to this large-scale irrigation expansion, the government also continuously paid special attention on community based developed irrigation systems.

In response to the successful physical First-Generation developments, the Second Generation of Water Resources Developments emerged to continue to subsequent implementation of more extensive development endeavours. This was initiated by the development of large reservoirs in Citarum River of West Java Province, started in the 1950's, followed by several major infrastructural developments in Brantas River of East Java Province, started in the 1960's. The major activities conducted in the second generation for water resources development and management are listed in Table 2.

As stated above, it was quite obvious that since the First-Generation developments, it had been experienced that water resources development and to some extent managements were based on centralistic approach, with less efforts for capacity development of local authorities. Other obvious impacts were the rapid escalation of development costs, with continuously less and less allocation for O&M and management of water resources infrastructures. This matter had been triggered by the rapid escalation of development budget, while the routine budget remained constant.

Considering the apparent constraints capacity development on conducting integrated operation and management of water resources and irrigation infrastructures, since 1984, efforts had been initiated to strengthen the capacity development of the developed irrigation infrastructures. This was executed through the support of the World Bank under the Sector Adjustment Loan, Capacity Development for O&M as well as management of Irrigation and water resources infrastructures.

Towards sustainable integrated water resources management

The enactment of Water Resources Law No. 7/2004, March 18, 2004, had brought about a new expectation on the possibility to fully implement the sustainable

Table 2. The second-generation water resources development (1950-2000)

Year	Government polic	Triggering factor	Characteristic
(1)	(2)	(3)	(4)
1974	Enactment of Law No. 11/1974, about water resources development	• technology on green revolution • the country's program on rice self-supporting	• centralistic development and management approach • low construction quality • shorter rehabilitation cycle • expansion of project based WUA's establishment
1987	Irrigation sector policy: • strengthening the capacity of WUA's • trial on management transfer of small-scale irrigation schemes • efficient operation and maintenance	• significant increase of development budget • decrease allocation of routine government budget.	Much effort of the government officials was concentrated on physical infrastructural development and less on O&M efforts.
1999/2001	Irrigation management transfer to WUA's	Severe economic crisis	Increase of power competition amongst the government authorities dominated by the power of centralistic bureaucracy
2004	Enactment of Law No 7/2004 about water resources	• influence of international politics • effort to recover the bureaucracy demand.	Increasing demands on clear interagency roles and responsibilities amongst stakeholders
Source: Translated with some modifications from Effendi Pasandaran, 2008			

Integrated Water Resources Management, as the major approach prescribed by the law on water resources development and management on integrated basis. However, the development of Water Resources Law No.7/2004 suffered with negative views from a number of non-governmental organizations (NGO) which were put before the constitutional court for Judicial Review of the newly enacted water law by a number of non-governmental organizations (NGO). The main issue argued by the NGO's was concerning the fear of 'privatization' and water resources management by applying the 'water right system' or licensing right system for water utilization. However, after a sound substantial consideration and all the legal aspects, the Constitutional Court eventually decided to turn down the claim of the NGO's.

The remaining problem that had been encountered was the actual implementation of the law started with the development of all the related regulatory instruments for conducting integrated coordination as well as role sharing amongst the government agencies and stakeholders involved in water resources development and management. The immediate prescription of law No. 7/2004 concerning integrated coordination mechanism was the establishment of Water Resources National Council, which would develop all the policy issues on integrated water resources development and management on: (1) Water conservation, including protection, preservation, water quality management, pollution control; (2) Water Resources Utilization including, water use management, water resources allocation, water utilization, water resources development, and water resources exertion; (3) Management of the Destructive Forces of Water, including protective actions, repressive actions, and rehabilitative actions; (4) Water Resources Information System including management information system of hydrology, management information system on hydrometeorology, and management information system and hydrogeology. The activities were to be implemented by the National Water Resources Council. Other Water Resources Councils at the Provinces and Regencies, for Integrated Basin were scrutinized, and developed and implemented, parallel with the related institutional arrangements according to the actual condition.

Future Perspective on Institutional Arrangement and Sustainable IWRM

Taking into consideration the long history of water resources institutional arrangements in Indonesia, it gave indication of the future perspectives and directions for the need to scrutinize and adjust the shift of paradigm of institutional arrangement toward integrated water resources management. For this purpose, there were at least four paradigm shifts that must be taken into consideration.

- **First:** The spectrum of the old institutional arrangements on water resources had only been focussed on part of the integrated water resources management. From now on, the water resources management must consider the entire spectrum of water resources utilization, by involving all the related stakeholders in the decision making of the overall process. These included integrated scrutiny of environmental ecosystem of the 'blue' and 'green' waters as well as groundwater management.

- **Second:** The old paradigm on the water resources management which was considered for commodity production should be shifted to the use of water for all sectors – agriculture, domestic and industries, as well for maintaining the environmentally friendly ecosystem – for maintaining the harmony amongst ecosystem services, regulatory services, cultural services and support service systems, and not mainly consider the production system.

- **Third:** The sectoral approach paradigm for water resources management had shifted to multi-functional use of water resources as the main approach in resources management. The multi-functional roles, must address the resources' function that were essential for economic development, and to encourage the implementation of social justice, that could enhance sustainable development of water resources. For this purpose, a multi-stakeholder on IWRM was considered on water resources problems, but more than that the forum must accommodate the entire concerns that were related to water resources utilization and conservation.

- **Fourth:** The old centralistic and/or 'command and control' paradigm as well as the focus on the control of government bureaucracy shifted to new paradigm with special scrutiny on management flexibility, transparency, involving integrated participation of all of the social capitals.

In spite of the already existing efforts for capacity development of bureaucracy as well as empowerment of community involvement coupled with policy instrument and political commitment that had been gradually developed since the beginning of water resources development and management, it was apparent that all of the underlying institutional setups were yet still far from capable to adopt as well as to implement the new policy on Institutional Arrangement toward IWRM. With the continuously existed threat on the destruction of existing system on water resources development and management, it became more and more obvious that the institutional setup must be implemented parallel with infrastructural development by new generation (the Third Generation) development. These efforts were exceptionally important, because if these were not consistently undertaken, it would bring about ecological disaster and physical disaster in the future.

CONCLUDING REMARKS

Development and management of water resources in Indonesia had been directed for a fairly long time since the ancient Kingdoms of Mulawarman at the 5th century followed by the flourishing era during the Buddhist and Hindu Era of the 7th to 9th century. However, the introduction of water resources technology only started in the middle of the 18th century through the implementation of the Dutch Colonial Government Policy. The follow up institutional arrangements was only started several decades later parallel with irrigation aspect of water resources, which were conducted on experimental basis by virtue of trial-and-error approach.

The improvement process of water resources development and management and the subsequent institutional arrangement were undertaken gradually through four phases: First, accumulation of the long terms of community experiences for more than thousand years started with the development of rain-fed agriculture, followed by water resources technology of water diversion from rivers; Second, coexistence between community based development and management and the government based approaches, which took place for over one century (from 1848 till 1970s); Third, full government based implementation on O&M of Water resources infrastructures; Fourth, restructuring of water resources and irrigation development and management following decentralization and government autonomy. Parallel with irrigation transfer policy, the government also started to scrutinize the policy on water resources development and management.

Followed by about five decade's studies, there existed a strong political commitment for implementing the policy, with the emergence of the First Generation for development of public irrigation at the large scale during 1850-1950. The expansion of public irrigation under the First-Generation development was also supported by the fast development of technology within the middle of 19th century to enable the development of water resources infrastructures at the large scale. In response to the successful physical development of the First Generation, the Second-Generation development emerged to continue to more extensive development efforts. This was initiated by the development of large reservoirs in Citarum River of West Java Province, started in the 1950's, followed by several major infrastructural developments in Brantas River of East Java Province, started in the 1960's.

Today, Indonesia is entering the Third Generation of the developmental process, which are becoming more complex, because it requires a comprehensive insight on development and management, which are not only required to integrate the water resources management but also urged to integrate the use of water for all sectors – agriculture, domestic and industries, as well for maintaining the environmentally friendly ecosystem – for maintaining the harmony amongst ecosystem services, regulatory services, cultural services and other support service systems.

One of challenges that should be anticipated is the urgency to escape from the old paradigm and move towards new paradigm of integrated water resources development, involving all development sectors, community and stakeholders in all the decision-making process of WRDM on integrated basis. Being the case, experiences indicated that institutional setting must be carried out parallel with the entire process of infrastructural development of Water Resources Management, including the provision of all the required government regulations, and regulatory instruments for the appropriate institutional arrangement as well as implementation of Integrated Water Resources Development and Management (IWRDM).

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CHAPTER – 12

Innovation and Intuition in Hydraulic Engineering: A Brief History of Hydraulic Engineering in Central Europe

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INTRODUCTION

The profession of hydraulic engineering is quite ancient and most of the early civilisations are unthinkable without the advances it had made. For thousands of years, the skills that went into hydraulic engineering were a precise observation of nature, experience, and intuition. New demands by the society and new technical possibilities have led to constant innovations in the field of moving drinking into and waste water out of the cities. Since the term 'engineer' first made an appearance in Europe in the Middle Ages, this chapter first addresses the question setting engineers apart and how they have helped drive the technological progress. This article first examines briefly the major developments in pre-historic Europe through antiquity, the Middle Ages, the Renaissance, and the early modern period. The considerations of ancient engineering are not focused on Central Europe, but on the Mediterranean and the Middle East, because these areas were the main inspiration for what was to come later in Central Europe, which boasted the hydraulic engineering activities at the time. This overview ends with the turn of the 20^{th} century with the transition from intuitive solutions of hydraulic engineering problems to solutions supported by calculations and experimental models.

This look at the history of the engineering profession shows just how closely technological progress and the engineering profession are intertwined and what challenges it has overcome in the past. This very brief account of the profession's history over the past 5,000 years, with its focus on Europe, meant that many details were ignored as it was only a rough overview. The aim of this chapter was to identify the key developments and clarify the importance of engineering contributions in providing water supply and drainage services to the continent's cities. An extensive description of the engineering profession without a focus on hydraulic engineering is offered, for example, by Kaiser and König (2006). Some of the ideas about the development of the engineering profession in general have been taken from this work. Closely associated with the engineering profession was the technological progress of the human race, which had always been shaped by engineers. An overview was provided by König (1997).

With regard to sustainability, it was of interest for each society and the hydraulic engineers of each age to know about sustainability and what impact this knowledge had on their own plans and structures. Social demands had repeatedly led to situations where the long-term consequences of actions were not considered, in part because such correlations were still unclear and in part because other interests prevailed at the time, such as the need to feed the growing population. A look at history repeatedly demonstrated that earlier eras often had very detailed knowledge of different aspects of natural cycles that was subsequently incorporated into their engineering plans. Other contributions to this volume provided examples of this. Just looking at the past 150 years in Central Europe, it was clear that much ancient, albeit sometimes intuitive knowledge on the sustainable handling of water as a resource had been lost or ignored. It therefore matters what a society and its engineers in any given era knew about sustainability and how sustainably they handled that knowledge.

What is an engineer?

At first glance, the engineering profession appears to be a modern and relatively young profession. But, at

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least as construction and hydraulic engineering are concerned, they are almost as old as human civilisation itself. For the past two centuries, engineers in Central Europe have been mostly defined by their training, usually at a university. Since the 1970s, for example in Germany, the law has even regulated who can call themselves engineers. But before the emergence of the modern universities of applied sciences, engineering expertise was almost exclusively acquired and tested on the job. More generally speaking, over the millennia, engineers can therefore be seen as those who were responsible for solving challenging technological tasks and the associated organisational problems. The technological problems go far beyond purely artisanal aspects, even if the early engineers often did come from the trades.

Although the word 'engineer' is derived from the Latin 'ingenium' (talent, ability), the Romans did not have engineers as we know them. The Romans knew the 'architectus', where the book 'De architectura' by Vitruvius suggests that this included the matters now addressed by civil engineers. Apart from that, the early civilisations of the Nile and Mesopotamia, like the later peoples in the ancient Mediterranean, did not have a distinct concept of the 'engineer' as a collective term for technological experts. Likewise, the advanced civilisations in Asia and America do not appear to have had a concept that would correspond to today's engineer. The job title of engineer only came to be used in Europe at the end of the Middle Ages. Nevertheless, there have been professional designations for certain sectors of the engineering profession in all of these eras and cultures, such as the 'aquarius' (the Roman waterworks master), maser builders, well masters, or the 'dijKmeester' in the Netherlands, but the generic term' engineer 'was not used. From the 11th century, variations on the term 'ingeniator' begin to show up in written documents to refer to siege engineers. From the 15th century, the term is also used in Italy for the civil sector. Later, the term begins to be used in the Roman languages, before finally entering German in the 18th century from the French. 'Civil Ingeniuer' comes to be used in Germany to distinguish them from military engineers. This use of the term 'civil engineer' survives in English to this day.

From the Roman Empire to early modern times, there has often been a close connection between the engineers in the military and in the civilian sector. As in other areas, military units have been used in peacetime to perform public works such as surveying, construction of aqueducts or waterways management. Military engineers had a number of similar tasks, such as the construction of bridges or laying defensive walls, either against the enemy or against water, which is why work on coastal and inland dikes has often been compared to building entrenchments for sieging or defending a city. In Germany, military engineers were involved in public works until the 18th century.

Engineers and technical progress

The description 'solving challenging technological tasks' and the terms 'technical progress' and 'innovation' are often used interchangeably, with 'innovation' certainly being the most comprehensive as it also includes areas outside the technology. But how has this process unfolded in the field of hydraulic engineering?

Since hydraulic engineers often had to build their solutions in landscapes with differing conditions, previous solutions had to be repeatedly adapted and adjusted to the new circumstances. For example, adaptations were necessary to the topography, the kinds of materials available in the vicinity, or the special tasks that the structure had to perform. This resulted in innovations and new technical solutions which led to the gradual expansion of technical knowledge. This knowledge, in turn, enabled ever larger structures to be built as well as the building of structures under particularly difficult conditions to solve problems that had remained unsolved until then. The speed of this process of innovation depended in particular on the transfer of knowledge, the level of integration among different areas of knowledge, and the need for new solutions. In addition, personal interest and chance also played an important role, of course.

Originally, professional knowledge was accumulated from one's own experiences and passed on to one's apprentices or successors. Professional exchange took place at the regional level among colleagues. For hydraulic engineers, the opportunities for professional networking were often limited because the tasks, problems and constraints were frequently very different and the number of experts in the vicinity were often low. Military engineers had the advantage in that they were building similar structures such as bridges in different regions and under different conditions and that they had constant contact with other experts in the military with whom they could collect and exchange a wide range of knowledge.

An important advance in this area came about when the knowledge began to be recorded in writing and especially with the later invention of printing. The collected experiences and recommendations could now be passed on by authors without temporal or geographical limits and thus lead to new ideas that would go far beyond their own experience, without the need of a personal encounter. For individual, often local issues, memoranda were frequently drafted; later the existing knowledge came to be summarized in printed textbooks.

The appearance of trade journals finally allowed timely reporting on current projects, experiences and research. Recommendations that were generally accepted could lead to norms or technical standards that made what was once an innovation into a regulation. Another leap in the transfer of knowledge came with the systematic training of engineers in larger groups by specially designated experts, a task now fulfilled by universities.

Collaboration and exchange among persons working in different fields led to the integration of different areas of knowledge. This enables a deeper understanding, the transmission of solutions and procedures, and the use of new materials. The pressure to seek new solutions was often driven by social, cultural or climatic changes, but also by colonization and the conquest of new regions. Conversely, travel and conquest led to the acquisition of the technical achievements of other cultures.

These developments were not always straightforward: some were already known in antiquity and had even became the norm, but were lost in the Middle Ages and then newly discovered or developed in modern times. Even today, some of the knowledge of previous generations of engineers' remained lost because there no longer was a need for this knowledge, partly because it has been rendered obsolete by technological progress and partly because the problem was not currently relevant. Major changes, such as climate change or dwindling oil reserves, could however make previously lost solutions, such as old methods of energy efficiencies, once again current and eventually adapted or combined with recent findings to help solve the current problems of our era.

Hydraulic engineering and sustainability

In Germany, the introduction of the general concept of sustainability can be attributed to the field of forestry. An initial use of the German term *Nachhaltigkeit* ('sustainability'), meaning the long-term responsible management of a resource, was found in a 1713 work by Hans Carl von Carlowitz 'Silvicultura oeconomica'. This simple resource-based view of sustainability meant that humankind would no longer remove the resource from nature before it could be replenished. However, hydraulic engineers had been following the principles of sustainability for thousands of years without using a corresponding term. Water management meant creating a balance between the demand and supply of water. Hydraulic engineering created the means to achieve this, from build stores in all sizes from the cistern to the dams as well as building canals and pipelines. Since water was an absolutely vital resource, the permanent settlement of a region was only possible through the sustainable use of the water. This requirement had led to various innovations in obtaining, storing and economical use of water, especially in regions where water was scarce or very unevenly distributed throughout the year. In regions where water is not a scarce resource, as is the case for large parts of Central Europe, other aspects such as food, construction and heating materials, transportation options, etc. came to the fore. However, even Central Europe has seen various problems related to water supply in terms of the available quantity. A detailed analysis of water as a source of sustainability could be found in Pohl (2012).

HISTORICAL DEVELOPMENT IN CENTRAL EUROPE

The following sections provide the highlights of the main developments in different eras. The choice of selection as to which achievements to mention is subjective and incomplete. Dimensions are given for individual structures to help the reader understand the scope of the projects; these data often differ slightly in different sources.

Antiquity

As already stated, there is no evidence of hydraulic engineering in pre-Roman Central Europe. In ancient times, it was especially the Romans who contributed their expertise to Central Europe by providing water supply and drainage systems to the cities they built here. The Romans, in turn, obtained their knowledge from the Greeks and from the Near and Middle East. Therefore, a look at these regions is useful because their achievements had a crucial influence on subsequent developments in Central Europe.

Very early on in human history, the uncertainty of water supply only by precipitation led to water storage systems (temporal transfer) and redirecting the flow of water from its natural flow path (spatial transfer). This was all the more important in semi-arid or arid regions where water was usually a minimum requirement for all further developments. As human settlements grew, the requirements to ensure the supply also grew, requiring engineering measures that became larger with time (Figure 1).

In the arid and semi-arid regions, the largest consumer of water was agriculture, which would be impossible without irrigation. In addition to supplying water to the human residents, large numbers of domesticated animals needed water as well. In addition, crafts such as tanning and fabric dyeing required water. The civilisations of the Nile, the Indus, Assyria and Mesopotamia were, therefore, highly dependent on solving water management and hydraulic engineering problems. Agricultural irrigation continues to be of vital global importance, as about 70% of human water consumption (incl. the water used to cool power plants) is still used for irrigation. In Central Europe, agricultural irrigation has played a subordinate role, since the natural rainfall here is adequate and also relatively evenly distributed throughout the year. Therefore, agricultural irrigation plays a minor role in this chapter. Forward-looking and long-term planning were needed to enable societies to develop and civilisations to rise. Consequently, social developments and the solutions to water management problems had influenced one another and the growth of ever larger territorial powers,

Figure 1. Large cistern for storing rainwater in the Nabatean city of Humayma

because water management problems could no longer be solved by a single clan, a village or a city-state. This led Karl Wittfogel (1977) to coin the term ‘hydraulic societies’ for these first civilisations. The same was true much later in Europe in regions such as northern Germany and the Netherlands, where life would not be possible without large-scale, continuous defence of the coast. Here, too, water management needs have played a decisive role in the development of organisational and power structures in the region’s societies.

The tasks and requirements for solving water management problems grew as societies grew and could no longer be handled solely by local craftsmen after a certain point, but required the guidance and coordination of a trained person, which gave rise to the new profession of master builder. The master builder can be seen as a combination of today’s engineers and architects, with a differentiation of the two professions only happening later.

The Near and Middle East saw the construction of some edifices early on with dimensions that remain impressive to this day. In the area making up modern Germany, structures of these dimensions only began to be built at the beginning of the modern era. Some of these structures in the Near and Middle East include:

- At Jawa in the north-east of present-day Jordan, two water retention ponds were built in the middle of a basalt desert. The third retention pond required the construction of a 5 m high dam (Figure 2). Together, these three ponds were able to hold 42,000 m^3 of water. These ponds were built in 3750-3350 BC (Vogel, 1991);
- Sadd-el-Kafara in modern Egypt was probably built around 2600 BC (Figure 3). It stood about 14 m high and 113 m wide and was able to store between 465,000 to 6,200,000 m^3 of water. The edifice was destroyed by a flood shortly before its scheduled completion and was never rebuilt. For the following 800 years, no other dam projects are known to have been attempted in Egypt (Grabrecht, 1995);
- The Marib dam is located in modern Yemen. Construction of the dam, which remains standing, began in 900 BC, with the final version finished by 250 BC. There were probably other structures that predated this one. It stands a total of 14 m high and 600 m wide. Irrigation channels are found on both sides of the dam which could provide water to a total of 1,600 ha of land (Schütz, 2009);
- Finally, the aqueduct of Jerwan, which was built to supply water to the Assyrian capital Nineveh. It was built between 703 and 690 BC and is 290 m long, 22 m wide and reaches a maximum height of 9 m. It could carry up to 50 m^3 of water per second. This aqueduct was part of a 50 Km long canal line built to supply the city (Garbrecht 1995).

It can be assumed that these structures were most likely the high-tech buildings of their time. This also means that there must have been older structures where the builders gathered the necessary knowledge and experience to build these monumental structures and test the relevant techniques. It is also likely that large numbers of perhaps equally impressive structures around the world have now completely disappeared or have yet to be discovered.

Figure 2. Ancient dams: remains of the dam at Jawa in the north-east of Jordan, one of the oldest dams in the world, originally standing about 5 m high

Figure 3. Sadd el-Kafara in Wadi Garawi, Egypt, 30 Km south of Cairo, height 14 m, a crest length of 113 m (right; photo: Henning Fahlbusch)

From 600 BC, increasingly monumental temples began to be built in Greece, whose designs required new technical solutions that clearly went beyond the skills of mere craftsmen. While these structures have always been quite impressive in their own right, they also necessitated the construction support infrastructure that was no less impressive. It was during this time that the Eupalinos tunnel, running for more than one kilometre, was dug out over 8 years on the island of Samos. Another masterpiece was the water supply for the high-altitude city of Pergamon (Figure 4), which drew its water supply from the mountains 40 Km to the north. Part of this water supply with several lines included a 3.5 Km long pressurised pipeline with water pressures of up to 175 m H20. Such long lines could only have been possible through sophisticated surveying techniques and a corresponding knowledge of hydraulics.

Figure 4. Ancient water supply: view of the Pergamon massif from about 3 Km away: in the foreground the remains of the water chamber which was the beginning of the penstock. The pressures were set at 175 m H20

From the 5th century BC, the foundations of mechanics arose. Alexander the Great was conquering vast territories which made significant amounts of resources available. This led to the establishment of new cities which required supplies of water. As self-confidence grew, increasingly technological feats came to be mastered. At the same time, the contact with the older cultures in Egypt and Persia resulted in new knowledge and new ideas. With the rise of Roman dominance, Greece came to be supplanted as the drivers of the innovations in Europe. The Romans came to see the development of infrastructure by the state as a chance to show off their might and for the glory of the emperor. As a result, the structures no longer had to be just functional, but also things of beauty. Outstanding hydraulic engineering examples of this could be seen in the aqueducts that supplied water to Rome and Nimes. Even before the Empire, Rome had a water supply with several gravity channels, some of which were as long as 60 Km. Each channel was designed to divert the water as high as possible into the city to provide as many areas of the city with running water for the running fountains and spas. In Nimes, the length of the channel was 45 Km, and was most impressive at the triple arch Pont du Gard over the Gard (Figure 5) (technical data: 275 m long, 49 m high, up to 6 m wide, slope 0.4 per thousand), largely because it is still intact. And similar structures exist all over the Roman Empire. The mean gradient across the channel line was even lower and amounted to about 2.4‰.

Figure 5. Pont du Gard along the 50 Km aqueduct of Nimes; the road bridge on the lower level was later erected over the aqueduct (right; photo: Henning Fahlbusch)

In the Roman Empire, standardisation was a key to success. Planning and construction were simplified. There were quality assurance systems and construction and repairs could be accelerated. Standardisation also made the knowledge of the technical elite available to a wider audience. This could be seen in the hydraulic and water supply systems, particularly in the repeated use of the same components and construction methods. Large structures such as dams have remained unique to this day because of the need to adapt to local conditions.

Middle Ages

Much of the knowledge of antiquity was lost in the Middle Ages and the pace of technical development slowed down. The decline in population also led to less need for extensive water supply projects. In Central Europe, the irrigation of agricultural land played only a minor role because most regions had sufficient natural rainfall. Only the irrigation of meadows was important in some regions for some time. The water supply to the significantly smaller cities initially required no special hydraulic engineering expertise. The activities of the hydraulic engineer instead focused on the construction of waterways and harnessing the power of water. The construction of waterways in the Middle Ages was largely done to harness water power and was, therefore, quite restricted locally. While waterway construction to improve navigation and flood control saw no major innovations until the introduction of the steam-powered excavator (around 1900), the development of hydropower and water-powered pumps played a crucial role in further technical progress.

Importance of hydropower

Hydropower was already used in ancient times to power mills or to lift water vertically in irrigation systems. Vitruvius first mentioned a water mill with an angular gear in about 25 BC. For many tasks, however, the muscle strength of slaves and animals was available on a large scale in ancient times. In the Middle Ages, the situation had changed as Christianity forbade slavery and there not enough people available and the necessary efficiency could not be achieved by muscle power alone. There is evidence of water mills in Germany dating back to the 8th century, such as the one at Dasing near Augsburg (Eugen, 2005). Starting from the simple grain mill, the forces of water came to be used in more and more areas of work. The problem was how to replicate human movement, such as milling fabric, operating a bellows or a forging hammer (Figure 6) with a mechanical movement propelled by a water wheel. Particularly challenging were the tasks involved in mining, as there was usually only a little water available to allow the water wheel to move pulleys and pumps up and down. In many cases in mining, the power was not available where it was needed, so it had to be transferred spatially.

Figure 6. Forging hammer driven by a water wheel (Tobiashammer, Ohrdruf)

Two activities in the Middle Ages contributed significantly to innovation in the collection and dissemination of knowledge: the monasteries and mining.

Monasteries

In many cases, the Christian orders held extensive lands. Since knowledge and further development in one monastery could be of use to other monasteries, this led to a great interest in innovations and knowledge sharing. The exchange on spiritual matters already existed within the orders and the good options available to record experiences in writing was a major contribution to spreading knowledge about the use of water power from monastery to monastery. The Cistercians were particularly masterful in this regard and the rules of the order even included details about locating monasteries at sites with good hydrological and hydraulic conditions. Within the order, some monks developed specific expertise from their specific job assignments, including the construction and operation of mills. As needed, appropriate experts would visit monasteries or other landowners to offer advice. Thus, knowledge came to be collected across regions and was often written down for the generations to follow. Given the large number of mills within an order, often even within a single monastery, it was worth training a qualified specialist to 'research' ways to optimise their efficiency; a single miller could never have been able to do something comparable.

Mining

Mining followed basically a similar path. The driving forces here were the relatively high profits that could be achieved in mining. However, the easily exploited veins metal ores and coal lying near the surface were quickly exhausted, in some cases already in ancient times. Deeper underground mining only became possible, if groundwater seeping into tunnels and shafts could be pumped out.

The Romans had already made use of muscle-driven pumps, but this was not sufficiently efficient for deeper deposits. In addition, the ore had to be lifted out of ever greater depths. The further processing required to turn ore into metal also needed a variety of energy-intensive work processes. Some of the special problems facing mining included deposits being located in mountains near watersheds with only very small amounts of water and with widely varying levels of precipitation. While grain mills could be built at strategic spots with plenty of water, mining was dependent on making hydropower available wherever the deposits were located. The power thus had to be mechanically transferred to these sites (Figure 7). For these special requirements, more and more powerful systems came to be devised to lift water from chains of buckets to piston pumps and hydraulic ramps. The low water volumes were offset by the greater leverage of a large-diameter water wheels. The seasonal differences in water availability were balanced by ever more extensive water storage and transfer systems. An outstanding example of this in Germany is the Upper Harz Water Regale, named a UNESCO World Heritage Site in 2010 (Ohlig, 2012). The drops available to the mining industry were generally quite large, so that the water could be used several times through multiple cascades driving different assemblies. In the Harz mining region around the Upper Harz Water Regale, the optimal use of the available water was organised on a regional basis. As this had significant advantages over purely local regulation, this idea was soon exported to other mining regions.

Figure 7. Waterwheel with artificial linkage for transmitting power to the pump (model demonstration, Upper Harz Water Regale)

Here, too, locally accumulated expertise was collected and exchanged across national through the various rulers or through financial incentives and subsequently adapted to new circumstances. The mining industry remained an important industry throughout the Renaissance and the modern age, although the importance of hydropower in mining declined with the introduction of the steam engine which was more flexible in various respects, even if the efficiency of these machines was initially quite poor.

RENAISSANCE AND EARLY MODERN ERA

The Renaissance and the early modern period saw the rebirth of a deeper interest in scientific and technical questions. On the one hand, the knowledge of the ancient world was once again rediscovered, read and translated. On the other hand, new observations, analyses and research into natural processes were carried out, even if they were partly against the commonly-held beliefs of the Church. There was a new in-depth understanding of the relationships in nature and new technical solutions were sought and found in many fields, including hydraulic engineering.

One of the outstanding people of this time was Leonardo da Vinci (1452-1519), who engaged intensively with general hydraulic questions but was also involved in very specific water construction projects. This period also saw the founding of constantly growing, self-sufficient cities which presented engineers with a large number of tasks to solve. These cities needed a supply of fresh water and a way to dispose of waste water, excreta and waste. First, it was often the experts from the mining who were advising the cities and building their water supply systems. In the Middle Ages, cities had mostly obtained their water from nearby surface waters and a large number of wells. However, as the population grew in the cities, the water quality deteriorated significantly due to inadequate waste disposal and the water had to be brought in from clean sources that were further and further away. Even if the exact processes were not yet clear, the relationship between a lack of cleanliness and hygiene and the plagues and other diseases came to be increasingly recognised. In some cities, further economic development also depended on a sufficient supply of good-quality water. In particular, cities that had been built on hills for improved defence now required technically advanced solutions to provide running water to the higher parts of the city where the rulers and ecclesiastical centres were usually located. Aqueducts and, more frequently, penstocks, as they were known in ancient times, came to be used. However, the penstocks were now being made from iron. The normal pipes without strong pressure were made of wood or ceramic (Figure 8).

Figure 8. Development of the pipe in the water supply from wooden pipes (rear) to clay pipes (centre) to cast iron pipes (front) (TechniKmuseum Neue Mühle, Kassel)

Land reclamation

The growing population and the lack of good farmland in Central Europe forced people to settle in more and more areas and to gain additional farmland from already populated areas. This led to a growing population along coastal zones and large river valleys. A continuous protection of the coastline, according to uniform standards, was a prerequisite for a lasting settlement of the coastal regions. Wet and swampy areas along the coast and in the river valleys were drained and dry regions were sometimes irrigated with elaborate systems. The systems were either created by the local rulers or guilds would build and maintain such systems.

Shipping

With the overall economic growth, trade with ever more distant regions began to grow. This regional and long-distance trade could only be operated economically with ships, since the road network had only been barely developed and was largely unusable for long-distance transport of goods. Even in antiquity and the Middle Ages, almost all of the German inland waterways saw vessel traffic in small boats for the local trade.

Long-distance trade also took place, but probably mainly in stages, with the participation of many traders and only comparatively small quantities. Trade increased in modern times to an ever-greater extent and took place over longer and longer distances. In particular, precious goods that were produced only in certain regions were being traded over very long distances. But ordinary goods for a wider circle of the population also experienced an ever-extending trade, resulting in ever increasing cargo volumes.

From boats for fishing and local transportation grew merchant ships that were adapted to the requirements of the busy waterways. The goods were unloaded and reloaded for long-distance transport and to overcome obstacles, such as mill weirs. In the course of this development in trade, existing ports and the associated stevedore facilities came to be enlarged and improved in the cities. Even local bottlenecks in natural waterways were increasingly overcome and, in those areas lacking natural waterways, canals were dug. However, the impact on the waterways initially remained localized because of the political fragmentation in Germany, but also because of wanting technologies. A systematic and large-scale development of waterways only began in the 18th century. However, there were a few exceptions, such as the Stecknitzfahrt, which at the end the 14th century established a connection between Lüneburg and Lübeck, largely to transport salt to the sea port. This connection between the North Sea and the Baltic Sea was Europe's first fully functional canal that crossed a watershed. The enormous costs could be covered by the lucrative salt trade.

Education

The next key steps in the development of engineering as a field were the invention of printing and the creation of universities dedicated to the applied sciences.

While the printing press with movable type had already become an economically feasible option with Johannes Gutenberg's invention in the middle of the 15th century, it took another 150 years for the printing press to be used in the field of hydraulic engineering in Germany. This made it possible for the first time to share the accumulated knowledge of individuals to a wider circle of interested parties. Better than in manuscripts and letters available in one or only a few copies, the knowledge could now be transported long distances over time and space. This created new possibilities for combining and comparing the knowledge of individual persons and regions. This was the beginnings of the generally accepted rules of technology in modern times. With the proliferation of technical books, it was possible to make use of the experience of others in addition to one's own practical experience, to weigh these ideas against one's own, to test them and thus increase one's own knowledge or even try out new ideas.

Thus, Jacob Leupold (1674-1727) collected the technical knowledge of his time in 10 volumes, with 3 books dedicated to hydraulics and one each to mills and bridge building. In 1755, Albert Brahms (1692-1758) published his book 'Anfangs Gruende der Deich und Wasser Baukunst' (Basics of Dike and Water Construction). In 1772, the first volume of 'Ausführliche Abhandlung der Hydrotechnik oder des Wasserbaues' (Detailed Discussion of Hydrotechology and Hydraulic Engineering) appeared, followed by the 2nd volume by Johann Esaias Silberschlag (1721 bis 1791), a Protestant pastor, secondary teacher and a royal engineering consultant for the Kingdom of Prussia. These two books could be regarded as the first hydraulic engineering textbooks in Germany, where the knowledge was systematically collected with specific instructions on how to implement it. A collection of short selected historical quotes from the hydraulic engineering literature of the last three centuries is offered by Deutsch (2009). This collection showed how just and how deep the knowledge in the fields of hydraulic engineering and water management already exited. It also showed that many of the problems of the time continue to exist to this day, such as preventing further development of floodplains to prevent flood damage.

As the demands for their expertise increased, more and more engineers came to be needed for the practical work, such that a systematic training of engineers began to develop in Germany from the end of the 18th century. Initially, this was done mainly in the context of the military corps of engineers, where the smaller German states, who could not afford such institutions, would access the experts from their larger neighbours who were hired specifically for certain projects. In those places, where technical training was offered, it was not initially specialised to particular areas of expertise. The technical training was viewed at the time as a key engine for industrialisation.

Today's Technical University of Braunschweig has roots going back to 1745, but what was the Collegium Carolinum was initially considered to be a novel type of educational institution somewhere between the *Gymnasium* and the university and only later came to be regarded as a university in its own right. The Bergakademie Freiberg, founded in 1765, was likewise regarded as an important driver of innovations and trained engineers systematically, but it only became a 'technical university' much later.

In the first half of the 19th century, the German-speaking countries saw the establishment of various trade schools, polytechnics and technical universities. Within the borders of modern Germany, the cities of Berlin, Karlsruhe, Munich, Dresden, Stuttgart, Hannover, Braunschweig and Darmstadt were the first to have such institutions. All of these cities remain home to important technical universities. The cities were at that time, in each case, the capitals of the kingdom, duchy or the like, where the smaller territories often had major problems providing long-term financing to such institutions.

A special water management and hydraulic engineering specialization did not exist at that time, however. The topics were covered as part of civil engineering, if at all, which remains the case at most universities in Germany to this day. Today, hydrological topics, together with waste management and environmental aspects, are usually treated as a specialisation within civil engineering or, less frequently, environmental engineering. The training of hydrologists is distinct, as they are more often considered to belong to the natural sciences. Early on, there were different opinions about the distribution between the practical and theoretical aspects of the training. This has been preserved to this day in Germany with the division between (regular) universities and universities of applied sciences. These early universities and other educational institutions largely trained recruits for the civil service at first; few graduates went into their own practice or went into industry.

In 1898, the first hydraulic engineering laboratory at a university was built in Dresden, with most of the technical universities in Germany following suit by 1923. Germany was thus at the time the leader in experimental hydraulic engineering research with physical models. The experiments also contributed significantly to healing the division between the theoretical developments in hydromechanics and the practical developments in hydraulics and leading to the increased use of theoretical insights in the solution of practical problems.

FURTHER DEVELOPMENT IN THE COURSE OF INDUSTRIALISATION

From the middle of the 19th century, the scale of hydraulic engineering projects continued to grow as it became increasingly technically easier to build dams (Figure 9) on larger rivers, reservoirs with higher and higher dams and larger capacities (Figure 10), larger ship locks and boat lifts (Figure 11). Besides the necessary technical knowledge for the design and planning, the possibilities for implementing such projects such as the steam dredger (from 1800) and modern concrete (from 1824) also helped. Some construction projects only became possible with these innovations. Moreover, construction costs could also be lowered so that technically possible measures also became economically feasible.

Figure 9. 'Letzter Heller' barrage built on Werra around 1920 originally as the first barrage to connect the Werra and the Main

Figure 10. Edertal dam, gravity dam may of greywacke rubble, completed in 1914

Figure 11. Old ship hoist at Henrichenburg (float lift), completed in 1899

It turns out that some inventions often required many decades until they found their way into everyday construction practices. Gravity dams for reservoirs, for example, were made of concrete only after 1945. It took over a century, from the invention of concrete, to find it entering the general practice. At the same time, the turn of the 20th century also marked an end to predominantly intuitive practices of engineering based on practical experience. Intuition and experience were increasingly complemented and sometimes eventually replaced by calculations, where the intuition needed to be confirmed by the relevant expertise and intensive observation of nature. Since the formulas used in calculations always describe only a part of the natural process, negative consequences of unreflective, practical application are inevitable. As in previous centuries, much had to be learned from failures for new, better solutions to be sought. The possibilities of ever more accurate calculations could significantly reduce the required number of tests needed to identify the optimal solution.

For the further improvements in the 20th century, such as the development from purely hydraulic, simplistic assessment to consistently more and more physically accurate calculations were needed. Later, the movement of solids in the form of bed load and suspended solids were added to the field's work on the movement of water. Previously missing ecological components were added to water quality models and social and monetary aspects came to be included in decision-making processes. This way, intuition, experience and knowledge of individuals are once again being systematically used for new plans. Many projects have also become so complex that they can no longer be completely managed by a single individual or an individual discipline, such that their individual experience and intuition is pushed to its limit.

The high quality of many old engineering plans built with a lot of intuitive knowledge is demonstrated by the fact that some systems have been in use for centuries, such as the Chebar dam (Figure 12) in Iran, which has been operating for 700 years. Likewise, old ideas are being taken up once again, such as the flood protections used in the ancient city of Petra (Figure 13). These examples have shown that the ancient knowledge of the engineers remains important and that this historical knowledge can improve our current solutions.

Figure 12. Historic dams: the 700-year-old Chebar dam, a combination of weight and arch dam, in Iran had a height of 22 m originally, the 3 m high concrete bar was added during rehabilitation work about 30 years ago

Figure 13. The flood protection wall modelled after the ancient original in the city of Petra, Jordan, with the wall keeping back flash floods in the neighbouring valleys

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CHAPTER – 13

Sustainable Irrigation in South Africa: Evidences from History

Lani van Vuuren [a]

INTRODUCTION

A net food exporter, South Africa has a robust and productive agricultural sector. Despite the fact that arable land is restricted to between 11 and 15% of the country (Van Niekerk, 1991), South Africa is one of the only countries in Africa that is considered nationally food secure. Agricultural activities range from intensively irrigated crop production and mixed farming to cattle ranching and sheep-farming in the more arid regions (Government Communication and Information System (GCIS), 2013/2014). Farming ranges from large-scale, commercial farms to small, subsistence farming activities. In 2021, the gross value of agricultural production was 377 317 Million R[1] (DALRRD, 2021).

In terms of irrigated agriculture, South Africa is among the top five countries in Africa regarding land area under irrigation, the other countries being Egypt, Morocco, Madagascar and Sudan (FAO, 2005). Various irrigation techniques are employed (Figure 1). Of the estimated 1.5 Million ha under irrigation (1.5% of total agricultural land), about 50 000 ha are smallholder irrigation schemes (DAFF, 2012). Irrigated agriculture, while being the largest single user of surface and groundwater in South Africa, contributes more than 30% of the gross value of the country's crop production (GCIS, 2013/14).

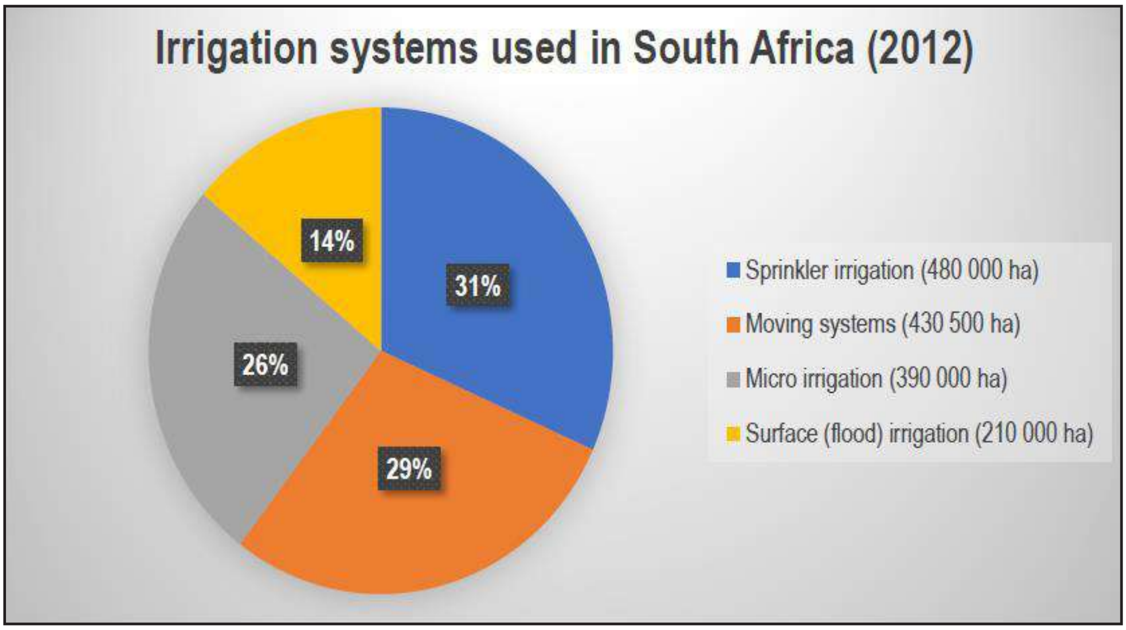

Figure 1. Main irrigation techniques used in South Africa (Van der Stoep and Tylcoat, 2014)

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1. R = South African Rand. 1 Rand = 0.059 US$ price level 2023

The country has an estimated 1.5 million hectares under irrigation

The importance of the sector, especially in rural areas of the country can be seen in the factsheet. According to the Statistics of South Africa, while the agricultural sector in South Africa only contributes 2.2% to the country's gross domestic product, the sector's contribution to employment is 5.2% (Stats SA, 2013). If the entire value chain of agriculture is taken into account, its contribution to GDP reaches approximately 12%.

An estimated 2.9 Million households or 20% of the country's population are involved in agriculture of some kind, which are mostly subsistence activities. South Africa mainly grows fruits and vegetables, tobacco, lucerne, wheat, cotton and sugarcane under irrigation (Backeberg *et al*., 1996).

An important consideration is the sustainability of these irrigation ventures. Sustainable irrigation requires that benefits are realised for the present population without compromising benefits to future generations (Backeberg, 1996).

SOUTH AFRICAN CLIMATE AND THE NEED FOR IRRIGATION

South Africa is blessed with a rich mix of natural and mineral resources, but not where water is concerned. As a result of its location at the southern tip of Africa between cold and warm sea currents, as well as its topography, the country has to endure an extremely variable climate over space and time, with droughts and floods being a regular occurrence (SANCOLD, 1994).

South Africa receives only about 450 mm of precipitation a year – well under the world average of 860 mm per year. The distribution of rain varies widely across the country, generally reducing from east to west, with 65% of the country receiving less than 500 mm a year (DWA, undated). The total runoff of all of South Africa's rivers (approximately 49 Million m^3/year) is about equal to the Zambezi River in the north of the country (Van Vuuren, 2009).

In addition, most of South Africa comprises a geologically warped plateau located more than 1000 m above sea-level. The country's few well-watered rivers that rise at the escarpment and flow eastwards towards the Indian Ocean are relatively short and fall sharply (DWA, 1986).

The country's semi-arid nature results in much water being lost to evaporation, and in many areas evaporation from the surface exceeds the average annual rainfall. As a result, it is estimated that less than 9% of the precipitation that falls on the ground eventually finds its way into South Africa's river systems (Van Vuuren, 2009).

South Africa's climatic variability, along with the fact that precipitation often takes the form of intense summer thunderstorms over large parts of the country, has led to the fact that the country has few perennial rivers. South Africa also has few inland lakes and permanent snow caps to stabilise flow, while groundwater resources are generally meagre (SANCOLD, 1994). The dry western interior comprises almost entirely of episodic rivers that only flow following infrequent rainfall. With a per capita water availability of only 1 200 m^3 per capita per year, South Africa is considered a water scarce country (DEAT, 2006).

This water scarcity has been verbalised for centuries in South Africa, but became an important concern as the country started to expand its economy in the 19th century – first through agriculture and later on the foundation of its mineral resources, followed by industrial development (Backeberg and Groenewald, 1995).

It is due to these climatic constraints that South Africa has focused on irrigation as a means of increasing food and fibre production. In many irrigation schemes, large storage reservoirs have had to be constructed in addition to irrigation canals to stabilise supply in times of need. These dams typically store two to three times the mean annual flow of the rivers on which they are constructed. The country's 320 largest dams, many of which were partly or wholly constructed for irrigation purposes, together store some 66% of the country's mean annual runoff (DEAT, 2006). South Africa is also one of the only countries in Africa to make extensive use of inter-basin water transfer schemes. An estimated 3 000 Million m^3/year of water is moved in this way from catchments of water surplus to areas where more water is required (DWA, 2010). The country also imports water from neighbouring countries as in the case with the Lesotho Highlands Water Project, which supplies water to South Africa's economic heartland, Gauteng.

A COMPACT HISTORY OF IRRIGATION DEVELOPMENT IN SOUTH AFRICA

South Africa cannot boast an ancient irrigation history such as Syria, Egypt, Iran and Turkey, yet irrigated agriculture forms an important part of the country's agricultural sector. The combination of influences varying from traditional African to European, combined with the country's unique agricultural challenges makes for an interesting history.

Irrigation prior to European settlement

The Southern tip of Africa has been continuously occupied by humans for nearly two Million years. In South Africa, the remains of the oldest anatomically modern humans have been discovered dating from around 100000 years ago (Van Vuuren, 2012). These early modern humans were hunters, gatherers and fishers. Around 2000 years ago some of these hunter-gatherer groups evolved into hunter pastoralists, when they acquired livestock such as sheep and horned cattle (Van Vuuren, 2012). They were later joined by evolving iron-using farmers crossing the south of the Limpopo River – the northern border of modern-day South Africa – around 350 to 450 years ago. Settling in the wetter, eastern parts of the country (where annual average rainfall exceeds 200 mm), these communities practiced agro-pastoralism. Yet, while these settlements often stretched over kilometres, housing as many as 10000 inhabitants, their historical irrigation practices largely remain unexplored (Van Vuuren, 2012).

At first it was thought that these early farmers only practiced dry land farming, but from research undertaken by Tempelhoff (2008) and others, we now know that they applied traditional forms of rainwater harvesting, water storage and irrigation. Traces of pre-colonial irrigation works have been reported at various sites from Limpopo to the Drakensberg escarpment. In 1956, anthropologist AC Myburgh uncovered a pre-colonial irrigation site, a farm near Carolina, in Mpumalanga (Tempelhoff, 2008). There were a number of canals on a fairly level tract of land and a dam of sorts had been built to store water from a small nearby stream. Consequently, a floodplain was formed and water could be siphoned through the lands.

Other traditional forms of irrigation and drainage, such as stone terracing, are still practised in parts of South Africa by rural communities. For example, in Gogela Village, in rural KwaZulu-Natal, terraces, which could be as high as a metre, have been constructed to arrest and divert surface runoff (Denison and Wotshela, 2009). These stone walls, geared for water-flow management and soil preservation, are usually stacked at the base of slopes or downhill areas.

Figure 2. Traditional stone terracing being practiced in Gogela Village, KwaZulu-Natal. (Denison and Wotshela, 2009)

Irrigation during Dutch and British occupation

South Africa's first 'modern' irrigation systems were installed during the occupation of the country by Dutch and British settlers in the 17th century. When the Dutch East India Company, at one time the richest corporation in the world, made the decision to establish a halfway station at the Cape to serve its ships travelling to and from the East, European-style furrows were constructed to irrigate food gardens with water from the rivers of Table Mountain (SANCOLD, 1994). By 1661 irrigation reached such an extent that the Dutch East India Company issued a *Placaat* or ordinance forbidding the use of certain streams in Cape Town for irrigation (Kokot, 1948). A century later, water demand had become so high that water restrictions had to be enforced, forcing irrigators to restrict their water use to four hours a day. Thus, the limitations of South Africa's water resources were realised early on in its development.

As the Cape settlement continued to grow and European settlers began to move from the Cape Coast to the dry interior, trading in their pastures for livestock and hunting rifles, the frontier expanded ever northwards and eastwards. These *trekboers* (translated as nomadic farmers) as they became known, found their surroundings to be largely arid and settlement was mostly concentrated around groundwater springs and a few perennial rivers (Beinart, 2003). Springs were later dammed to provide water for livestock while rudimentary furrows were led from streams to irrigate household gardens and small plots.

In 1806, South Africa became a permanent part of the British Royal Empire, with British rulers bringing with them their newly-found engineering expertise. In 1820 they also brought British settlers who, it is hypothesised, stimulated private investments in dams. These immigrants would have been accustomed to dams as a legitimate form of water infrastructure as it was by then firmly established in Britain to serve the Industrial Revolution, particularly to feed canals and riverside factories (Turpin, 2008).

The British government at the Cape was, however, initially reluctant to invest in their new African colony and early initiatives were instead taken by European missionaries and individual farmers (Backeberg and Groenewald, 1995). One of the most ambitious irrigation infrastructure schemes attempted during this period was the Hankey Tunnel constructed by William Philip of the London Missionary Society. This 228 m-long, hand-dug irrigation tunnel, completed in 1845, was the first of its kind to be built in the country, and led water from the Gamtoos River through the Vensterhoek mountain to water irrigation lands on the other side (Malan, 1970). While no longer in use, the Hankey Tunnel has been declared a historical monument.

Another innovative irrigation initiative was the use of water wheels or *bakkiespompe* (literally translates as 'bukket pumps') used in irrigation schemes such as Kakamas located on the Lower Orange River. The original canals were hand dug by members of the local labour colony operated by the Dutch Reformed Church (Hopwood, 1922a).

Figure 3. Remnants of the original water wheels can still be seen at Kakamas irrigation scheme on the Lower Orange River. (Lani van Vuuren personal collection)

In addition to importing European water engineering technologies, the descendants of the first European settlers also adopted traditional African technologies. A traditional water storage method that not only survived the arrival of European settlers but was adapted and used extensively by them was that of *saaidams* (loosely translated as 'sowing' or 'planting dam'). From the 18th century, farmers in the arid Northern Cape were particularly fond of this system of constructing low (one metre to two metre) earthen walls across large, shallow basins to retain floodwater over large tracts of land to plant grains and later lucerne (Hopwood, 1922b). This technology is still in use today over the more arid parts of South Africa.

From the 1860s, the discovery of diamonds and gold provided significant impetus to bulk water infrastructure development in South Africa. Newly sprung towns such as Kimberley and Johannesburg – located close to mineral deposits rather than water resources – suddenly required reliable water supply for thousands of newcomers from all over the world searching for riches and glory, while the demand for foodstuffs found farmers searching for innovative ways to improve their yield (Van Vuuren, 2012).

Figure 4. The diamond fields in Kimberley in 1870. The discovery of gold and diamonds offered a new market for farmers as mining towns sprung up overnight. (National Library of South Africa image collection)

The British government appointed the country's first hydraulic engineer, John Gamble, in 1875, and he travelled the country dispersing engineering advice to municipalities and farmers alike, with many of his designs later being constructed (Van Vuuren, 2012). This was followed in 1877 by an Irrigation Act, which provided loans to farmers for water resource development for agricultural purposes as long as they organised themselves into so-called irrigation districts. This distinct event in South African history – which led for the first time to the more formal organisation of the country's agriculture – marks the beginning of modern irrigation in South Africa (Backeberg and Groenwald, 1995).

An interesting stimulus to the South African irrigation sector was the emergence of the ostrich feather export market in South Africa to feed the fashion stores of Europe. When these wild African birds were paddocked to meet the global demand for feathers for the fashion industry, irrigation had to be employed to grow their preferred fodder – lucerne. In the early 19th century, ostrich feathers were the fourth-largest export product in the Cape – after gold, diamonds and wool, and by 1910 ostrich numbers had reached 800000 (Van Vuuren, 2010). Overall, these irrigation schemes remained small and rudimentary, employing mostly surface irrigation methods.

Figure 5. Paddocked ostriches in the Port Alfred district, 1911. (National Library of South Africa visual collection)

The emergence of state irrigation schemes

Investment in large dams and irrigation schemes would only follow the collapse of the ostrich-feather industry at the start of the First World War (1914-1918) with large-scale investment by the South African Union government, established in 1910, and its associated irrigation laws. During this period in South Africa's development, 96% of all water consumed in the country was used by stock watering and irrigation (DWA, undated). Farmers were encouraged to create irrigation boards during this period, who could then apply for government loans and access engineering expertise to construct irrigation schemes or drill boreholes. South Africa's first large dams (all exclusively for irrigation purposes) were constructed during this peak period, including Hartbeespoort Dam (59 m high), Kamanassie Dam (41 m), Sundays River Dam (34 m), Lake Arthur (38 m), Grassridge Dam (24 m) and Tygerpoort Dam (20 m) (DWA, undated). By 1925, 27 large dams had been constructed in South Africa – nearly all linked to irrigation schemes.

Figure 6. The Hartbeespoort Dam was originally completed in 1923 and raised through the addition of sluices (pictured) in 1970. (Lani van Vuuren personal collection)

It was the period following the First World War and prior to the Second World War (1939-1945) that the country's largest irrigation schemes were constructed (three of which will be discussed in more detail in the case studies below). These irrigation schemes had a dual purpose – to address the country's joblessness caused by the after-effects of the Great Depression and a prolonged drought period and, to settle returning soldiers following the war. As a result, these schemes used manual labour almost exclusively, resulting in the construction of large labour camps (Union of South Africa, 1935). These projects were heavily government subsidised. It is interesting to note the sizes of plots given to farmers on these government schemes – size was often determined by 'doubling the area which could be cultivated with one span of draught animals' (Bruwer, 1991). These older schemes were often laid out as near rectangles or squares, without taking soil boundaries into consideration.

Figure 7. Construction of an irrigation canal for the Marico-Bosveld scheme in 1932. Note the exclusive use of manual labour. (Lani van Vuuren private collection).

As South Africa's industrial and mining economy grew exponentially in the post War-period so did the number of dual-purpose bulk water infrastructure schemes in line with the international trend. Irrigated agriculture was no longer the sole recipient of the benefits of the large dams and related infrastructure. The high growth in demand for water from the mining, industrial and urban sectors highlighted the limitations of available water resources, resulting in Government efforts to start curtailing the often-excessive water use of the irrigated agriculture, which was seen by many as a 'waster' of water (DWA, 1986). One way in which this was done was to upgrade and improve many of the old historic irrigation schemes (Bruwer, 1991).

By 1970, South Africa's dam had a total storage capacity of around 20000 Million m^3 (storing 40% of the country's total runoff). The country now had 104 dams, each with a capacity of more than 5000 Million m^3 (Van Vuuren, 2012). While the construction of bulk water infrastructure schemes slowed down considerably in South Africa after 1970s, some notable inter-basin transfer schemes were constructed, including the Orange-Fish Tunnel and the Lesotho Highlands Development Project (Turton *et al*., 2004).

South Africa's democratisation in 1994 hailed a new era for the country with a strong focus on the equitable and sustainable use and management of water resources. Government's focus has moved away from the construction of large bulk water schemes towards optimisation of existing use. This means conserving water through the irrigation process, reducing water losses in water storage and distribution systems to using water more efficiently on farm. Many former irrigation boards have now become water user associations, becoming more inclusive of catchment water users and decentralising the management of water resources. With most of the country's available water having been allocated, the South African government, through the Department of Water and Sanitation is now considering the re-allocation of water from the agricultural sector, to activities with a higher economic value, such as mining and industry (Van Rooyen *et al*., 2011).

SUSTAINABILITY OF IRRIGATION SCHEMES – THREE CASE STUDIES

While South Africa has numerous successful irrigation schemes, the following three case studies represent a good sample of the typical sustainability issues that these scheme face.

Vaalharts Irrigation Scheme

The land located at the confluence of the Harts and Vaal rivers on the border of what is now the North West and Northern Cape provinces was first sited as a potential location for an irrigation scheme by surveyors in the late 1870s, and efforts were made to survey the area (Louw, 1980). In the years to follow, the potential of establishing an irrigation settlement at that location was discussed in various government fora, but it was only in 1925 that investigations started in earnest (Turton *et al*., 2004). The scheme finally received the go-ahead in 1933. The scheme infrastructure consisted mainly of a weir and a series of concrete-lined canals purposely constructed through labour-intensive methods in order to provide employment during the years of economic depression. The first plots were ready for occupation in 1938. By 1940, there were 304 settlers on the scheme (Bornman, 1988).

The 750 m-long Vaalharts weir is a concrete barrage-type structure, with a height of 11 m. Three sluice gates of 8 m by 6 m have been built into the weir. In 1967, the weir was raised by 1.2 m to increase the storage capacity to 48.7 Million m^3 (Van Vuuren, 2010).

Vaalharts comprises two main canals – a North Canal and a West Canal. In total, the network of canals covers a distance of more than 100 Km supplying water to more than 1 800 abstraction points through pressure regulating sluices. With a scheduled area of 29 181 ha, Vaalharts is the largest irrigation scheme in South Africa (Prins & van Niekerk, 2020).

Figure 8: The Vaalharts Weir
(Lani van Vuuren private collection)

At the start of the scheme basic housing was provided. Probationary lessees received livestock and production material, seed and fertiliser. In exchange, these new farmers had to give the state a percentage of their harvest for the first four years. After the four years had expired, farmers had the option to purchase their plots. Through the decades many of these initially small plots have been consolidated into larger, privately-owned, farming units, ranging up to 75 ha in size (Verwey and Vermeulen, 2011).

Little was known about which crops would be most suitable and in the early years of the scheme, farmers mostly grew lucerne, ground nuts, potatoes, grains and vegetables. Today, farmers also grow pecan nuts, cotton, olives, citrus, apricots, grapes, watermelon and peaches (Van Vuuren, 2010). All major forms of irrigation are used on the scheme, including surface irrigation, sprinkler and micro irrigation.

The scheme has a current water quota of 9140 m^3/year. Despite its age the scheme is invaluable to the economic growth of the Northern Cape province, contributing 14% of the total agricultural output of the province and sustaining 7 500 direct jobs. The scheme also provides water to the towns in the area (Van Vuuren, 2010).

The scheme has experienced issues with salinization (Van Rensburg *et al*., 2012). Natural surface and sub-surface drainage was historically poor due to the flat gradient, and typical soil profiles. The raising of the groundwater table from an initial 24 m to about 1 m due to irrigation resulted in waterlogging and increased salinity in the root zone of crops (Herold and Bailey, 1996). To overcome this problem a comprehensive system of 240 sub-surface drainage systems were installed between 1976 and 1979, and the feeder canals were lined with concrete (Verey and Vermeulen, 2011). These drains successfully controlled the groundwater table and greatly improved crop production (Herold and Bailey, 1996). Other improvements, such as rehabilitation of irrigation canals, and improved irrigation systems have also assisted in decreasing the salts.

The Vaalharts Water Association (Vaalharts Water) took over the water management of the management of the scheme from the South African government in 2003. Like many irrigation schemes in South Africa, Vaalharts works on the demand basis. This means that farmers only receive water once they order it. Farmers order water from Vaalharts Water through a *segman* or farmer representative. This system is quite unique in South Africa. There are 240 such representatives at Vaalharts (Van Vuuren, 2009b).

Vaalharts is one of many irrigation schemes in South Africa applying the ICID award winning, locally-developed, computerised Water Administration System (WAS) to assist in its water distribution. In the first year after implementing the programme, the scheme managed to decrease water losses from 32% to 26.7%, a significant achievement considering most of the infrastructure has been in operation for over 60 years. Ageing infrastructure is a challenge, particularly water loss control, and ongoing rehabilitation is required to keep the old weir and canals in working condition (Van Vuuren, 2009b).

Lower Olifants River irrigation scheme

Known today for its rooibos tea and wine, the hamlet of Clanwilliam lies at the foot of the Cederberg Mountains near the West Coast of South Africa. Regarded as one of the ten oldest towns in South Africa, Clanwilliam's beginnings go as far back as 1660 when a team of Dutch explorers first reached the Olifants (translated as 'Elephants') River. The first farm in the Olifants River valley was awarded to Pieter van Zyl in 1732 and by the late 18th century small-scale irrigation was well established (Van Vuuren, 2010b). As the years progressed, more farmers started settling in the area, using various irrigation initiatives, including steam pumps, windmills and water wheels.

In 1911, the South African government approved the proclamation of an irrigation district in the area and plans began for the construction of a weir and associated irrigation canals. The Bulshoek Weir, designed by British-born irrigation engineer, FE Kanthack, was constructed from masonry in the Roman design style, featuring 15 hand-operated gates. Following lengthy delays due to the outbreak of war and Spanish Influenza, the scheme was eventually completed in 1920.

When the demand for water by irrigated agriculture in the area started outstripping supply, plans were made for the construction of a large dam at Clanwilliam. At the height of construction around 800 workers laboured on the Clanwilliam Dam, and the dam was eventually completed in 1935. The original structure was a mass concrete gravity dam with a centrally situated overspill section, 117 m long, but was raised between 1962 and 1964 to its present height of 43 m, with a capacity of around 122 Million m^3 (Van Vuuren, 2010b).

Today, the Lower Olifants irrigation scheme as it is known comprises the Bulshoek and Clanwilliam dams, as well as a main canal split into a left bank canal of 136 Km and a right bank canal of 123 Km. A total of 1052 sluices are used to draw off water for a scheduled area of 9510 ha. The scheme is operated by the Lower Olifants River Water User Association (LORWUA), which has been in operation since 2001. The scheme is subdivided into eight sub-districts or wards managed by seven water control officers. Each water control officer serves around 150 clients (Van Vuuren, 2011).

Figure 9: One of the canals in the Lower Olifants River irrigation scheme. (Lani van Vuuren private collection)

Apart from a betterment scheme in the 1960s which saw the canals being lined with concrete, the canal system has had no major refurbishment. Yet this antiquated system is hardly obsolete. The semi-arid region receives only about 152 mm of rain per year, and without the system no irrigated agriculture would be possible. Irrigated agriculture is by far the largest employer here, and the Lower Olifants scheme supports a burgeoning wine and table grape sector, supplemented by other produce such as tomatoes, vegetables, deciduous fruits and citrus (Van Vuuren, 2011). Apart from commercial farmers, the canal system also feeds an emerging farming community at Ebenhaeser, agriculture-related industry as well as seven small towns dotted along the West Coast.

This scheme also uses the WAS system. Here, irrigators request their water through strategically placed post boxes dotted across the scheme. Water allocation periods run from Mondays 06:00 to 06:00 the following Monday. The Lower Olifants River scheme is rather unique in the country in that it runs at six-hourly intervals for the calculation of water distribution rather than the usual 12 hours. The scheme also operates on a 'revolving chance' system, meaning that farmers are not allowed to order water with the same starting day every week (Van Vuuren, 2011). This is done to ensure the maximum volume of water is placed in the canal without exceeding the maximum abstraction right.

A significant challenge for this scheme is the fact that it is currently over-scheduled, and that the canal is physically too small to transport all the water required (Van Vuuren, 2011). In addition, the capacity of the Clanwilliam Dam is inefficient to meet the water requirements of the scheduled area. While the yearly water quota is 12 200 m^3/ha, the limited capacity of the canal allows for a maximum extraction rate of 325 m^3/ha each week, resulting in an annual deficit of 55 Million m^3 (Holtzhausen, 2006). Between October and middle-May, the scheme is only able to supply 8200 m^3/ha. As a result, irrigators have had to become more water efficient. Surface irrigation on the scheme has largely been replaced by drip irrigation, resulting in substantial water savings per hectare.

Despite these challenges, the water user association has managed to reduce water losses from 48% (in 2002) to 24% (2011), mainly due to improved irrigation scheduling (Van Vuuren, 2011). Water is now mainly lost to breakages and leaks in the system. Evaporation out of the canals caused by hot temperatures and winds also contributes to water losses. Plans to raise the Clanwilliam Dam are well advanced, although most of this additional water will be used to support smallholder irrigation (Holtzhausen, 2006).

Loskop irrigation scheme

Another of South Africa's largest irrigation schemes is also located on an Olifants River. However, this river is located on the South African Highveld, in the province of Mpumalanga. The river was originally surveyed by state surveyors for the potential of establishing an irrigation scheme at the turn of the 19th century where three potential sites were identified, including a site on the farms Vergelegen and Loskop in the Olifants river gorge (Turton *et al*., 2004).

Following repeated requests from the growing farming community in the district, the Loskop Dam and associated canals were constructed between 1934 and 1945. At the time of its construction, Loskop Dam was the largest single concrete structure in South Africa, and is still considered large by international standards. Like so many other state construction projects at the time, the Loskop irrigation scheme was also a labour-intensive project. According to reports of the time, life on this scheme was certainly not dull as labourers often had to fend off curious crocodiles. As the area is known for its hot summers, the most precious piece of equipment on the construction works was the ice-making machine (Anon, 1976).

The Loskop Dam comprises a mass concrete gravity wall with an ogee crest spillway. The original dam wall was 45 m high, but was raised in 1979 to 54 m. A note of interest is the fact that the ashes of the original Resident Engineer, Lt Col DF Roberts, are buried in the dam wall (Van Vuuren, 2008). The dam wall incorporates an interesting technical feature in the form of splitters on the lower face of the overspill section of the wall. These flat-topped concrete projections are about 8 m down from the top where they split up the sheet of overspill waters as they flow down the face of the dam. This helps to minimise scour to the concrete below (Anon, 1976).

Figure 10: Loskop Dam on the Olifants River. (Lani van Vuuren private collection)

There are 495 Km of concrete canals, including two main canals of 96 Km (Left Bank) and 60 Km (Right Bank), respectively, with the remainder being branch canals. During peak periods, up to 33000 m^3 of water per hour can be delivered by the Left Bank Main Canal (Loskop Irrigation Board, 2015).

Loskop irrigation scheme is the second-largest irrigation scheme in South Africa. At present, the scheme comprises a scheduled area of 16,117 ha, divided into 702 properties. At the allotment of a full water quota 7,700 m^3 of water per hectare is allocated. Wheat, vegetables, tobacco, peanuts, cotton and citrus fruit are cultivated, many for the export market. The scheme is managed by the Loskop Irrigation Board, a private body. Loskop was the first irrigation scheme in South Africa to make use of the WAS water management system.

Unlike the two schemes above, the greatest challenge to the sustainability of the Loskop irrigation scheme is not the quantity of water or the age of the works, but water quality. The dam receives poor quality water from upstream industries, mines and human settlements, and as a result is showing signs of becoming hypertrophic (Van Vuuren, 2010). Massive fish kills have been experienced in the last few years, with great concern being expressed over the falling numbers of crocodile and terrapin populations. The Loskop Irrigation Board has been working with the Olifants River Forum and other stakeholders in the catchment to collectively find solutions to this issue and improve water resource management in the catchment (Van Vuuren, 2013).

CONCLUSION

Like other agricultural sectors in the world, the South African sector also faces the challenges of producing more food with limited resources to feed a growing population. The availability of water has been singled out as the most important factor that limits agricultural production in South Africa (WWF, 2014). As demand from other sectors of the economy places more pressure on the country's scarce water resources, South Africa's farmers will have to find new ways of not only remaining sustainable, but producing more with less. New developments, such as improved irrigation technologies and irrigation scheduling are eagerly implemented.

The country's irrigation history has shown that South Africa's farmers are innovative and adaptable to difficult circumstances. The case studies presented here demonstrate that sustainable irrigation is achievable through adoption to changing markets, changes in investment and adjustment in the size of farmers as well as in the size of farms as well as improvements in management (Backeberg and Groenewald, 1995). Through the support of knowledge producing agencies such as the Water Research Commission in partnership with universities and state research councils, such as the Agricultural Research Council, the sector is poised to remain a cornerstone of the South African economy.

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CHAPTER – 14

Can the Dutch Keep their Polders Dry? Impact of Changes in Land Use and Climate on Water Management and Flood Protection of the Polders in the Netherlands

Bert Toussaint [a] and Bart Schultz [b]

In recent years, there is, especially in relation to climate change, quite some discussion on what the low-lying Netherlands might expect in the field of water management and flood protection. Although changes in land use and land subsidence play a significantly greater role, there is almost no discussion on these aspects.

In this chapter a brief outline is given of the developments in the Netherlands since the first interventions in the landscape by our distant ancestors. Attention is paid to the potential impact of climate change, land subsidence and changes in land use on water management and flood protection. Finally, there is an outlook in the future. Our conclusion is that technically we will be fully able to keep our polders dry for the centuries to come. However, the fundamental question is whether our society will continue to be able to take the required measures in time.

INTRODUCTION

Since its creation the Dutch landscape has undergone many changes (Schultz, 1982; De Bruin and Schultz, 2003; Van de Ven, 2004). About 1000 years ago, the surface level in the lower part of the Netherlands was at 2 - 3 m+MSL (mean sea level). Since about that time the first human interventions in the landscape took place in the Netherlands with progressive changes and nowadays the deepest polders are at about 6.5 m-MSL (Figures 1 and 2). Due to this, approximately two-thirds of the Netherlands would now permanently or regularly have been inundated if there would be no dikes and the water would not have been pumped out. The deepest parts are found in the drained lakes. These are reclaimed 'natural' lakes, or lakes that were formed by excavation of peat, which was used for fuel (Schultz, 1992 and 1993). Subsidence due to compaction and oxidation occurred mainly in the peat polders and therefore the soil here is now predominantly 1 - 3 m-MSL, which corresponds to an average subsidence of five meters. In particular, due to this subsidence and to a certain extent due to sea level rise, our country became lower and lower and excess water from the lower part has to be removed nowadays with drainage pumping stations. For the major part this is done by collecting and transport systems, and a level of about 0.50 m-MSL is being maintained since centuries. From there, the water is discharged to the North Sea, or the IJsselmeer and the main rivers. In the past, this discharge took place through discharge sluices, but increasingly drainage by pumping is applied.

In addition to these developments in the field of water management, huge changes have taken place in the population and land use, from predominantly natural and agricultural land, to far- reaching urbanization and industrialization. Due to this, in our polders, increasingly a diverse landscape has been developed where besides the water management, an optimal effectiveness has to be found based on the land use for agriculture, nature, recreation and urban areas. This requires at the local and regional level substantial efforts by our Water Authorities and at National level by the Ministry of Infrastructure and Water Management with its executive agency *Rijkswaterstaat*.

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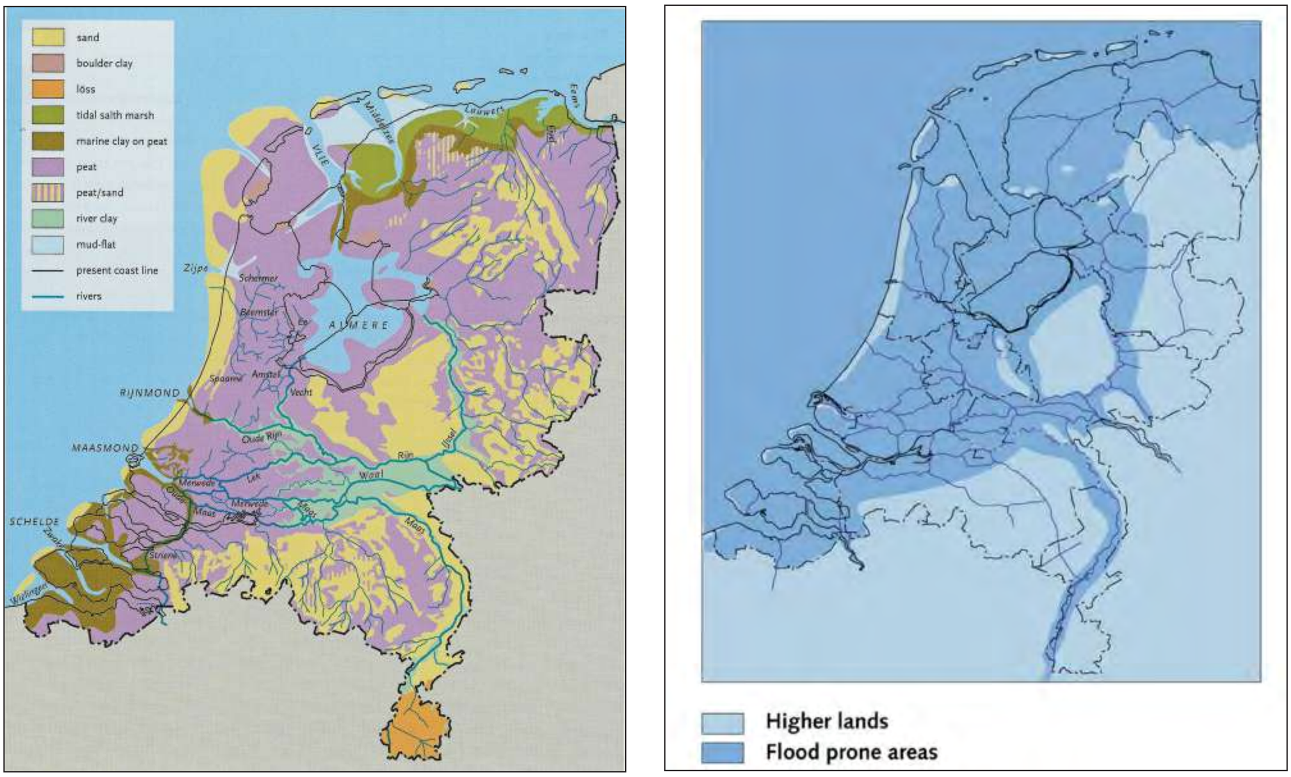
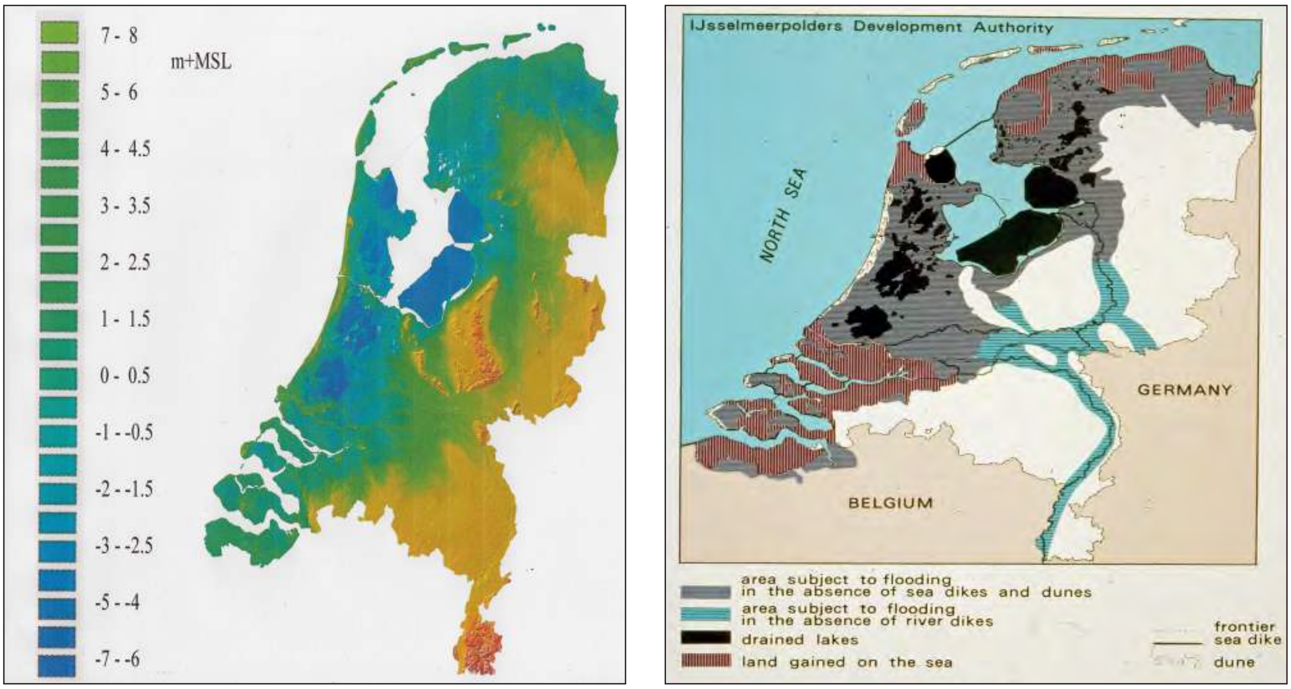


(a) (b)

Figure 1. The Netherlands about 1000 years ago (a). The surface level in the low part of the Netherlands was then 2 - 3 m+MSL. The flood prone part of the Netherlands (b) when nowadays there would be no dikes (De Bruin and Schultz 2002; Van de Ven, 2004)



(a) (b)

Figure 2. Current altitude in m+MSL (a) and polder types in the Netherlands (b)

In this chapter, attention will be paid to some characteristic developments that have occurred over the centuries in the lower part of the Netherlands. This continues with an outlook to the future.

FROM NATURAL TO DEVELOPED LANDS

If we look at the measures in the field of water management and flood protection that were taken through the ages, the following main stages could be distinguished:

- artificial mounds;
- dikes, drainage and discharge sluices;
- drainage;
- water quality control;
- integrated water management;
- integrated environmental management.

As our ancestors in the lower part of our land increasingly faced floods, they started to live on artificial mounds, while during floods the surrounding land was under water (Figure 3). These mounds were gradually raised. Most of them have been gradually excavated after the construction of the dikes, because they consisted of very fertile soil. However, the artificial mound of Hoge Beintum (pictured right) is still there and can be seen as an example of how the construction was in the past.

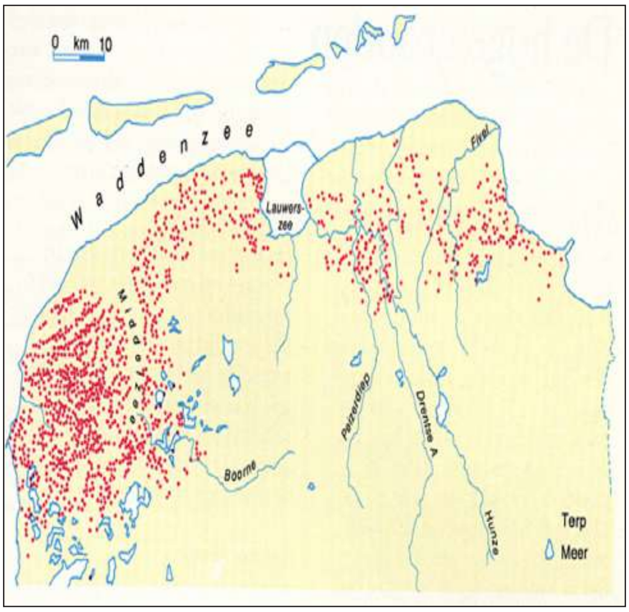


Figure 3. Artificial mounds in the northeast of the country (the red dots)

Equally important were the changes in the natural environment taking shape between the 9th and 16th century. A substantial part of the western and northern parts of the Netherlands was covered by peat bogs. These was areas were increasingly drained and cultivated, mainly responding to a steady population growth. Between year 800 and 1250, the Dutch population expanded from about 100,000 to 600,000 - 700,000 inhabitants. The drained peat lands created fertile farmland providing food supply for the growing population. Gradually, a number of villages developed into towns. A serious side effect of this draining process was a continuous process of land subsidence and oxidation. Consequently, the lowlands in Central Holland began to sink at a rate of about a meter per century (Figure 4). In the 11th century the construction of first local dikes started that later on were linked to the larger units.

This process was completed in the 14th century. The drainage of the reclaimed land mainly took place by discharge sluices that could be closed off at high outside water levels. Due to the lowering of the surface level drainage, pumping became mandatory. In this period, water management was directed at water quantity control, in particular at water-level management. This has in fact lasted until 1970.

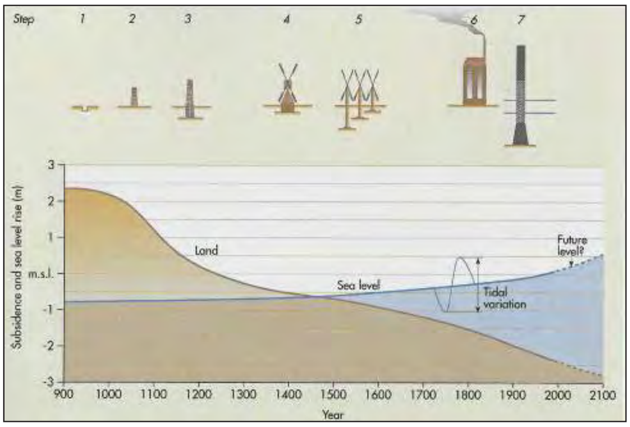


Figure 4. Sea level rise and soil subsidence between 1000 and 2000 (after De Jong et al., 1999)

In addition to these processes, peat mining was carried out on an increasing scale, as peat provided excellent fuel for the urban inhabitants. Around 1350, commercial peat digging became big business. Peat cutters were digging increasingly deeper, removing the thick peat cushions, and creating big holes that were filled with water and, over time, grew into lakes. In addition, the possibilities for drainage by gravity reduced as well due to the continuous subsidence and sea level rise. Consequently, arable farming often had to be abandoned or restricted, and cattle-raising was being developed instead. Due to frequent heavy western winds, water levels being stirred up by winds, daily wave movements, soil subsidence and shore destabilization, the peat lake shores eroded, increasingly creating flood risks. Not only farmland, but also complete villages submerged because of floods. Thus, intensive peat exploitation resulted in widespread ecological damage. Landscape degradation necessitated the population to switch to other or additional economic activities such as fishing, hunting, poaching and bird-catching.

The authorities were unable to respond effectively to these disastrous processes. In 1255, the first regional Water Authority had been set up, being responsible for the regional water management, followed by a myriad of other local and regional Water Authorities. These institutions were able to develop regional water management further, but they were unable to offer remedies for the landscape degradation caused by peat mining. On the contrary, Water Authorities commissioned to monitor peat-mining production often profited as they received the income from taxes levied on peat digging.

Land subsidence, oxidation and landscape erosion made the lowlands increasingly vulnerable to storm surges. The North Sea encroached on western and northern regions, creating and enlarging inlets that broadened to estuaries. One of these developed, after the 1170 flood, into the Zuider Zee. This new sea posed flood risks to the eastern and central parts of the country. Flood risks, thus, were multiplied and aggravated the dangers to the population. Between 838 and 1717, more than 40 major floods have been recorded (Figure 5). Regional dike constructions were undertaken at a large scale since the 12th century, but they were not always effective. The local communities were able to develop coping mechanisms during or after floods, transport by water and relief organization. In the river areas, farms were adapted to floods by building attics and other elevated rooms in their farms to protect their cattle. However, these measures obviously offered no structural solutions. The defence capacity against floods had to be improved. Concomitant with dike building, drainage capacity had to be substantially enlarged.

Figure 5. Map of flooded territory in northern-Netherlands due to the Christmas Flood, 1717

This existential challenge induced two major innovation processes: better sluice building technology, developed since about 1300, and more effective polder drainage technology, epitomized in the use of windmills. Windmills geared for the pumping of water, probably were introduced in 1408, became scattered over the polder lands and by 1500, 208 windmills were being used. They remained a crucial drainage tool until the mid-19th century, as the steam power pumping stations gradually took over. In the beginning of the 20th century, diesel and electric pumping stations took over the job. Better dike construction and more effective and better-organized drainage capacity enabled the Water Authorities to take over the offensive against the sea. Land gains began to outweigh land losses. Starting in the Middle Ages, land was being reclaimed from the sea. In the 16th century, 19 inland lakes were being transformed into farmland. These reclamations required special engineering techniques. First, a lake was circumvented by a circular canal, and a dike was constructed between the lake and the circular canal. Subsequently, windmills pumped out the water, discharging in the circular canal; from there it was transported into one of the rivers. Reclaimed land was further drained by constructing internal systems of tertiary, secondary and main drains.

In the 17th century, reclamation projects were initiated on an even bigger scale, funded by investment companies set up by rich merchants, who expected to make profits from farming products to be produced on the new land. Dairy products, vegetables and meat from cattle were sold to the booming cities. Regarded from a longer time scale, population roughly doubled between 1500 and 1800, from 900,000 to 2 Million. In the first half of the 17th century, 58 lakes, situated in the northern and western regions, were transformed into polder land. The most famous reclamation, due to its geometrical layout, inspired by renaissance symmetry ideals, was the Beemster polder, drained in 1612. Reclamation projects also induced important innovations. The Schermer polder had its water lifted in four stages, windmills lifting the water from lower to upper levels. Thus, height differences no longer formed insuperable obstacles to effective draining. Secondly, paddle wheels, being used in discharging the water, were increasingly replaced by open Archimedean screws, introduced in 1630, the latter having a greater lifting capacity (Figure 6).

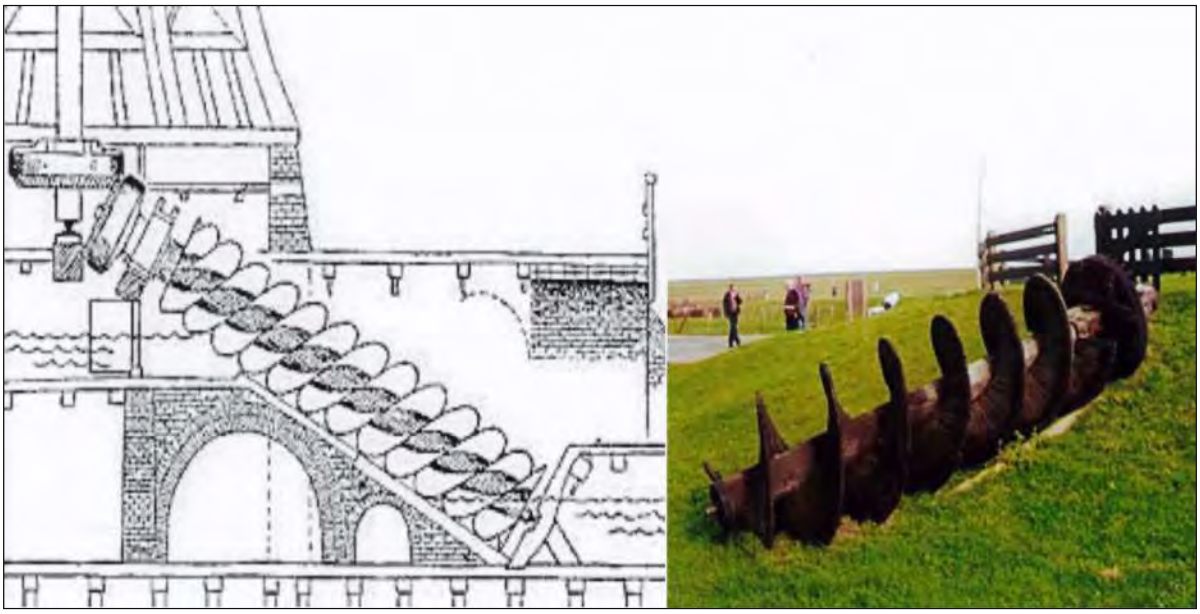


Figure 6. Archimedean screws, having a greater water lifting capacity than paddle wheels, made draining more effective

After 1650, the Dutch economy began to stagnate, urbanization began to reverse, and for a long period, no new reclamation projects were initiated. However, in the 18th and 19th centuries, the western provinces took the initiative to resume reclamation projects, aiming at reducing flood risks. In addition, in the second half of the 18th century, agricultural prices started to rise again, thus making reclamations potentially profitable. Population rose from 2 Million in 1800 to 5.1 Million in 1900. To respond better to big challenges - flood safety, infrastructure development and knowledge development - a new national water management organization Rijkswaterstaat, was founded in 1798. The new organization took a substantial share in reclamation projects. In the first decades of the 19th century, steam technology was being developed in order to enhance pumping capacities, enabling the draining of larger water surfaces than before. The most ambitious 19th century reclamation project, the draining of the Haarlemmermeer (1848-1852), was accomplished by the use of three huge steam power-pumping stations. Nowadays, the international airport Schiphol is located on this drained lake.

More than 300 years of reclamation efforts culminated in the development of the Zuider Zee polders. In 1891, the brilliant engineer Cornelis Lely drew up a master plan to close off the Zuider Zee by a 32 Km long Enclosing Dam (Figure 7). This plan would not only drastically improve flood safety, but would also transform the Zuider Zee into a freshwater lake. At the edges, four polders were planned, meant to contribute to the national food supply. As the 1916 flood had brought havoc in the region, and food shortages became acute in the course of the First World War and therefore Lely's plan was approved in 1918 by Parliament. Between 1927 and 1932 the Enclosing Dam was constructed, with the aid of hydraulic modelling and the mechanization of building techniques. Complexes of drainage sluices at both edges of the dam were constructed, enabling a controlled water discharge. It was a demonstration of the growing scientific impact on engineering, equally enabling the upscaling of engineering constructions. The polders were subsequently drained between 1930 and 1968. The latest polders developed, deviating from the 1891 plan, multifunctional features: agriculture, city building, recreation and nature development were put on at par.

Meanwhile, new dangers were impending. In 1908, measurements at the Rotterdam Waterway, the main entrance for ships heading to Rotterdam harbour, demonstrated an increasing salt intrusion, necessitating the closure of a freshwater intake point that provided the vegetable and greenhouse farmers with fresh water. In the next decades, salt intrusion steadily progressed in the main inlets and estuaries, with increasing socio-economic costs. Salinization progressed also in River Rhine, caused primarily by Alsatian potash mines, coalmines and steel plants in the Ruhr River Basin. In addition, salt intrusion in the groundwater became to a certain extent a problem, notably in the coastal dunes, where potable fresh water originating from River Rhine, since the late 1940s, was increasingly pumped in and after some time extracted

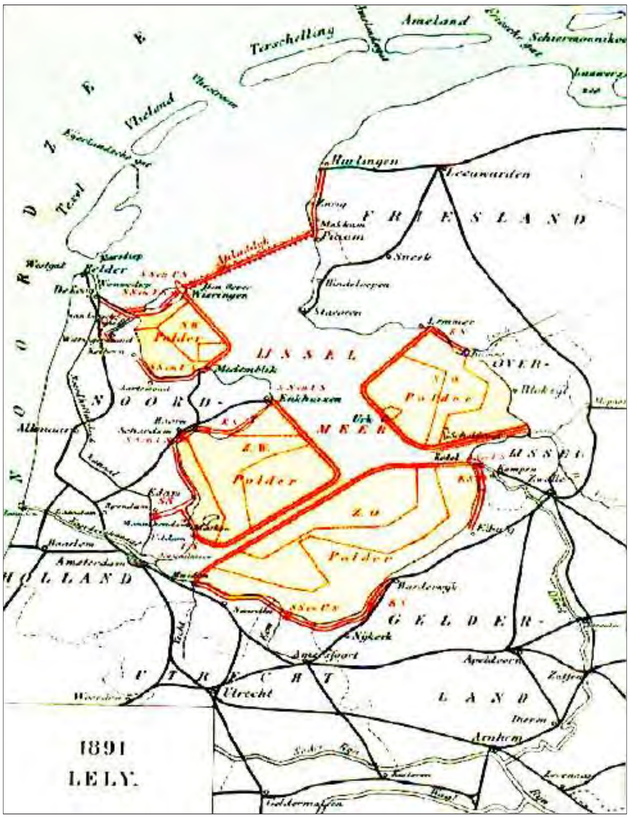


Figure 7. Lely's Zuider Zee scheme, encompassing an Enclosing Dam and four polders (left) and the closure of the last gap of the Enclosing Dam (1932) (right)

from the artificial fresh water pocket by drinking water enterprises. Industrialization and urbanization also heavily contributed to sewage problems and industrial pollutants. A new phase in sustainability management had begun. Since the Middle Ages, the balance of land gain and land loss, landscape degradation, land erosion and soil degradation had been main problems to be addressed by water managers aiming at a better sustainability. In the 20th century, deteriorating water quality became a prime concern. Fresh water preservation had become even more important, as the population growth sustained, from 5.1 Million in 1900 to 16.9 Million in 2015.

Rijkswaterstaat elaborated preliminary plans to close off estuaries in the south-western Province of Zeeland, thus simultaneously enhancing flood risk safety and creating new freshwater reservoirs. The recently created IJsselmeer, the former Zuider Zee, provided a key to a structural solution. Between 1940 and 1942, these plans were integrated into a master plan, meant to create a notational hydraulic system in order to safeguard sufficient national freshwater supply coupled with a reduction of flood risks in the western regions. Between 1954 and 1971, three weirs were constructed in the branch Neder-Rhine and Lek of River Rhine. The weir at Driel, situated near Arnhem, enabled a controlled division of River Rhine water between the branches Neder-Rhine and IJssel of River Rhine. As the latter branch fed the IJsselmeer, the weir at Driel ensured a sufficient fresh water flow to this lake at low river discharges (Figure 8).

Figure 8. The national hydraulic system, with the weir at Driel a controlled division of water of River Rhine between the branches IJssel and Neder-Rhine has been established, thus ensuring sufficient flow into the IJsselmeer

Whereas the problem of salinity and the strategic freshwater supply had been increasingly addressed successfully, the broader issue of water quality still posed huge challenges. Water pollution had been proliferating after 1945. Emissions from chemical and petrochemical plants, the agricultural use of fertilizers and pesticides and the growing popularity of detergents in households caused poisonous waste disposals. Poisoned fish and repugnant smells began to enter the senses and public opinion became activated in the early 1960s. A Rijkswaterstaat research institute standardized and expanded river water quality measurements. In 1964, the government presented the Surface Water Pollution Act to Parliament. The act introduced two principles: the polluter pays and pollution will be tackled at the source. Wastewater discharge required a permit and the discharge of polluting substance would be taxed. Thus, water had to be purified for the production of drinking water and to be made useful for industrial and agricultural purposes. In 1969, the act was approved and it became enacted the next year (Ministry of Transport, Public Works and Water Management, 1970). Purification stations, already being developed, proliferated after 1970. Rijkswaterstaat monitored the emission discharges in the main rivers, the North Sea, the Wadden Sea and the IJsselmeer. Water Authorities were assigned in the 1992 Water Boards Act with water quality management tasks in their territories.

Meanwhile, flood safety policies had been transforming in the aftermath of the 1953 flooding. Responding quickly to this disaster, that took 1,836 lives, a Delta Committee was inaugurated, commissioned with developing a master plan to prevent future flooding in the south-western region of the country. The resulting Delta Plan encompassed a scheme to close off a number of estuaries and other tidal waters, to construct parallel secondary dams in order to attenuate strong currents that might jeopardize the closure dam construction process and to build a storm surge barrier in the Hollandse IJssel, to protect the Central-Holland hinterland. In addition, a new set of safety standards was introduced. The design of the sea dikes and other flood defence structures would have to be able to withstand a storm surge level with a probability of flooding of 1/10,000 per year, the southwestern flood defence structures with a probability of flooding of 1/4,000 per year and most Wadden-islands with a probability of flooding of 1/2,000 per year.

The Delta Plan progressed more or less on schedule until the last, broadest and thus most difficult estuary was tackled, around 1970, to close off the Eastern Scheldt (Figure 9). This estuary had a very rich biodiversity and it was an important place for shell fishery. Combined opposition from environmentalist and shell fishery organizations was successful and a new, more environmentally friendly storm surge barrier was developed in the second half of the 1970s. This storm surge barrier included movable gates that usually would be open to tidal currents in order to maintain the ecological richness of the Eastern Scheldt. Only during storm surges, the gates are closed. During the design process, a variety of options had to be elaborated and impact on multiple interests had to be taken into account. The American think-tank, RAND Corporation, provided the project organization with a mind map, including a balanced score card, to enable an optimal decision-making process.

Figure 9. Delta project scheme (left), Eastern Scheldt storm surge barrier (right)

With the *First National policy paper on spatial planning*, published in 1960, a general framework for land use planning was offered for several decades until the fourth policy paper in 1988 with an addition in 1992. The *Fifth National policy paper on spatial planning* was submitted for approval to the Parliament in 2001. However, the government resigned, before this paper was approved. The third government headed by premier Peter Balkenende then ended the series and published the *National Spatial Strategy* in 2004, which was approved by Parliament in 2006. In this policy paper, the planning was extensively decentralized. In addition to the spatial planning papers, several other specific policy papers were published, such as the *National policy paper on rural areas*, of which three editions have been published, and the *National policy paper on urbanization*.

The integrative process, balancing flood risks, ecological and socio-economic impacts, had a substantial impact on national water management policy development. The 1987 United Nations Brundtland report '*Our Common Future'* was another influential source of inspiration (World Commission on Environment and development, 1987). The Brundtland Committee defined sustainable development as the kind of development that meets the needs of the present without compromising the ability of future generations to meet their own needs. This broad definition, balancing and interrelating economic development and environmental health, became a generally accepted conceptual framework.

More specifically in the field of water, four policy papers on water management have been published. Also in the Netherlands, water policy makers felt that a more comprehensive, integrative approach seemed necessary. In 1989, the *Third National policy paper on water management* was presented, introducing a water system approach and integrated water management (Rijkswaterstaat, 1989). Water was regarded as a multi-faceted system of subsystems (surface water, groundwater) and functions (transport, drinking water, ecological values, recreation and other functions).

Water management policy-making and implementation required a subtle balancing of these functions. In addition, spatial planning and nature development had to be connected. The *Fourth National policy paper on water management* (Ministry of Transport, Public Works and Water Management, 1998) and the report '*Water Management in the 21st century'* (Ministry of Transport, Public Works and Water Management, 2000) developed these views further. The latter policy document entailed a new approach to improve flood risk strategy and to tackle other related problems. Citizen-awareness to flood risks should be enhanced; a three- step flood risk strategy was introduced: retaining, storing and discharging water, spatial planning had to be focused on impeding economic or housing projects in the floodplains and international cooperation was to be intensified.

In the same vein, a new river management strategy was developed in the aftermath of the 1993 and 1995 near-floods: the Room for the River concept, adopted in 2000 by the Dutch government. This marked a shift from traditional flood risk measures heavily depending on dike strengthening to a much broader approach, aimed at increasing water discharge capacities during extremely high river stages. The latter are expected to materialize more often than in the past, due to climate change. Its aims are a peak flood level reduction of 20 - 30 cm, ecological restoration and nature development. More than 30 projects have been implemented, such as dike relocation, floodplain excavations, the construction of flood bypasses, the creation of flood storage capacity and, in a few cases, traditional dike strengthening. The Room for the River programme has been developed and implemented in a network approach, involving provinces, local governments and Water Authorities, and in cooperation with a variety of other stakeholders.

In the meantime, also in this case, a trend reversal has been made and the '*Fourth policy paper on water management'* was succeeded by the '*National Water Plan 2009-2015'* (Ministry of Transport, Public Works and Water Management, Ministry of Housing, Spatial Planning and the Environment and Ministry of Agriculture, Nature and Food Quality, 2009). This plan focused on adaptation of the water system to climate change challenges and on implementation of Room for the River and the Delta Programme, thus integrating flood risk safety and ecological aims. In December 2014 its successor, the *Draft National Water Plan 2016 - 2021* has been published (Ministry of Infrastructure and the Environment and the Ministry of Economic Affairs, 2014a). In this context, it was also important that the *Water Act* came into force in 2009. This law has replaced eight old water laws.

INTERNATIONAL DEVELOPMENTS

The development of a legal water quality framework and integrated water resources management was co-shaped by international developments, initially pivoting around the River Rhine. Drinking water enterprises initiated a Rhine water quality monitor programme. In the aftermath of the disaster caused by a gulf of poisonous effluents in 1949, the International Commission for the Protection of the Rhine (ICPR) was established in 1950 by Switzerland, France, Luxembourg, Germany and the Netherlands. The ICPR conducted water quality research and prepared international regulations. Under the aegis of ICPR, the Rhine states concluded agreements in 1976 and 1987 to reduce pollution, caused by harmful industrial effluents. The 1987 agreement was concluded in the aftermath of the Sandoz disaster, a fire in a Swiss chemical storehouse that produced huge amounts of poisonous water streaming into River Rhine and causing massive fish kills. The 1987 *Rhine Action Plan (RAP)* included as prime goals, a 50% reduction of emissions for many substances and the return of the salmon and other migratory fish species into River Rhine. These targets were reached at the end of the 1990s. With the adoption of the 1998 Meuse Action Plan, a similar water quality improvement scheme was outlined for River Meuse.

Figure 10. The Sandoz plant fire caused massive fish deaths in 1986

WATER FRAMEWORK DIRECTIVE

European Union water polices equally have had much impact on water management in the Netherlands, leaving their mark on both flood risk management and sustainable water management. In 2000, the '*Water Framework Directive' (WFD)* was adopted (European Union, 2000). WFD's main aim was to strive for a good chemical status and a good ecological status in the European waters, acquired in 2015. Aquatic ecosystems and the environment have to be improved by further reducing pollution and mitigating the impact of floods and droughts. To this end, river basin management plans had to be drawn up for the international river basins. Thus, the WFD induced further harmonization and internalization of integrated water resources management.

Prompted by the massive 2002 summer floods, the European Union issued a *Floods Directive* in 2007 that required concerted flood risk measures in the river basins and the coastal zones. Its aim was to reduce and manage the risks that floods pose to human health, the environment, cultural heritage and economic activity. Flood risk assessments were to be held by 2011, and for high-risk zones flood risk maps were to be drawn and flood risk management plans to be developed.

Thirdly, in 2008, a *Marine Strategy Framework Directive (MSFD)* was adopted. This policy document focused on sustainability, as it aimed to achieve a 'good environmental status' of the European Union's marine waters in 2020. To that end, a broad research programme has been drawn up.

The European legislation was increasingly crucial for policy making, planning, implementation and management. Following suit, the *EU Bird Species Directive* (1979), aimed at protecting 187 rare or endangered bird species, and the *EU Habitat Directive* (1992) protecting natural and semi-natural habitats with a rich biodiversity, had also an impact on Dutch water management policies. The areas related to both directives have been subsumed under a nature development network Natura 2000.

It was expected, however, that the Netherlands will go one step further in the future and that land use and water management planning will be fully integrated. We will then arrive at the stage of integrated environment management. All in all, our country is relatively well organised with respect to its measures in the field of water management and flood protection for the various forms of land use. However, constant attention and improvement remains a crucial requirement (Figure 11).

WATER MANAGEMENT IN POLDERS

For the design of the water management systems in the polders, primarily precipitation and evapotranspiration were of interest (Figure 12). In addition, the soil and land use played an important role (Van de Ven, 2004; Schultz, 2008). As far as the soil was concerned, distinction was made in clay and peat. With respect to the land use; agriculture, nature, recreation and urban areas were important. An essential distinction between the rural and urban areas was created by the paved surface, which covered a significant part of the urban areas, and of which the excess rainfall was channelled through sewer systems from where it was, whether or not, through a wastewater treatment plant, discharged to the receiving open watercourses.

Figure 11. Today the Netherlands has predominantly a rational parcellation, in which water plays an important role. This applies to both agriculture, cities and nature. The water level can be accurately controlled at all these forms of land use

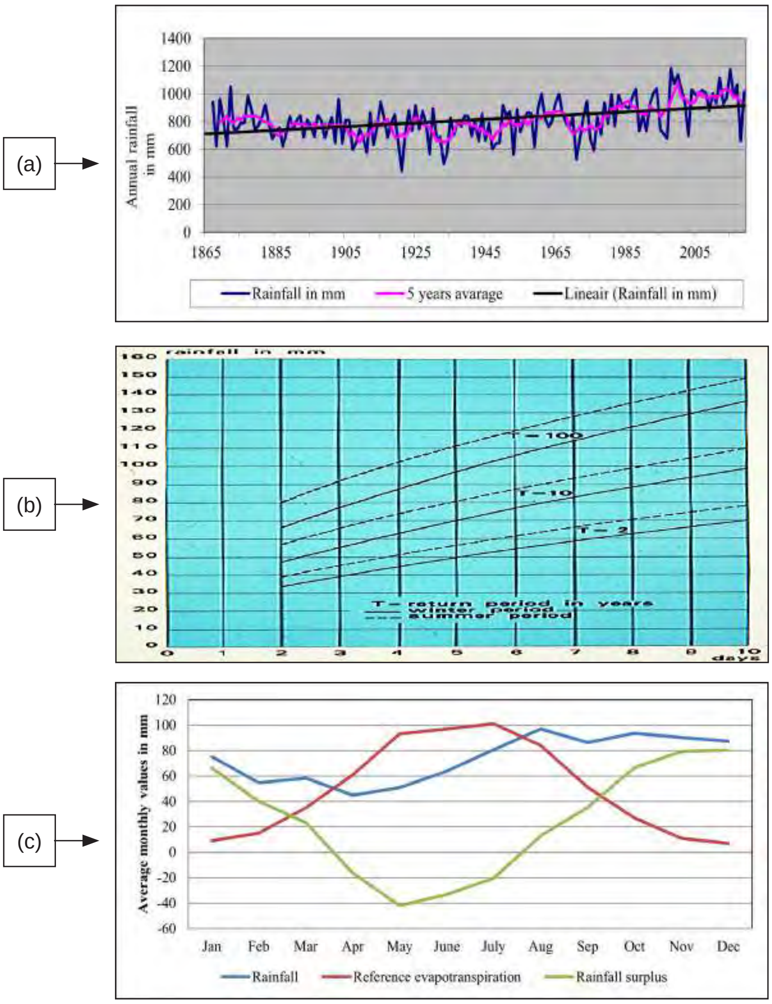


Figure 12. Annual rainfall (a), extreme rainfall for the summer (continuous lines) and winter period (dotted lines) (b) and average monthly precipitation and evaporation (c)

The water management systems were tailored to water level control and drainage (Figure 13). Water supply in dry periods played a relatively insignificant role in the lower part of the country. The drainage and discharge were realized by trenches in the peat areas and subsurface pipe drainage in the clay areas. From there the water flew through collector drains, sub-main drains and main drains to the drainage pumping stations. As stated above, originally windmills took care of the drainage, which in the 19^{th} century were replaced by steam power pumping stations and since the beginning of the 20^{th} century by electric and diesel pumping stations. The design standards were based on a target water level. This was the level which was preferably maintained in the watercourses. In addition, with a probability of occurrence of 1/5 to 1/10 per

Figure 13. Components of the water management systems of our polders

year a certain level rise is accepted. Finally, to verify the design guidelines it was checked at a probability of occurrence of 1/50 to 1/100 per year if the water could reach the surface level. In fact, in more extreme situations inundation could occur. However, this would generally be a few centimetres and was pumped out by the pumping stations within a few days.

FLOOD PROTECTION

With respect to the protection against flooding by the dikes, dunes and storm surge barriers (Figure 14) a distinction had to be made between sea dikes, dikes along the main rivers and dikes along canals and lakes. Design standards for flood protection were significantly higher than the standards for the design of water management systems. A distinction was made in primary defences - along the sea, the main rivers and the IJsselmeer - and secondary defences - along the waterways. For the primary defences the standards were applicable as shown in Figure 15. For the secondary defences the design standards were lower, and mainly determined by land use in the protected areas.

Figure 14. By dunes, dikes, storm surge barriers, river dikes and dikes along the collecting and transport systems and lakes flood protection is achieved

If the plans in the Delta Programme 2015 indeed were to be realized in the coming years, especially for the main rivers, the defences will have to become much stronger for two reasons (Ministry of Infrastructure and the Environment and the Ministry of Economic Affairs, 2014a). The first reason is the increase in the design standards of the probability of flooding of 1/1250 per year to a failure rate of 1/30,000 per year. In addition, the calculations will be adjusted from just overtopping to the different failure mechanisms. In this way, significantly more factors that can cause the failure of a flood defence will be taken into account, than hitherto has been the case. This development will lead to significantly higher and/or wider dikes along the main rivers. Given the oppositions that have occurred in the past with the envisaged improvement of the river dikes, where the initial standard of 1/3000 per year finally was reduced to 1/1250 per year, we face an interesting period.

IMPORTANT EVENTS

In the recent past, there have been a number of events that have played a major role in policy making and decisions with respect to the water management and flood protection provisions. Consideration needs to be given to:

- flooding from the sea in Zeeland and South Holland in 1953;
- urbanization and development of multiple land use;
- high discharge / flooding of the Rhine and the Meuse rivers in 1993 and 1995;
- extreme rainfall in 1998 and 1999;
- reports of the Intergovernmental Panel on Climate Change (IPCC);
- flooding of New Orleans due to the impacts of hurricane Katrina;

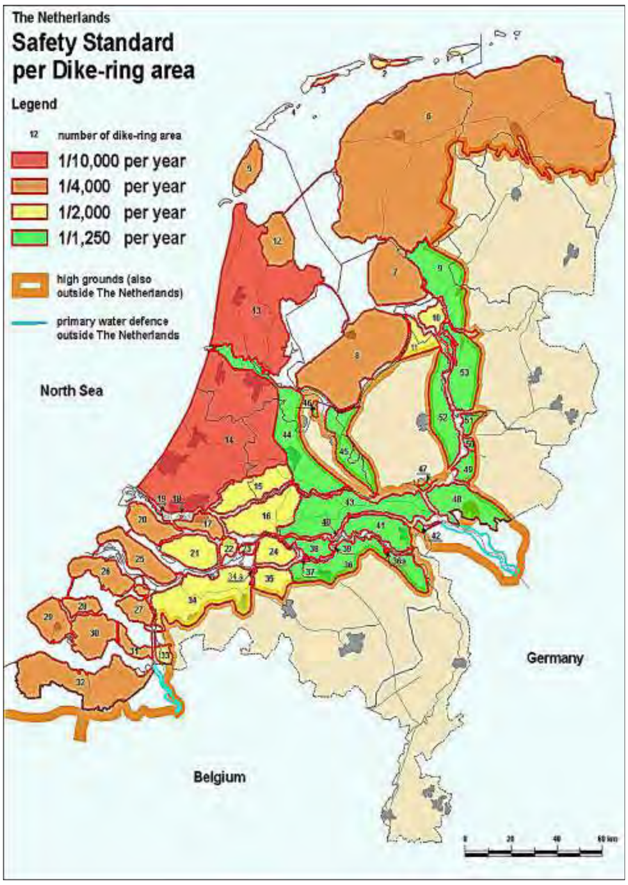


Figure 15. Existing levels of safety for the primary flood defences (Technische Adviescommissie voor de Waterkeringen (TAW), 2000)

- the film An Inconvenient Truth of the former vice president of the United States, Al Gore;
- more or less disappearance of water specialists in key positions within the relevant ministries and in the Water Authorities;
- adjustments in the 2009 elections for the Water Authorities in which the ancient principle of *interest, pay, say* has essentially been abandoned;
- dry summers in 2018, 2019 and 2022.

These events have often given a boost to implementation of measures that had been discussed over a long time, or have led to significant changes with regard to the policy in the field of water management and flood protection.

URBANIZATION AND CONSTRUCTION LEVEL

Related to water management and risk of flooding it is also interesting to learn that at which surface level the villages, towns and new urban quarters have been built over the centuries. Until 1950, the towns and villages were usually built on the higher parts, sometimes with some landfill. After 1950, there has been a rapid urbanization with buildings in the deeper polders. However, in these cases generally a surface level above the water level in the collecting and transport system for pumped out water from the polders (approximately 0.50 m-MSL) was applied. After 1970, when the sand for the landfill became increasingly scarce and expensive more and more building at a certain height above the polder level, up to 6.5 m-MSL was being applied. Particularly due to the Katrina flooding of New Orleans (USA) in 2005 and the movie of the former Vice President Al Gore (USA), there was a discussion whether we should continue with building large urban extensions in deep polders. This discussion came to an end in 2009 with the acceptance by the Government of the report of the Delta Commission (Veerman Committee) and the subsequent decision by the Government to conditionally build in deep polders (Delta Committee, 2008).

Recently the government has issued a policy letter in which is stated that properties of soil and water would have to be the leading decision-making criteria on land use planning (Ministry of Infrastructure and Water Management, 2022). We have to see how this principle will be implemented in the coming period.

PREDICTIONS FOR 100 YEARS

With respect to the predictions for 100 years, in this case, the impacts of climate change mainly relate to the rise in the sea level, the change in river regimes and in extreme floods and the increase in mean and extreme precipitation. What stands out here is that there is quite a bit of variation in the predictions. The latest forecasts of the Intergovernmental Panel on Climate Change (IPCC) (2022) show a global mean sea level (GMSL) to rise by 0.15-0.23 m and 0.20-0.30 m by 2050, respectively. By 2100, GMSL is projected to rise 0.28-0.55 m and 0.63-1.02 m, respectively, representing roughly 3 to 10 mm per year. In its report, the Delta Committee assumed an upper bound for sea level rise of 1.20 m. The program Room for the Rivers was based on a design discharge of River Rhine at Lobith, where the river enters the Netherlands, of 16,000 m^3/s, assuming that during the century, it may go to 18,000 m^3/s. This discharge is also the basis for the measures proposed in the report Delta Programme, 2015. For the Meuse a corresponding increase is expected. The Royal Dutch Meteorological Institute (KNMI) forecasts an increase in extreme precipitation of 8 to 45%. In addition, an increase in dry periods is also predicted. Overall, the impacts of climate change are in the order of magnitude of 5 - 45% per century.

EFFECTS OF CLIMATE CHANGE AND CHANGES IN LAND USE

In addition to the effects of climate change, there are also effects of subsidence and of changes in land use. Of these, especially the effects of changes in land use are important. They concern increase in public and private ownership, increase in population and increase in the value of crops. These changes are in the order of magnitude of 100 to 1000% per century. As an illustration, Figure 16 shows the urbanization in the area of the Principal Water Authority of the Delfland between 1925 and 2030. Such changes would have to play a much more important role in the decision-making on water management and flood protection than at present.

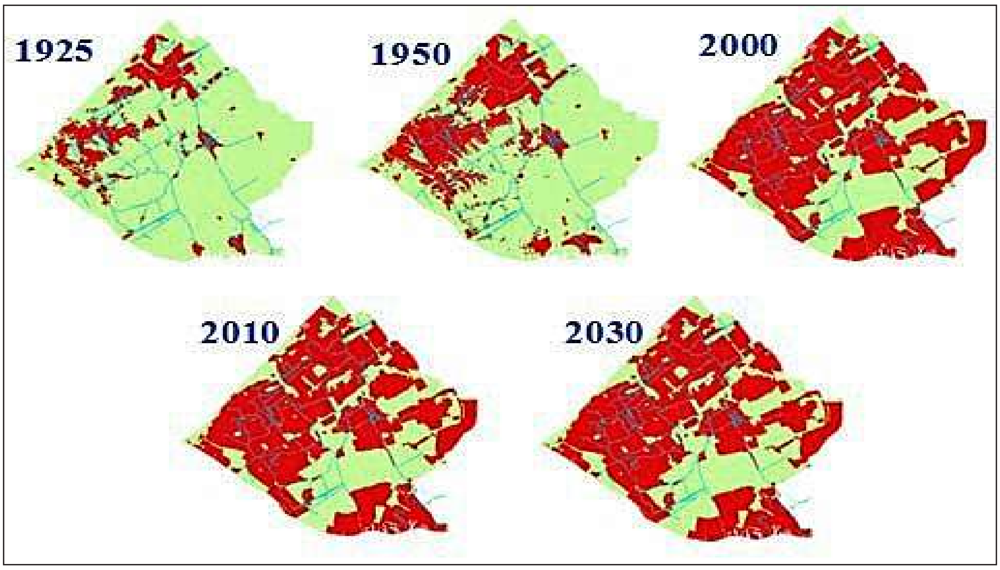


Figure 16. Urbanization (red) in the area of the Principal Water Authority of Delfland between 1925 and 203

CLIMATE CHANGE AND EFFECTS TO DATE

To put things in a clear framework it is also important to examine what have been the effects of climate change to date. By astronomers, the age of the earth is estimated at 4.5 to 5 Billion years. Since the creation of the earth, climate change has occurred, with much warmer and colder periods than what we experience at present. This can also be clearly observed on the geological scale. Over the past 130 years, the temperature increase has been between 0.3 - 0.6 ^{o}C. It is assumed that for each degree increase in temperature the precipitation increases by 3%. Due to melting of the glaciers in Alps in Switzerland, their volume has over the past 100 years reduced by 50%. For example, we can observe this in the discharge of River Rhine, which increasingly becomes a rainfed river and less a meltwater river. Over the past 100 years the sea level rise has been 0.10 - 0.25 m.

HOW EXTREME WERE OUR EXTREMES

It is also interesting to verify how our extremes have been. We come to the following values:

- the 1953 flooding disaster had a probability of occurrence of about 1/300 per year;
- both high river discharges of 1993 and 1995 had a probability of occurrence of about 1/150 per year;
- the extreme rainfalls in Delfland, the north-east of the country and in the Province of North-Holland had a probability of occurrence between 1/50 and 1/300 per year;
- in 1976 and 2003, the summer periods have been dry with roughly a probability of occurrence of 1/25 per year. Storage of water in the IJsselmeer at a level up to 1.5 m+MSL as proposed by the Delta Committee (2008) would imply 2 Billion m^3 of water. This is many times more water than would be required. A problem, however, will be that it will be technically quite costly to achieve, given the problems that will occur in the areas around the IJsselmeer.

By looking back, it can therefore be said that the disaster of 1953 and the evacuation of 240,000 people and a Million animals in the River Rhine area in 1995 could have been prevented if the dikes had been at their current level of safety of 1/4000 and 1/1250 per year, respectively. Some of the extreme rainfalls were beyond the current design standards for the water management systems and inundations have occurred, because these systems were typically designed for water at the surface with a probability of occurrence of 1/100 per year.

MEASURES RELATED TO SEA LEVEL RISE

With respect to the measures that could be taken in relation to sea level rise, it was interesting to note that the Rijkswaterstaat and Delft Hydraulics have developed scenarios in 1991/1992 to cope with the expected sea level rise of that time. There were two extreme scenarios: Atlantic Wall and Controlled Retreat and Surrender. The Atlantic Wall would be a dike in the sea at 15 Km from the coast with a large reservoir and land reclamation thereafter. In Controlled Retreat and Surrender, the city of Amersfoort would become a coastal city. In between, there were two more realistic scenarios. Assuming a sea level rise of 0.7 m in a century, the preferred scenario would cost about 16 Billion Euros. This would amount to less than 0.5% of the Gross Domestic Product, as these costs would be spread over 100 years. On this basis, it was decided to significantly improve the monitoring system along the coast. If the measurements would indicate an accelerated rise of the sea level there would be enough time to take the required measures. Curiously, this, in our opinion, good recommendation could not be found anymore in the subsequent reports of the Delta Committee (2008).

MEASURES IN RELATION TO HIGHER RIVER DISCHARGES

In relation to the expected higher river discharge, first of all, proper monitoring will be important. At present, the programme Room for the River has been completely implemented. Due to this, a level of safety would have been achieved based on a probability of failure of 1/1250 per year at a discharge of the River Rhine at Lobith of 16,000 m^3/s. Land use in the river area has equally been restructured. An increase in the capacity of the discharge sluices in the Enclosing Dam, including the construction of a third discharge sluice and the construction of a drainage pumping station in the Enclosing Dam are on-going. In relation to sea level rise, this pumping station will increasingly have to take over the drainage by gravity through the sluices. At a later stage, there will probably be the possibility of another discharge distribution over the three branches of the River Rhine - Waal, Lower Rhine and IJssel. At present, this distribution is: 2/3, 2/9 and 1/9.

MORE EXTREME RAINFALL

Also, regarding the more extreme rainfall, it is important that the observations be continued and the statistics of extreme rainfall will be regularly updated. Concerning the polder areas, it is important that the operation of the water management system be determined by the combination of storage and discharge. While in the polders, rapid changes may occur, it will be important to carefully monitor these changes and their possible effects in order to make, on a regular basis, the required improvements in the water management system. With respect to new developments, it will also be of importance to take due account of the vertical zoning. The urban areas would preferably have to be developed slightly higher than the surrounding rural area and that within the urban area, the houses will be located higher than the streets and that the streets are located a bit higher than the parks and green areas. When such a vertical zoning will be applied, inundations will concentrate in the areas where they cause the least inconvenience.

However, in general, it can be stated that well designed polders are still on the safe side with respect to their water management. This can be illustrated with the daily data of the pumped-out water of the Northeast polder, which are available from 1945 to 2006 (Figure 17).

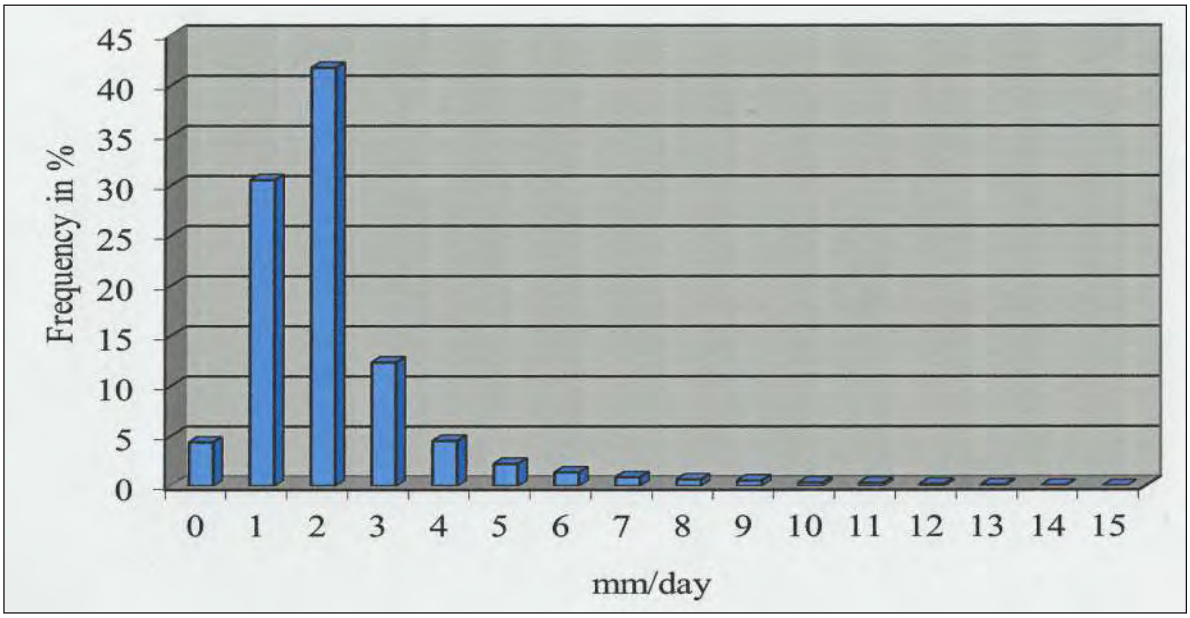


Figure 17. Frequency of amount of water pumped out from the Northeast polder, based on daily data for the period 1945 to 2006

Based on these data, it can be deduced that 90% of the time the amount of pumped out water was less than 4 mm/day, 96% of the time, it has been less than 6 mm/day (40% of the pumping capacity), and that in the entire period, the pumping stations have only been working for two days at full capacity. With the currently much better information on expected wet periods, there are also more opportunities for preliminary drainage, which will result in additional storage.

FINAL REMARKS

In the area of water management and flood protection, a lot of work has to be done. Apparently, the will to do it is there, but wisdom is needed and thorough knowledge and analysis is essential. In the Report on the Delta Programme (2015), especially for the river dikes, the proposed design standards and modified design approaches will lead to a huge increase in these dikes. When it comes to detailed design, one may expect that this will, on several occasions, lead to substantial problems. The question is how these problems will be resolved. It will be relatively easy to cope with the impacts of climate change with continued improvements in design. The bigger question will be whether our society can and will continue with the careful maintenance and management practices of the past ten centuries. When we will be able to do this and timely take the appropriate improvement measures, we can continue to live in our low country for many centuries to come.

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CHAPTER – 15

History of Irrigation for Sustainability in Rice Cultivation in Korea

Kim, Ju-Chang [a]

1. INTRODUCTION

For the history of irrigation, four (4) periods are considered; 1) Early times, 2) Medieval period, 3) Joseon period, and 4) Modern period.

Early times cover prehistoric period and three kingdom eras in the Korean Peninsula. Three kingdoms consist of Silla (57 BC to AD 668), Goguryeo (37 BC to AD 668), and Baekje (18 BC to AD 660). Silla Kingdom was in the southeastern part of the Korean Peninsula, Goguryeo in the northern part of it, and Baekje in the southwestern part of it.

The Medieval Period consists of Unified Silla Kingdom (AD 668 to 935) and Goryeo Kingdom (AD 918 to 1392), covering 724 years.

The Joseon period consists of only Joseon Kingdom from 1392 to 1897, covering 505 years.

The Modern period covers 123 years from 1897 to present. This period has three sub-periods; (1) Korean Empower (1897-1910), (2) Japanese colonial era (1910-1945), (3) Republic of Korea (1945-2020).

Drainage was not much considered in the history, because rice cultivation is greatly dependent on irrigation. However, tidal land reclamation started in 13th century, and many estuary dams and tidal land reclamation were implemented in the 20th century.

2. EARLY TIMES (BEFORE AD 668)

2.1 Beginning of Rice Farming

In several archaeological excavations in Korea, carbonized rice kernels and remains of paddy field with irrigation ditches were found. This means that rice farming started very early in prehistoric age in Korea.

In the history book, Samguksagi, rice cultivation was recorded in AD 33, as the King, Daruwang of Baekje Kingdom, ordered to begin rice cultivation in the southern parts of the country. It didn't mean to start rice cultivation in Baekje in AD 33, but to begin it in the month of February of AD 33. Therefore, it was reasonable to state that rice cultivation in Korea started much earlier than AD 33.

Table 2.1 Archaeological excavations in Korea

Location	Items	Age (years)	Remarks
Soro-ri, Oksan-myeon, Cheongju-si	Rice kernels at a peat bog	About 15,000	1998 excavation **
Gawaji, Daehwa-dong, Goyang-si	Chaff shaped rice kernels	About 5,000	1991 excavation **
Heunam-ri, Jeomdong-myeon Yeoju-si	Carbonized rice kernels	7-6 century BC	1972 excavated **
Daepyeong-dong, Sejong-si	Paddy field with bund & inlet	12-13 century BC	2015 excavated ***
Mugeo-dong, Jung-gu, Ulsan-si	Paddy field & irrigation ditch	4 century BC	1997 excavated **
Majeon-ri, Yeonmu-eup, Nonsan-si	Paddy field & irrigation system	4 century BC	1999 excavated **

1) Rice in Korean History (2000), * Korea Institute for Archaeology and the Environment

a Member of the Korean Committee on Irrigation and Drainage (KCID); Member of ICID WG-HIST; Member of the Korean Society of Agricultural Engineers; kljckim@naver.com

Figure 2.1.1 Carbonized rice kernel (Heunam-ri)

Figure 2.1.2 Paddy field with bund (Daepyeong-dong)

Figure 2.1.3 Remains of paddy field (Mugeo-dong)

2.2 Reservoirs in Three Kingdoms Era

More than 20 reservoirs in the three-kingdom era were recorded in various history books. Major reservoirs are presented Table 2.2. Most of the reservoirs were located in the southern part of the Korean Peninsula, Baekje and Silla Kingdom areas, not in the northern part, Goguryeo Kingdom area.

Figure 2.2.1 Byeokgolje gate

Figure 2.2.2 Uirimji reservoir

Figure 2.2.3 Susanje tunnel

3. MEDIEVAL PERIOD (668 AD - 1392)

3.1 Reservoir

More than 10 reservoirs in the Medieval Period were recorded in various history books. Major reservoirs are presented in Table 3.1.

Table 2.2 Major reservoirs built in Three Kingdom Era

Name of reservoir	Location	Year of construction	Dam length (m)	Irrigation area (ha)	Sources
Byeokgolje	Gimje-si	AD 330	3,250	10,000	1) 3) 6)
Hwangdeungje	Iksan-si	unknown	1,100	3,300	3) 5)
Nulje	Jeongeup-si	unknown	1,400	unknown	3) 5)
Sije	Jeongeup-si	AD 429	3,918	unknown	1) 5)
Uirimji	Jecheon-si	AD 540-575	300	289	3) 4)
Susanje with Tunnel	Milyang-si	unknown	Dam: 1,040 Tunnel: 25	unknown	3) 4)
Cheongje	Yeongcheon-si	AD 536	243m	134	1) 2)

Sources: 1) Samguksagi – Chronicles of the Three States; 2) History of Goryeo Dynasty; 3) Annals of the Joseon Dynasty; 4) Korean Irrigation Facilities and Cultural Heritage (2002); 5) No remains of reservoirs; 6) ICID WHIS (2016)

Table 3.1 Major reservoirs built in Medieval Period					
Name of reservoir	**Location**	**Year of construction**	**Dam length (m)**	**Irrigation area (ha)**	**Sources**
Hapdeokje	Dangjin-si	900-935	1,771	720	2) 4)
Gonggeomji	Sangju-si	1195 (Reconst.)	430	265	1) 2)
Geumho	Jinju-si	790-818	640	100	3)
Hoehak	Pohang-si	810	215	168	3)
Yeongji	Gyeongju-si	742-764	144	129	3)
Imchuncheon Tunnel	Yecheon-gun	1170 (Reconst. 1919)	50m tunnel (H2.2xW2.4)		3)

Sources: 1) History of Goryeo Dynasty; 2) Annals of the Joseon Dynasty; 3) Korean Irrigation Facilities and Cultural Heritage (2002); 4) ICID WHIS (2017)

Figure 3.1.1 Location of Hapdeokje reservoir

Figure 3.1.2 Gonggeomji reservoir

3.2 Sea Dike and Tidal Land Reclamation

In 1256, garrison farms were established in tidal land reclaimed in Jepo, Wapo, Ipo, and Chopo areas of Ganghwado Island. Because of Mongol invasions of Goryeo, the Goryeo Government moved in Ganghwado Island for 59 years from 1232 to1291. Sea dikes were constructed first to fight against infiltration of Mongol ships and later for rice cultivation to ensure food self-sufficiency in the Island.

a. Before tidal land reclamation

c. Tidal land reclamation until 1800s

b. Tidal land reclamation in Goryeo era

d. Tidal land reclamation until 1990s (Thick lines are old seadikes)

Figure 3.2 Progressive tidal land reclamation in Ganghwado island (Gukto and Minjoksaenghwalsa (1997))

Based on the experience of tidal land reclamation in Ganghwado Island, large scale tidal land reclamation projects in the western coast of Korean peninsula were implemented from 1970s to 1990s.

Tidal land reclamation in Ganghwado Island continued until 1990s as shown below. Most of small bays were closed with sea dikes, two and three islets were connected with multi sea dikes, and several new sea dikes were built in front of old sea dikes to increase reclamation area for rice cultivation. Therefore, small islands merged and coast line straightened.

4. JOSEON PERIOD (1392 - 1897)

4.1 Reservoir & Sea Dike

Several new reservoirs were built as presented in Table 4.1. However, many old reservoirs were rehabilitated or repaired during Joseon Period.

Table 4.1 Major reservoirs built in Joseon Period

Name of reservoir	Location	Year of construction	Dam length (m)	Irrigation area (ha)	Sources
Manseokgeo	Suwon-si	1795	387	82	1) 2) 5)
Chukmanje	Suwon-si	1799	615	300	1) 2) 6)
Magupyeong	Nonsan-si	1700-1800	unknown	386	2) 3)
Mansu	Anseong-si	1837	358	134	2)
Joyeon	Chuncheon-si	1837	729	211	2)
Yusangdaeje	Yeongcheon-si	1870	388	144	2)
Seondupoeon (seadike)	Gwanghwa-do	1707	About 1,500	unknown	4)

Sources: 1) Annals of the Joseon Dynasty; 2) Korean Irrigation Facilities and Cultural Heritage (2002); 3) Included in Tapjeong Reservoir built in 1944; 4) A seadike connecting two islands, Ganghwa main island and Hwado island; 5) ICID WHIS (2017); 6) ICID WHIS (2016)

Figure 4.1.1 Chukmanje reservoir

Figure 4.1.3 Mansu reservoir

Figure 4.1.2 Mansokgeo reservoir

Figure 4.1.4 Seondupoeon

4.2 Diversion Weir

Diversion weirs in the streams were easy to construct at a village level. They raised water level of the stream such that water would flow into the canal and/or paddy fields. Many diversion weirs were washed away during summer floods and therefore were rebuild every spring season before the start of irrigation season.

4.3 Irrigation Organization for Reservoirs & Irrigation

Government organization for reservoirs and irrigation, Reservoir Administration Unit (RAU) was established in the Joseon Government in AD 15th century. It was responsible for reservoir and irrigation related works; inspection, statistics, preparation of regulations, reporting to the king etc. The total number of reservoirs and ponds in Joseon kingdom was 3,527 in 1728; 3,378 in 1781 and 3,685 in year 1808.

In the village or at water source level, farmer's irrigation groups were formed for construction of small irrigation facilities and its operation and maintenance. Later in the Modern Period, they were merged into irrigation associations.

Table 4.2 Major Diversion Weirs in Joseon Period					
Name of weir	**Location**	**Year of const.**	**Weir length (m)**	**Irrigation area (ha)**	**Sources**
Changri	Mungyeong-si	1500	199	142	1)
Myeongwol	Jinju-si	1533	150	166	1)
Jajeom	Icheon-si	1625	500	40	1)
Eojidun/Gyeongugung	Jaeryeong-gun	1643	unknown	4,800/3,800	1)
Dongdu	Yanggu-gun	1690	50	48	1)
Manseok	Jeongeup-si	1893	300	unknown	1)

Sources: 1) Korean Irrigation Facilities and Cultural Heritage (2002)

4.4 Other Parameters Related to Irrigation and Rice Cultivation

4.4.1 Rainfall Measurement

Rainfall measurement is one of the most important factors in irrigation. In 1441, cylindrical rain gauge was invented for the first time in the world, and measurements were made at several places in the country for the next 100 years. But measurements discontinued and records destroyed due to invasions from neighboring countries in 1592 and 1636. The measurements restarted in 1770 and continued until 1907 for 137 years and its records kept well.

4.4.2 Famine Relief Work during Drought

In dry years, especially in the months of May and June, drought brought famine and no planting and/or harvesting of rice could be done. The government had Famine Relief Administration to take care of the affected regions in such years, giving relief to famine-stricken people. For the period from 1661 to 1686, Reservoir Administration Unit was operated and controlled by the Famine Relief Administration to facilitate scarce water distribution for domestic use or otherwise.

During and after serious famine, the king and the government paid attention to the reservoirs and diversion weirs. The King, Jeongjo constructed three reservoirs: Mansekgeo (1795), Mannyeonje (1798) and Chukmanje (1799) after serious dry years of 1793, 1795 and 1797.

Table 4.3 Yearly rainfall in Seoul			
Year	**Yearly rainfall (mm)**	**Reservoir const.**	**Rain gauge**
1791	1,787	-	
1792	1,517	-	
1793	934	-	
1794	1,206	-	
1795	882	Mansekgeo	
1796	1,425	-	
1797	948	-	
1798	1,156	Mannyeonje	
1799	967	Chukmanje	

Source: A Comprehensive History of the Korean Construction Industry, Vol. II, 2017

5. MODERN PERIOD (1897 - PRESENT)

5.1 Reservoirs

Many reservoirs were constructed in 1920s depending on the Rice Production Increase Plan (1920) or Revised Plan (1926) as shown in Table 5.1.

5.2 Pumping Stations

Pumping stations for irrigation and drainage were first introduced in 1920s. And large pumping stations were accompanied with tidal land reclamation projects in 1970s to 1990s, because of large beneficial areas located higher than water surface of freshwater lake.

5.3 Sea Dike and Tidal Land Reclamation

More than 10 tidal land reclamations, for the purpose of farmland with irrigation, were implemented from 1960s to 2000s. Many rivers and streams were closed to make freshwater estuary lakes. Major sea dikes and lakes with development area are shown below.

5.4 Irrigation Development Plan and Survey

Multi-year irrigation-related development plans were prepared several times from 1920 to 1991, which accelerated construction of irrigation systems all over the country. Such national plans with financial plans helped to increase irrigated rice cultivation area.

Table 5.1 Major reservoirs built in 1920s in Modern Period					
Name of reservoir	**Location**	**Year of construction**	**Dam Height x Length (m)**	**Irrigation area (ha)**	**Sources**
Daea Dam	Wanju-gun	1922	32.7x254	6,110	1) 3)
Seobu	Seocheon-gun	1926	16.3x298	1,865	1) 2)
Dongbu	Seocheon-gun	1926	11.5x126	2,775	1) 2)
Unam Dam	Imsil-gun	1928	33x316	19,600	1) 4)
Masan	Asan-si	1928	10.7x247	552	1) 2)
Mulwang	Siheung-si	1930	10x290	866	1) 2)
Boksim	Buyeo-gun	1930	6.9x317	702	1) 2)
Oksan	Buyeo-gun	1930	11.2x548	690	1) 2)

Sources: 1) Korean Irrigation Facilities and Cultural Heritage (2002); 2) Based on the Rice Production Increase Plan (1920) or Revised Plan (1926); 3) New Daea Dam (zone type fill dam) constructed in the 2km downstream of the old dam (cobble mixed concrete arch gravity dam), 1989; 4) Seomjin Dam (concrete gravity dam) constructed in the 2.4km downstream of Unam Dam (cobble mixed concrete arch gravity dam), 1965; 5) All the reservoirs with earth dam except Daea and Unam.

Figure 5.1.1 Daea dam (old)

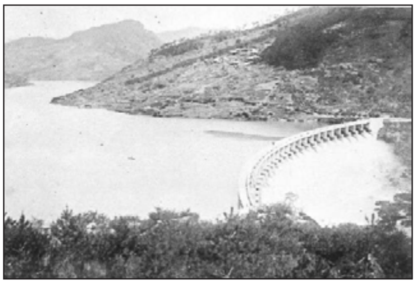

Figure 5.1.2 Unam dam (old)

Figure 5.1.3 Dongbu reservoir

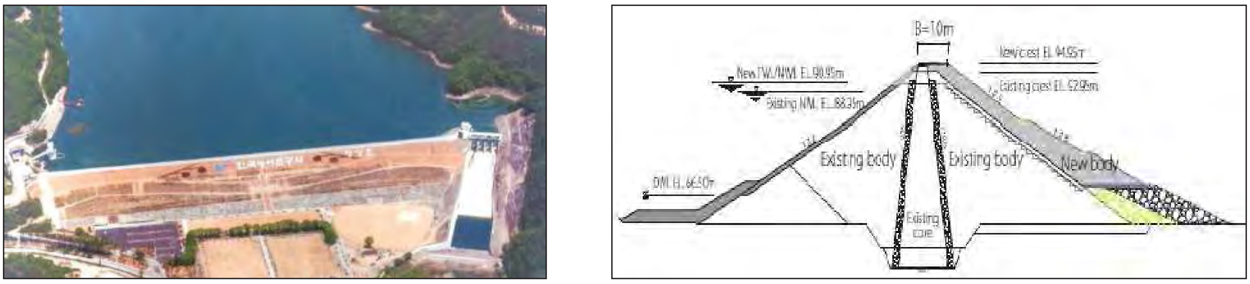

Figure 5.1.4 Jngseong dam (after remodeling)

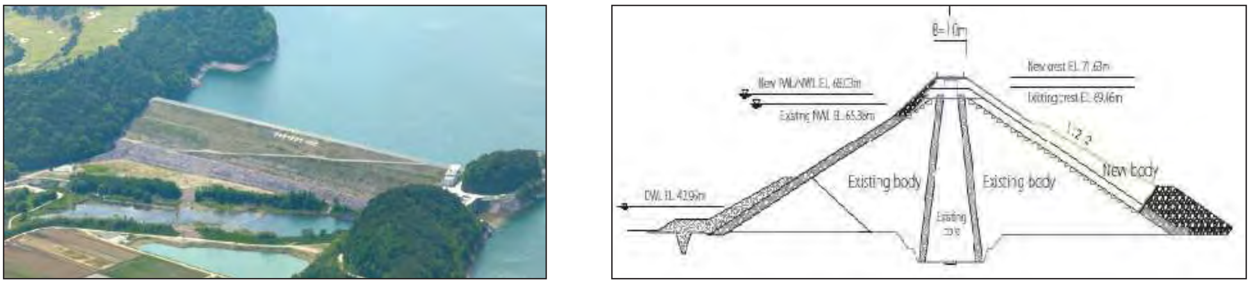

Figure 5.1.5 Naju dam (after remodeling)

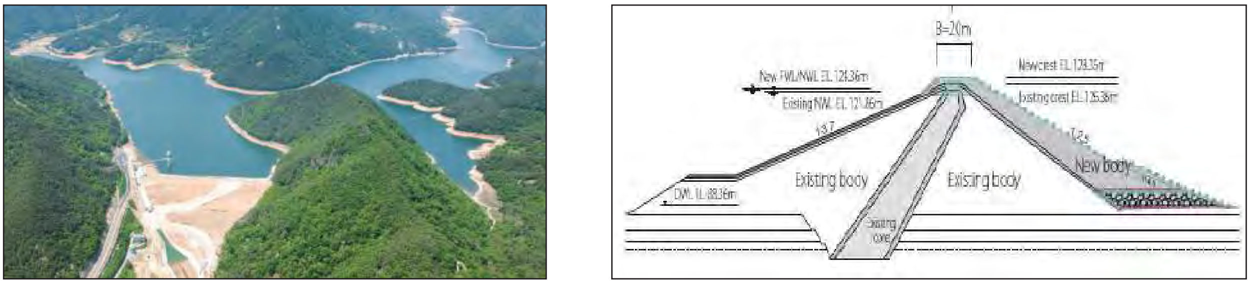

Figure 5.1.6 Damyang dam (after remodeling)

Table 5.2 Major reservoirs built after 1960s in Modern Period					
Name of reservoir	Location	Year of construction	Dam height x Length (m)	Irrigation area (ha)	Sources
Gosam	Anseong-si	1963	16.6x193	3,122	1)
Yedang	Yesan-gun	1964	13.2x314	10,005	1)
Idong	Yongin-si	1972	17.5x660	3,426	1)
Jangseong	Jangseong-gun	1976	36x603	13,900	1) 2)
Naju	Naju-si	1976	31x496	11,200	1) 3)
Damyang	Damyang-gun	1976	46x305	6,245	1) 2)
Gyeongcheon	Mungyeong-si	1986	63.5x368	3,400	1)
Hadong	Hadong-gun	1993	58.6x486	3,155	1)
Seongju	Seongju-si	1997	60x430	3,530	1)
Donghwa	Jangsu-gun	1999	59x474	3,000	1)
Sources: 1) Korean Irrigation Facilities and Cultural Heritage (2002); 2) Remodeling of dam body (Raising dam height by 2.0m) in 2010-2014; 3) Remodeling of dam body (Raising dam height by 2.17m) in 2010-2014					

Table 5.2b Major pumping stations (PS) built in Modern Period					
Name of PS	Location	Year of const.	Pump size / No. (mm/ea)	Irrigation area (ha)	Sources
Singok	Gimpo-si	1925	965/6	4,085	1)
Mokdong Ir & Dr	Yangcheon-gu	1924	Unknown	abolished	2)
Yeomchang Ir.	Gangseo-gu	1924	Unknown	abolished	2)
Yangcheon Dr.	Gangseo-gu	1928	1,320/3	abolished	2)
Muan	Yeongsan Lake	2010	900/8	6,100	3)
Hampyeong	Yeongsan Lake	2010	900/8	6,100	3)
Hyeongyeong	Yeongsan Lake	2010	900/15	11,096	3)
Yeongu	Yeongam Lake	2010	1,100/8	7,181	3)
Jinsan	Geumho Lake	2010	900/5	2,998	3)
Sources: 1) Korean Irrigation Facilities and Cultural Heritage (2002); 2) Drainage Pumping Station of Yangcheon Irrigation Association Report (2008); 3) From Poverty to Prosperity (2014)					

Figure 5.2.1 Mokdong PS

Figure 5.2.3 Hyeongyeong

Figure 5.2.2 Yangcheon PS

Figure 5.2.4 Yeongu PS

Table 5.3 Major Sea dikes built in Modern Period					
Name of seadikesea dike	**Location**	**Year of const.**	**Dam length (m)**	**Development area (ha)**	**Sources**
Daecheon	Boryeong-si	1958	6,170	623	1)
Dongjingang	Jeonbuk P.	1968	12,810	2,500	1)
Asan	Gyeonggi P.	1974	2,564	15,250	1)
Sapgyo	Chungnam P.	1979	3,360	18,840	1)
Yeongsan	Jeonnam P.	1981	4,350	20,700	1)
Daeho	Chungnam P.	1984	7,807	7,700	1)
Geumgang	Chungnam & Jonbuk P.	1990	1,127	43,000	1)
Yeongam	Jeonnam P.	1993	2,219	13,160	2)
Geumho	Jeonnam P.	1996	2,120	6,300	1)
Saemangeum	Jeonbuk P.	2010	33,900	40,100	(land/lake 28,300/11,800)
Sources: 1) Korean Irrigation Facilities and Cultural Heritage (2002); 2) From Poverty to Prosperity (2014)					

Figure 5.3.1 Yeongsan seadike (old)

Figure 5.3.4 Yeongsan seadike (remodeled with 240m additional sluice gate)

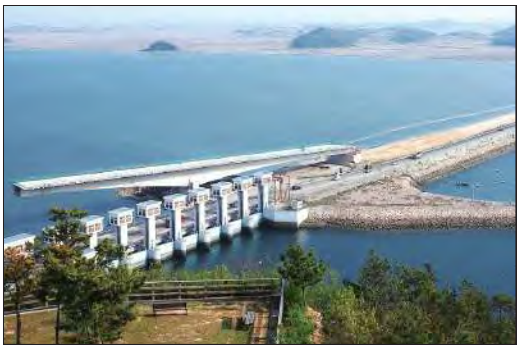

Figure 5.3.2 Yeongam seadike

Figure 5.3.5 Map of Yeongsan, Yeongam and Geumho lake

Figure 5.3.3 Geumho seadike

Figure 5.3.6 Saemangeum development plan

Survey for Availability of Water Resources corrected wrong statistics about irrigated paddy field area, followed by preparation of Agricultural Water Development 10-year Plan.

Survey of Potential Area for Tidal Land Development in the west and south coastal regions of the country were made 8 times during 27 years from 1962. Many tidal land development projects followed. This means there was a deep-rooted desire to cultivate rice in these lands.

Table 5.4 Development plan and survey

Year	Name of plan or survey	Period	Target (1,000 ha)	Sources
April 1920	Rice Production Increase Plan	1920~1934	Irrigation: 225 Upland to paddy: 112.5 Reclamation: 90	1) Revised in 1926
1926	Revised Plan for Rice Production Increase	1926~1939	Irrigation: 195 Upland to paddy: 90 Reclamation: 65	1)
1940	Rice Increase Plan	1940~1945	Irrigation: 113.6 Reclamation: 25.4 Land consolidation: 18 Tile drain: 6	1)
July 1961	1st Economic Development 5-year Plan	1962~1966	Farm income and new farmland development	1)
June 1965	All Weather Agricultural Water Resources Development Plan	1965~1973	Reservoir: 249 Pumping S: 39 Diversion weir: 29 Groundwater: 70	1)
July 1966	2nd Economic Development 5-year Plan	1967~1971	Food crop self-sufficiency	1)
Dec. 1968	Irrigation Water Development Plan (Blue book)	1968~1973	Reservoir: 74.4 Pumping S: 56.9 Diversion weir: 12.2 Feeder canal: 32.4 Infiltration G.: 87.4 Tube well: 171.9	1) Serious drought in southern provinces in 1967 & 1968
1980 – 1981	Survey for Availability of Water Resources for Irrigation during Droughty Period	1980~1981	Survey area: 893.36 No. of sites: 39,394 Irrigated area ratio: 86% → 68%	1)
Sep. 1981	Agricultural Water Development 10-year Plan	1982~1991	Irrigation dev. of 555 (permanent 390, addition 25, pumping 140)	1)
1962 – 1989	Survey of Potential Area for Tidal Land Development	1962 1965 1966 1968-72 1975-76 1979 1980 1987-89	1st: 71 - 189/165 2nd: 116 - 239/161 3rd: 182 - 213/163 4th: 149 - 230/160 5th: 59 area – 635/402 6th: 36 area – 406/121 7th: 59 area – 608/339 8th: 2,103 area – 810/461	2) No. of area – Tidal land/ Paddy field to be

Sources: 1) Korean Soil and Water (2008); 2) Tidal Land Reclamation in Korea (1995)

5.5 Implementation and O&M Organization

Operation, maintenance and management of Irrigation and drainage systems are implemented by the Korea Rural Community Corporation (KRC) and local governments of cities and counties. As of 2018, 69% of irrigation and drainage areas are covered and managed by KRC through its provincial and local branch offices and 31% by local governments. KRC covers larger schemes, while city and county offices cover smaller schemes.

Irrigation associations (renamed later as land improvement associations and farmland associations) were responsible for operation and maintenance of irrigation systems until 1999. The first irrigation association, Okguseobu Irrigation Association, was established in 1908 according to the Irrigation Association Act (1906) of the Government of Korean Empire. Local area-based associations, responsible for O&M of irrigation facilities, were continuously established following completion of irrigation projects, until 1999 when Korea Agricultural and Rural

Infrastructure Corporation (KARICO) merged all the associations in the country in 2000.

The total number of irrigation associations in Korea were 598 in 1945 (356,678 ha area): Northern Korea had 173 associations (with 168,511 ha) and Southern Korea had 425 associations (with 188,167 ha). And in 2000, the number of associations (Southern Korea only) decreased to 104 associations albeit with 506,926 ha area due to merging of small size associations.

Design and implementation of irrigation projects were made by the Joseon Union of Irrigation Association (JUIA) established in 1940. JUIA was later renamed as Daehan UIA, ULIA, ADC, RDC, KARICO, and Korea Rural Community Corporation (KRC) at present.

Table 5.5 Implementation and O&M organization

National organization				Farmers' group under local government	
O&M		Project implementation			
Name*	Period	Name	Period	Name**	Period
IA (Irrigation Association) in local area	1908-1962	Joseon Union of IAs	1940-1949	IG (Irrigation Group) in local area	unknown -1969
		Daehan Union of IAs	1949-1962		
LIA (Land Improve. Association	1962-1969	Union of LIAs	1962-1969		
FIA (Farmland Improvement Association)	1970-1999	ADC (Agricultural Development Corporation)	1970-1990	(FIG) Farmland Improvement Group	1970-1999
		RDC (Rural Development Corporation)	1990-1999		
FIA merged to KARICO	2000-	KARICO (Korea Agriculture and Rural Infrastructure Co.)	2000-2005	(IG) Irrigation Group	2000-
		KRC (Korea Rural Community Corp.)	2006-present		

* There were many IA, LIA, FIA and IG, FIG in the country. IA renamed as LIA and later as FIA, and IG as FIG

5.6 Foreign Loans

For irrigation development of the country, foreign loans (21.8% of total project costs) for 13 projects were used. Foreign loans helped the project implementation in two ways: smooth financing for the projects and technical support by the foreign consultants. After projects were established, technical capability of the Korean engineers was enhanced, who then started consulting services in Vietnam from1973 and later in Nepal and Indonesia.

Total development area of 155,000 ha in a decade correspond to 17% of total paddy field area of 893,000 ha in 1980.

Table 5.6 Foreign loan projects during 1970s

Project	Develop. Area (ha)	Project costs (Million Won)			Bank	Agreement date
		Total	Domestic	Foreign		
Total	155,269	1,013,238 (100%)	792,051 (78.2%)	221,187 (21.8%)		
Geumgang	12,148	16,823	9,715	7,108	IBRD	69. 5. 22
Pyeongtaek	18,419	37,657	26,154	11,503	IBRD	69. 5. 22
Yeongsangang (I)	34,500	81,238	58,602	22,636	IBRD	72. 2. 2
Gyeongju	1,140	4,916	3,636	1,280	IBRD	74. 1. 4
Gyehwado	2,500	12,521	6,942	5,579	OECF	74. 12. 26
Sapgyocheon	24,700	232,000	212,491	19,509	OECF	74. 12. 26
Changnyeong	2,269	17,358	11,823	5,535	OECF	74. 12. 26
Mihocheon	11,554	104,871	85,079	19,792	IBRD	76. 8. 5
Imjin	7,185	45,807	34,900	10,907	ADB	76. 12. 27
Namgang	5,754	61,903	44,242	17,661	ADB	76. 12. 29
Yeongsangang (II)	20,700	281,084	218,159	62,925	IBRD	77. 2. 11
Nkdonggang	3,600	23,029	13,848	9,181	ADB	77. 8. 31
Nonsan	10,800	94,031	66,460	27,571	IBRD	78. 1. 4

Sources: 1) Korean Soil and Water (2008)

5.7 Farmland Management Fund

Farmland Fund was introduced in 1972. And it was renamed as Farmland Management Fund operated by Agricultural Development Corporation (presently KRC) from 1981. Main purpose of the Fund is to prevent decreasing farmland area due to conversion of farmland to other uses such as urban and industrial areas. Total tidal land reclamation area funded by this fund reached 48,000 ha in a decade from 1981 to 1990.

Developers of the farmland for some other purpose have to pay some money to the Fund, and the Fund should be used only for farmland development and management. Therefore, many small tidal land reclamation projects for agricultural purpose were more easily implemented without any financial support from the government budget. Any projects depending on the government budget may be unstable, but fund-supported projects are financially more stable.

6. CONCLUSIONS

Archaeological excavations and historical records in Korea showed that history of rice cultivation and irrigation were very earlier in the Korean Peninsula. In dry weather condition, rice cultivation is almost impossible, therefore, irrigation was introduced nearly same time with rice cultivation.

Irrigation development for rice cultivation in Korea has been made in dual ways: administration by the government and farmer's self-help works. In the kingdom's era, kings were very much interested in the construction and O&M of the water source facilities such as reservoirs, diversion weirs, etc. The farmers constructed small scale ponds, weirs, etc.

In Modern Period, large scale reservoirs, tidal land reclamation and pumping stations were introduced based on the national plans prepared by the government for self-sufficiency in rice and some upland crops.

Major factors for irrigation development in Korea could be summarized as follows:

- Topography of Korea is suitable for water resources development. Mountainous areas that act as catchment area for rainwater forms about two third of the territory and located in the eastern part. While plain areas for rice cultivation are located in the western and southern areas.
- In drought years, rice planting and harvesting were impossible resulting in famine. People had famine experiences in the history. Therefore, in the kingdom era, kings were very much interested in water resources development.
- In 1967 and 1968, there occurred serious droughts in the grain belt of Korea. Therefore, the Government prepared intensive water resources development plans which were implemented in the 1970s and 1980s.
- Cultivable land area of rice was not enough to feed the Korean population. Therefore, tidal land reclamation was established for paddy fields from 13th Century onwards which flourished in the second half of the 20th Century.
- Foreign loans for irrigation projects from 1969 onwards accelerated the project implementation by smooth financing and technical support from foreign consultants.
- Farmland Management Fund contributed greatly to small and medium size tidal land reclamation projects.

As of 2016, total area under paddy cultivation is about 896,000 ha, of which the irrigated paddy fields are 728,000 ha (81.3%) and partially irrigated paddy fields cover 168,000 ha (18.7%). And, 546,000 ha (60.9% of total paddy fields) of paddy fields are made safe from a drought with 10-year frequency.

As of 2018, the total area under paddy cultivation is about 844,000 ha, of which the irrigated paddy fields are 696,000 ha (82.5%) and partially irrigated paddy fields cover 148,000 ha (17.5%). And, 526,000 ha (62.3% of total paddy field) of paddy fields are made safe from a drought with 10-year frequency.

As can be seen from above, between the two years, total paddy field area, irrigated paddy field area, partially irrigated area and safe irrigated paddy field area show a quick decreasing trend. This trend reflects the change of demand for food from rice to other cereals, vegetables, and meats, perhaps, as a result of improvement of living standards in Korean people.

Irrigation for upland crops, vegetables, fruit trees, etc. is increasing drastically in these years, replacing paddy crops, however, any statistical data for that irrigation are not easily available, because it belongs to private domain.

Several unique irrigation systems in the mountainous regions of Korea which were registered as ICID WHIS are as **Annex**.

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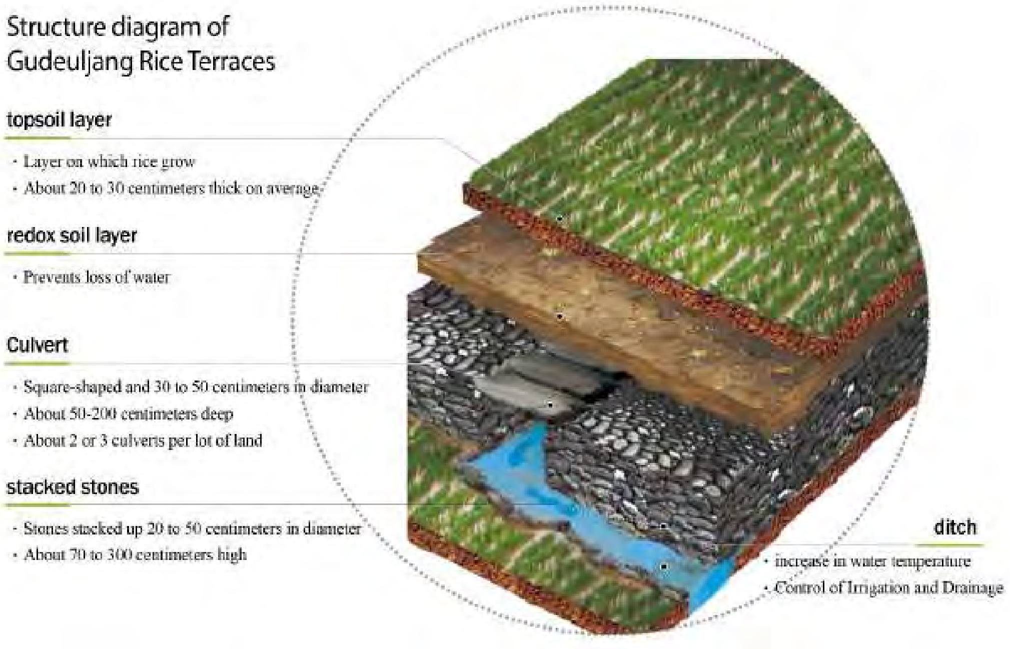
EXAMPLES OF UNIQUE IRRIGATION METHODS IN KOREA

1. Gudeuljang Irrigated Rice Terraces

Gudeuljang rice terraces are artificial rice paddies made from reengineering the natural environment to cultivate rice in areas with disadvantageous soil conditions and sloped hill sides, especially in Cheongsando Island, Jeonnam province.


Gudeuljang Rice Terraces of Sangseo-ri


Gudeuljang Rice Terraces of Cheonggye-ri



Gudeuljang Rice Terraces have 3 layers of top soil, clay soil, and stacked stone including culverts. Top soil functions as root zone of rice plant, clay soil as water-proof to keep irrigation water, and stone layer as base layer to form horizontal floor in sloping area. Several culverts are placed in the stacked stone for irrigation water flow from upstream to downstream plot.

It was registered in ICID WHIS in 2021 as follows;

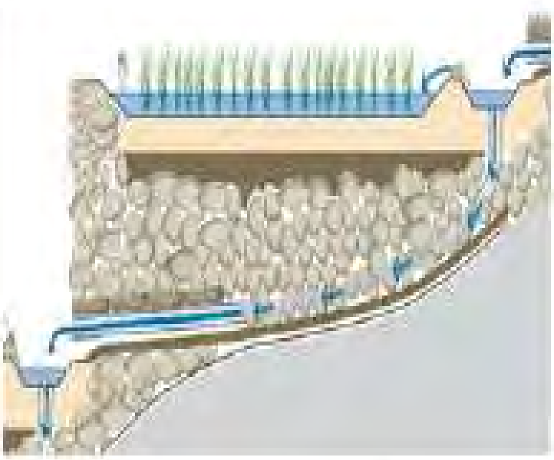
(a) Name: Gudeuljang Irrigated Rice Terraces in Cheongsando

(b) The year of commissioning: A.D. 17C ~ mid-20C

(c) Area Irrigated: 1,370.01ha

(d) Geographical Coordinates: 34° 10’ 56.1” N 126° 53’ 35.8” E (based on the core zone)

(e) River basin where located: Small Streams in The Eastern Part of Cheongsan-myeon



Cross section of the terrace

Before transplanting of rice seedling

Outlet of culvert

Transplanting of rice seedlings

Repairing culvert cover with flat stone

Changed from paddy to flower cultivation

2. Gangjin Lotus Small Reservoirs System

There are many small and shallow reservoirs including five (5) reservoirs in series. These reservoirs are covered with lotus in summer season, showing beautiful scenery.

These reservoirs supplied irrigation water and lotus flowers and roots in Gangjin County, Jeonnam province.

It was registered in ICID WHIS in 2021 as follows;

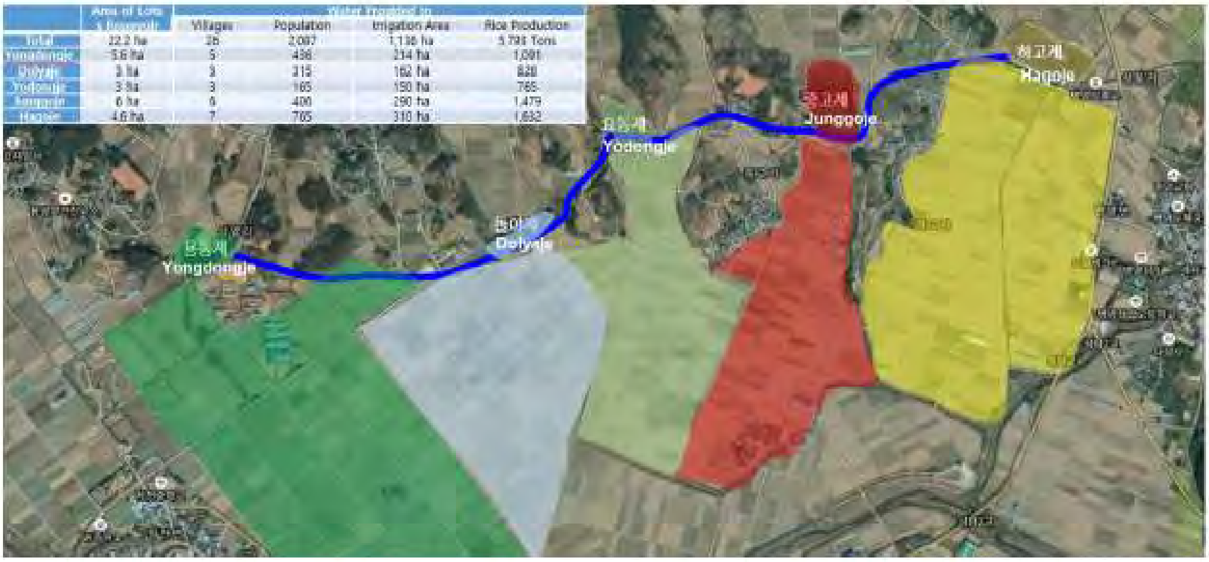
(a) Name: Gangjin Lotus Small Reservoirs System

(b) The year of commissioning: A.D. 14th Century

(c) Area Irrigated: 1,136ha

(d) Geographical Coordinates: 34° 43' 11.8" N, 126° 48' 01.3" E (based on the core zone)

(e) River basin where located: Byeongyeong-cheon Stream & others



5 small reservoirs in series (44.4ha)

4 small reservoirs in series

Dolyaje reservoir with lotus

Byeongyeongseong Fortress was built in 1417 to protect Jeolla province from invaders. Water supply to the moat of the Fortress was made from reservoirs and streams.

Byeongyeongseong Fortress moat

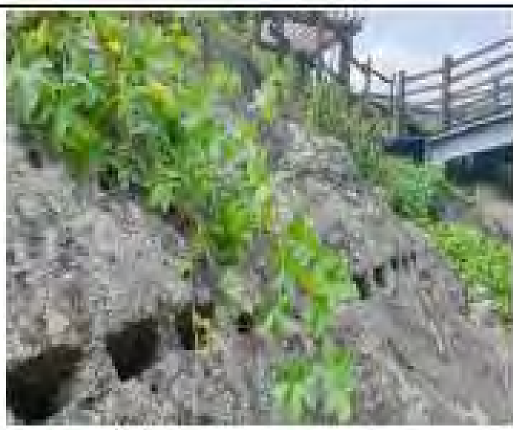
Hagoje reservoir with flowers

Byeongyeongseong Fortress initiated a grain exchange program between its residents and people in the neighboring area.

Annals of King Jeongjo (Dec. 25, 1794)

Canal from Junggoje to Hagoje

Rock excavated canal



Wedge holes for rock excavation

Folk ritual near reservoir

Traditional fishing using fish trap

3. Dumbeong (Goseong Coastal Area Pond Irrigation System)

There are many small ponds at the foot of mountains in the coastal area. Dumbeong is a Korean expression of pond. Subterranean flow in the sloped mountains supplies water to Dumbeong at the foot of the mountain. The groundwater level is maintained almost constant due to seawater level. Therefore, groundwater is available if Dumbeong is excavated. Irrigation in Gangjin County, Jeonnam province, depends on Dumbeong which is unique water sources in the region.

It was registered in ICID WHIS in 2020 as follows;

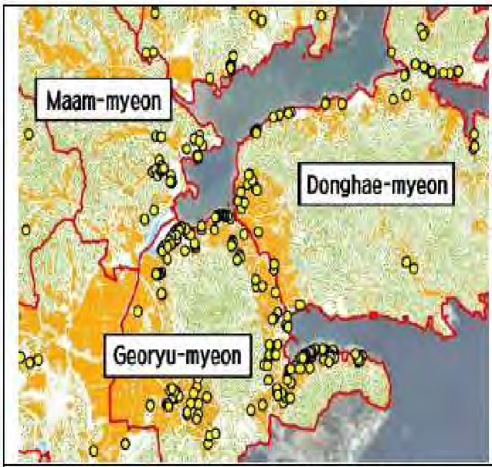
(a) Name: Dumbeong (Goseong Coastal Area Pond Irrigation System)

(b) The year of commissioning: A.D. 18th Century

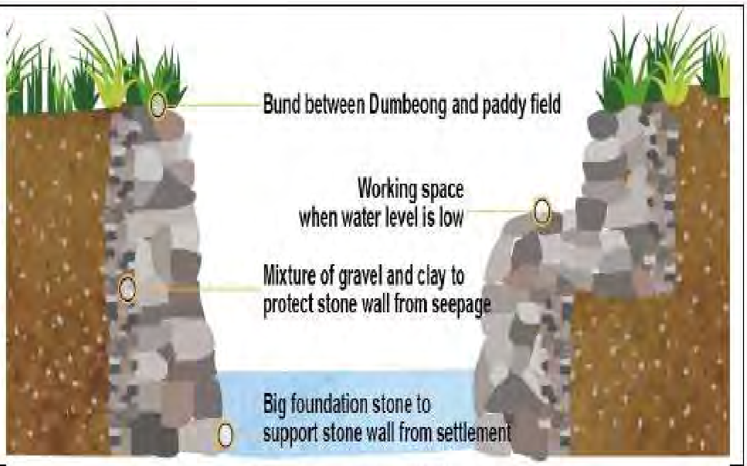
(c) Area Irrigated: 90ha

(d) Geographical Coordinates: 34° 58' 59.9" N 128° 25' 56.0" E (based on the core zone)

(e) River basin where located: No stream related



Location of many Dumbeong



Cross section view of Dumbeong

Harrowing paddy field in 1970s

Rice transplanting in 1970s

No. of Dumbeong in each sub-county

Sub-county	Gos.-eup	Georyu	Kuman	Gaecheon	Daega	Donghae	Maam
No. Dumbeong	30	197	3	9	10	51	27
Sub-county	Samsan	Yeongo	Yeonghyeon	Hayi	Hail	Hoehwa	Total
No. Dumbeong	22	1	3	30	30	31	444

Dumbeong in the paddy field

Water lifting by manpower

Dumbeong stone side wall
(Low water surface level)

Dumbeong stone side wall
(High water surface level)

Dumbeong in autumn season

Dumbeong in spring season

Dumbeong with step

Dumbeong with a culvert

4. Uiseong

There are many small and shallow reservoirs including five (5) reservoirs in series. These reservoirs are covered with lotus in summer season, showing beautiful scenery.

These reservoirs supplied irrigation water and lotus flowers and roots in Gangjin County, Jeonnam province.

It was registered in ICID WHIS in 2022 as follows;

(a) Name: Gangjin Lotus Small Reservoirs System

(b) The year of commissioning: A.D. 14th Century

(c) Area Irrigated: 1,136ha

(d) Geographical Coordinates: 34° 43' 11.8" N, 126° 48' 01.3" E (based on the core zone)

(e) River basin where located: Byeongyeong-cheon Stream & others

Small reservoirs/ponds & farmland in Tapri-ri at the western foot of Mt. Geumseongsan

Small reservoirs/ponds & farmland in Ungok-ri at the northern foot of Mt. Geumseongsan

Farmers participating in the ritual for the start of irrigation

CHAPTER – 16

The History of Development of Irrigation in India

Ashok Kumar Kharya [a], Ravi Bhushan Kumar [b], and Chaitanya K S [c]

1. INTRODUCTION

Worldwide, Agriculture uses about 70% of the available freshwater resources. It is estimated that in India, irrigated agriculture consumes about 75-80% of the total developed/managed freshwater resources. India is still on the road to achieving population stabilization. With growing urbanization and better standards of living, water demands of various sectors are on the rise and will continue to remain so. Any change in the hydrological cycle and evapo-transpiration regime, due to climate change, would directly affect India's water resources scenario in a big way. The per capita availability of water in India has decreased from around 5177 cu. m. /year in 1951 to 1545 cu. m. /year in 2011 and is projected to go down further. Apart from other inputs, expansion of irrigation systems has contributed significantly to achieving food security and insuring against famine and scarcity after Indian independence. Water continues to remain at the core of the global Sustainable Development agenda. Safeguarding India's food, energy and water security has a greater bearing on achieving the 17 interlinked Sustainable Development Goals (SDGs) by 2030.

The current chapter intends to review the history of development of irrigation in India since the proto-historic period to the present time.

2. LAND AND WATER RESOURCES OF INDIA

India is a vast country, with a kaleidoscopic diversity of topography, climate, and vegetation[1]. The total geographical area of India is about 329 million hectares (Mha) of which total cultivable land is about 182 Mha. India is also a land blessed with many rivers and water bodies– mighty to small. Agriculture occupies a key position in the Indian economy, continues to remain as the main occupation and a source of livelihood for majority of the population. Therefore, the available land and water resources need to be put to optimum use to support agricultural production.

India receives on an average annual precipitation of about 1170 mm which corresponds to about 3880 billion cubic metres (BCM) of water. Central Water Commission (CWC) in 1993 assessed average annual water availability in the country as 1869 BCM[2], out of which, it is estimated that owing to topographic, hydrological, and other constraints, the utilizable water is about 1128 BCM, comprising of 690 BCM of surface water and 438 BCM of replenishable ground water.[3] Reassessment of water availability in India using spatial inputs has been recently carried out by CWC in collaboration with National Remote Sensing Centre (NRSC), Hyderabad and the average annual water resource of the country for the study period of 30 years (1985-2015) has been assessed as 1999.20 BCM[4].

There is considerable variation in distribution of rainfall, both temporally and spatially which translates into variability in water availability. Barring the South-eastern region (Tamil Nadu, Puducherry, and Southern Andhra Pradesh) where much of the rainfall occurs due to North-East Monsoon during October-December, rest of the sub-continent receives about 75% of the annual rainfall within 4 monsoon months of June-September that too in about 40-45 rainy days (100-150 hours of

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rainfall). Spatial variability of rainfall is evident from the fact that while on one hand rainfall is of the order of 10,000 mm/year at Mawsynram in the North-eastern State of Meghalaya, it is merely about 100 mm/year in the western parts of the State of Rajasthan. In only few parts of India, can the rainfall be entirely depended upon as both sufficient in amount and regular in its distribution for raising crops with any degree of security against failure.[1]

3. DEVELOPMENT OF IRRIGATION IN ANCIENT INDIA

3.1 Pre-Historic Period

Great civilizations of the world flourished on the banks of mighty rivers with water harnessed for sustenance of life. Indians practiced the art of raising crops by artificial irrigation as early as the fourth millennium B.C.[1]

Earliest human settlements came up along the riverbanks and cultivation was carried out on the flood plains. Gradually, as the settlements grew in size and lands away from river banks were cleared of vegetation for cultivation, the practice of building inundation channels to carry waters of swollen rivers during the flood season began in the Indo-Gangetic plains and deltaic tracts of Southern India. Whereas flat alluvial plains did not permit construction of tanks for storing rainwater, undulating topography of the Peninsular India enabled irrigation from large number of tanks. Where surface waters could not be exploited, groundwater was tapped in the plains by means of dug wells and indigenous water lifting devices.

3.2 Indus Valley Civilization Period

People from the Indus civilization designed and constructed inundation channels for irrigating the flood plains which were further enlarged during the mature phase of civilization. Unfortunately, much of the evidence related to them got buried under series of river aggradations. Excavations carried out since the last century points to the existence of large non-agricultural population living in well-planned metropolitan cities with remarkable drainage system, flood protection embankments and huge granaries which could not have been possible without an extensive irrigated agricultural system supporting the same.

Mortimer Wheeler, who served as Director-General of the Archaeological Survey of India (ASI) in the 1940s, in his book *'Early India and Pakistan'* remarked that 'with the aid of some sort of irrigation system which is now deeply buried by post-Indus aggradations, but may in principle be assumed, it (the Indus civilization) grew food crops and cotton. It is not so difficult to infer that these people, who could build and maintain flood protection embankments, could align, grade and put up tanks for irrigation channels. Thus, the Indus Valley Civilization was essentially agricultural is borne out by the fact that huge granaries were put up for the storage of harvests.'

3.3 Development of Irrigation as per Ancient Texts

References to irrigation abound in the folklore and ancient literature of India. Historical records bear testimony to the existence of several old works in different parts of the country whose character was largely conditioned by the physiographical features of the area in which they were located.[5]

Knowledge of hydrological cycle was pervasive in the Indian ancient scriptures such as Vedas, Puranas, Jain, and Buddhist texts. Various verses of Rig Veda, Yajur Veda and Atharva Veda talk about water use by means of rivers, artificial canals, wells and ponds for agriculture and domestic purposes. Verse (VIII,3.10) of Rig Veda talks about the construction of artificial canals to irrigate desert areas also, which is possible only by efforts of skilled persons. Verses VI, 100.2 and VII, 11.1 of the Atharva Veda explains that the learned men bring water to desert areas by means of wells, ponds, and canals.[6]

Out of necessity, ancient Indians adopted location specific practices for conserving water, some of which are still being followed today. During the Mauryan era, the Pynes(diversion channels leading river water) in combination with Ahars (reservoirs with embankments on three sides built at the end of drainage lines or artificial works like Pynes) in Magadh region acted as combined irrigation and water management system.[6]The Arthashastra, a treatise on economics by Kautilya (295 BC) gives graphic details of modes of irrigation and rules followed during the period.[7]Meghasthenes, Greek ambassador to the court of Chandragupta Maurya records in his account 'Indica' that state officers measure the land and inspect the sluices by which is let out from the main canals into their branches, so that everyone have an equal supply of it. Kautilya says that 'king should construct dams, reservoir etc. filled with water either perennial or drawn from some other source or he may provide with sites, roads, timber, and other necessary things to those who construct reservoir of their own accords'.[6]Numerous epigraphical records – edicts, stone and copper inscriptions across the length and breadth of the country talk of generous donations made by kings and nobles for construction of tanks and wells for irrigating lands.

3.4 Some Ancient Irrigation Works

Ruins of ancient irrigation works are found all over India. Indus Valley Civilization sites such as Dholavira and Lothal were the evidence of small bunds and reservoirs for collecting rainwater which was then probably used for irrigation and domestic use.

Lake Sudarshana in the Kathiawar region of Gujarat State was a good example of a dam and storage reservoir constructed during the reign of Chandragupta Maurya (~300 BC), improved during the reign of emperor Ashoka (~250 BC), repaired by Rudradaman I (~150 AD) when it was breached. It was again repaired during the reign of Skandagupta (455-456 AD) of Gupta dynasty as recorded in the famous Junagadh rock inscription.

Kumrahar (Pataliputra) excavation report talks of a canal, 45 feet broad and 10 feet deep and traced upto the length of 450 feet and it is assigned to the Mauryan period (~300 BC). The canal was connected with the Sone and also with the Ganges for bringing monolithic pillars, but it is not unlikely that the canal also catered to irrigation needs.[8]

Kharavela, the great Kalinga king (1st century BC) brought into use an aqueduct constructed by Emperor Nanda (4thcentury BC) that had been neglected for a long time.[9]

Satavahanas (1st century BC to 2nd century AD), who ruled the Deccan region introduced brick and ring wellsfor the first time with the brick wells being solely used for irrigation. Gathasaptasati composed by Hala, a Satavahana king, has a reference to a water lifting machine called Araghatta.[8]

Karikala Chola of the earlier Cholas tamed the Cauvery River and built embankments and sluices to carry flood water to ponds. The Grand Anicut (Kallanai)on river Cauvery is attributed to him.It is amongst the oldest surviving and standing major irrigation works in the world.The original work (stones laid in clay) was probably built in the 2nd century AD. With subsequent additions and alterations, the Grand Anicut is by now a solid mass of stone masonry 329 m in length, 12 to 18 m in breadth and about 5 m height. Its alignment is serpentine in planand divert the waters of Cauvery across the fertile Cauvery delta region for irrigation via canals.[7]

Ruins of old inundation canals and traces of fields on hill terraces cultivated by channelizing rainwater which can be dated to the age of Kushanas (1st- 4th century AD) were found in North-Western part of Indian sub-continent. Due recognition was given to irrigated agriculture during Gupta age (4th – 6th century AD).

In Bengal, the system of overflow irrigation was very popular which made full use of abundant water of the Ganga and Damodar floods, and the monsoon rainfall. The system of irrigation essential for wet cultivation was also prevalent in Kamarupa (Assam) since early days as noticed by Hiuen Tsang (7th century AD) indicating that water from rivers or from lakes flowed round the towns.[8]

Figure 1: The Grand Anicuton the Cauvery River has been functional for over 2000 years

As per Kalhana's Rajatarangini, Lalitaditya, king of Kashmir is said to have constructed a series of water wheels in the 8th century AD to distribute the seasonal flood water of the Vitasta (Jhelum River) and the Mahapadma lakes for the purpose of irrigation. Several dams and canals were built during the reign of Avantivarman in the 9th century AD.[8]

Pallavas and later Cholas were pioneers in the construction of dams and embankments. Several tanks and reservoirs which have been maintained properly are still in use for e.g. Veeranam tank (10th Century AD), one of the drinking water sources of the Chennai city is fed by Cauvery waters and is connected to Cholagangam which was built by Rajendra Chola I (11th century AD) of later Cholas. Known as Ponneri tank, Cholagangam is currently maintained by Public Works Department of Tamil Nadu State and has an ayacut of 1374.37 acres. An inscription of Rajaraja-I of the later Cholas refers to Bahur tank near Puducherry (10th Century AD) and speaks of how the villagers had agreed to contribute towards the upkeep of the tank and agreed to arrange to remove the silt annually.[1]

Between 6th to 13th century AD, various dynasties that ruled the Deccan region such as the Chalukyas, Rashtrakutas, the Western and Eastern Gangas and the Kakatiyas patronized tank irrigation. System of tanks connected in a series was common in Karnataka, Telangana, Andhra Pradesh, and Tamil Nadu States. Small tanks were formed by earthen bunds, across the shallow valleys to harvest and store water for immediate use and allow the surpluses to pass down the contour to be picked up by similar tanks formed lower down.[10]

Bhojpur lake, said to have been constructed by King Bhoj of Dhara (11th Century AD) in Central India was 250 square miles in area which subsided after destruction of the embankment. W. Kincaid wrote about it in 1888 that engineers of those days understood that the drainage area of the Betwa and its tributaries was insufficient to fill the valley and that they skillfully supplied the deficiency by turning into the Betwa valley the waters of another river waters.[9]

4. DEVELOPMENT OF IRRIGATIONIN THE MEDIEVAL INDIA

4.1 Development of irrigation during the Delhi Sultanate Period

Historic records of early Muslim rule (712 to 1526 AD) show that irrigation from public canals, wells and tanks was popular.[7] Inundation canals and their remnants are seen in the Muzaffargarh and Dera Ghazi Khan districts of the West Punjab and Sind provinces of Pakistan. Many of them have since been abandoned, partly or wholly incorporated in the existing canal systems.[9]

During the Delhi Sultanate period, Ghiyasuddin Tughlaq (1320-25) was one of the first rulers who took interest in digging canals at the state's expense. Similarly, Feroz Shah Tughlaq (1351-86), built several canals.[11].

Feroz Shah Tughlaq is said to have built nearly 50 dams and 30 reservoirs for irrigation. The most notable canal built by him in about 1355 AD, was primarily meant to carry water from Yamuna River to his hunting grounds in Hissar District which is a precursor to modern day Western Yamuna Canal (WYC). As the canal was principally meant to convey water to the hunting grounds, in aligning it, advantage was taken of any natural depressions or drainage channels whose slope and direction were found suitable.[1]

4.2 Development of irrigation during the Mughal Period

Babur, the founder of Mughal Rule in India in his memoirs lamented about the absence of natural springs or artificial water courses in the flat plains of Northern India even though the rivers were bountiful. Akbar, son of Humayun got the early WYC built by Feroz Shah Tughlaq renovated in 1568, for irrigation of the lands in Hissar district. His grandson, Shahjahan got the canal again renovated, extended, and improved by the engineer Ali Mardan Khan. Munak branch canal to Delhi was also constructed to bring waters for his new capital Shahjahanabad, the present-day old Delhi. Shahjahan was also instrumental in building Hasli canal to bring waters from river Ravi to his Shalimar gardens at Lahore. The Hasli canal was 110 miles (177 km) in length, was about 30 ft (9.1 m) wide and carried a discharge of nearly 500 cusecs (14.16 cumecs).[1]The early Eastern Yamuna Canal was also begun by Ali Mardan Khan which was later abandoned owing to its bad alignment.[13]

4.3 Well Irrigation in the Medieval Period

Canals had limited reach during the medieval times and wells formed major means of irrigation, especially in the upper Gangetic plains. Various water lifting devices were employed for drawing water from wells, streams and ponds that are below the level of cultivated ground. Ibn Battuta, Moroccan traveler who visited India during the 14th century AD, mentioned about use of waterwheel in East Bengal and the Deccan. In the 16th century AD, Babur, in his memoirs observed that in Northern and Northwestern India two principal ways of drawing water out of wells were employed - the first device was akin to Persian wheel with a gear mechanism and drawn by oxen. Another device was based on the pulley with a rope thrown over it, one end of which reaching into the well had a water bag tied to it while the other end was tied to the yoke of oxen driven in a direction opposite to the well lifting the water bag which was then emptied by the person minding the rope.[12] Such a system was known popularly as Bullock Mot or Charsa. Another system which was in practice for shallow lifts was the Paecottah in the Southern India or the Lat in the Northern India which was like Shadouf system of Egypt involving human labor.

Figure 2: Paecottah or Lat was usually worked by two men for shallow lifts ('Irrigation in India' by Herbert M. Wilson, 2nd edition, USGS, 1903)

Figure 3: Charsa, a leather bucket pulled by bullocks with the aid of a pulley, Haryana ('A History of Agriculture in India', Vol.2, ICAR, 1982)

4.4 Development of irrigation in the Southern India

Epigraphical records of Southern India mention Jalasutradas (hydraulic engineers) employed in the department of vari-griha-karana (waterworks) to supervise the different departments of irrigation.[9]

Vijayanagara empire (1336-1646 AD) in the Southern India flourished because of the impetus provided to the irrigation works among other reasons. Vijayanagara Channels which are currently serving the Tungabhadra Dam Project command area were originally constructed as run-of-the-river channels by anicuts. Two of the World Heritage Irrigation Structures selected by the ICID in the year 2020 viz., Anantarajasagara or Porumamilla Tank in the Kadapa district and Cumbum tank in Prakasam district of Andhra Pradesh were built during Vijayanagara period. Anantarajasagara, built by prince Bhaskara of the 1^{st} Vijayanagara empire has a water spread of about 41.4 sq.km. and its bund consists of four natural hills connected by 3 earthen dams rivetted with Cuddapah slabs. An inscription dated 1369 A.D. on two stone slabs in a temple nearby throws light about the tank building activity of that period. It gives a remarkable specification for the selection of tank site and its construction. This shows that the science of building dams was well advanced in those days.[9] Cumbum tank is said to have been constructed by Gajapatis of Kalinga in the 15^{th} century AD and restored by one Vijayanagara princess during the reign of Krishnadevaraya, the greatest among Vijayanagara emperors. It is currently serving as a medium irrigation project with an ayacut of about 7000 acres.

Figure 4: Cumbum Tank, Prakasam District, Andhra Pradesh, Google Earth

Krishna Deva Raya paid attention for improving the irrigation of the dry lands around his capital. He constructed, in 1521 AD, the great dam and channel at Korragal on Tungabhadra and the Basavaiah channel, both of which are still in use. Another great irrigation work of his was the construction of an enormous Nagalapura tank around 1520 AD, which he carried out taking the help of a Portuguese engineer Joao de la Ponta whose services were lent to him by the then Governor General of Goa, Alfoso de Albuquerque.[10]

Figure 5: Porumamilla Tank, Kadapa District, Andhra Pradesh, Google Earth

5. DEVELOPMENT OF IRRIGATIONIN THE NINETEENTH CENTURY

The irrigation works in existence at the beginning of the 19^{th} century included innumerable wells all over the country, many tanks in Peninsular India and few inundation canals in Sindh, Punjab and submontane districts of Northern India. Large extensive irrigation works were not taken up until the British rule with few notable exceptions such as the Grand Anicut, which was irrigating over 0.24Mha at the beginning of the 19^{th} century.[5]

5.1 Administration and Financing of Irrigation Works during the 19^{th} Century

With the constantly evolving political and economic scenario, the administration and financing of irrigation projects in India has undergone many changes and modifications. Till the setting up of the Public Works Department (PWD) in 1854, all public works excluding railways were constructed and managed by the army engineers known as Royal engineers under the superintendence of a Military Board. In 1866, the PWD was divided into the Civil Works Branch including irrigation, roads, etc., and the Military Works Branch. By 1895, the Military Works Branch became a separate Military Works Department and the Public Works Department became purely civilian in nature.[1]

As the canal irrigation projects proved to be potentially profitable ventures, pressure was brought upon the Government to entrust further exploitation of irrigation potential of the country to the private enterprise. Government reluctantly allowed private enterprises, in 1858, under the ‘Guarantee system’ to take up irrigation projects guaranteeing a return of 5% on the capital outlay. Consequently, two private irrigation companies viz ‘The East India Irrigation & Canal

Company' and 'The Madras Irrigation Company' were floated in England.[1]

Experience of both these private irrigation companies has been one of abject failure. Their failure has led to some important policy decisions viz., (i) Irrigation projects would in future be constructed by the State through its own agency, (ii) Irrigation projects would be financed from public loans raised specifically for this purpose; and (iii) Political boundaries would not be allowed to come in the way, when best possible utilization of water of a river for irrigation purpose was being considered.[1]

Government adopted the practice in 1867, in respect of works which promised a minimum net return.[5] Certain measures were subsequently built into the system in 1879 for safeguarding the loan capital raised to execute irrigation projects because of the recommendations made by a sub-committee appointed by the British Parliament.[1]

The recurrence of drought and famines during the second half of the 19th century underlined need for development of protective irrigation works. Few protective works which were not likely to meet the 'productivity criteria' were taken up and financed from the current revenues.[7]

The construction activities during the nineteenth century can be divided into three periods:[1]

(i) 1800-1836: The Period of First Great Ventures

(ii) 1836-1866: The Period of Great Classic Works

(iii) 1866-1901: The Period of First Loan Works and Early Protective Works

5.2 The Period of First Great Ventures (1800-1836)

The early efforts of the British were directed towards the improvement and utilization of old indigenous works, rather than the construction of new irrigation projects. The following improvement schemes are worthy of note since they have resulted in three of the most lucrative systems in India.[14]

5.2.1 Western Yamuna Canal (WYC)

It replaced the old canal built by Feroz Shah Tughlaq and renovated by the Mughals which had ceased to flow from around 1750 AD. The system continued to remain functional with various remodeling, extension works taken up from time-to-time including a permanent weir at Tajewala, a low masonry darn at Dadupur[7], Sirsa branch, the largest branch of the canal[14]. Tajewala barrage was abandoned after construction of Hathni Kund Barrage on Yamuna River in 1999[7].

5.2.2 Eastern Yamuna Canal (EYC)

As in the case of the early WYC, early EYC built during the Mughal period mostly utilized the courses of river creeks and drainage depressions.[1]The same was remodeled and extended from time-to-time. A permanent head regulator for EYC has been provided after the construction of Hathni Kund Barrage on Yamuna River in 1999.[7]

5.2.3 Cauvery Delta System

In 1834, upon Sir Arthur Cotton's advice, Upper Anicut was constructed in 1836 about 32 km u/s of Grand Anicut[14]. In 1843-45, Upper Anicut was modified to construct a masonry dam across the head of the Cauvery. In 1899-1902, both Anicuts were remodeled and were fitted with lifting gates. After 1910, various improvements were made resulting in a considerable growth of irrigated area.[7]

5.3 The Period of Great Classic Works (1836-66)

Experience and knowledge gained coupled with financial returns led directly to further investigations as to the possibility of extending river irrigation to other parts of India. The period from 1836 to 1866 marked the investigation, development, and completion of the following four major works.[5]

5.3.1 Upper Ganga Canal

Upper Ganga Canal, the first great wholly artificial canal constructed in Northern India was conceived by Colonel Sir Proby Thomas Cautley. The surveys for the canal were commenced in 1836 and ground was broken in 1842 and opened for irrigation in 1854.It was constructed as Ganga Canal and was known by that name until the opening of Lower Ganga Canal in 1878. At that time, it was the largest irrigation canal in the world, originally designed to carry 191 cumecs, later revised to 257 cumecs. Gross irrigation then was 0.77 Mha. It served, as a model for several canal projects constructed later.[7]

In 1897, a surplusing dam was constructed to allow escape of surplus water back into the river. Solani Aqueduct is a famous structure of brick masonry in lime mortar. It consists of fifteen arches of 15.2 m. span each. The embankment which carries the canal is nearly 10.7 m. above the bed of the Solani Torrent. The canal was lined with brick masonry, in a length of about 3.2 km in this filling reach, on both sides of the aqueduct. To construct such a large and watertight embankment, when compaction machinery or even the rudiments of soil mechanics were unknown, was an exceptional engineering feat in itself.[1]

5.3.2 Godavari Delta System

The first proper headwork for a canal system in India was constructed in 1846 for Godavari Delta System. The success of the diversion works for the Cauvery System led Sir Arthur Cotton to propose permanent head works for the Godavari System also.[1] The design of the diversion was bold and was largest in world at the time comprising about 4 km of weir, 2.4 km of embankments and three sets of canal head works and navigation locks.[7] The delta, which was liable to famine till the beginning of 19th century is now an expanse of paddy fields broken by gardens of fruit tree.[14]

5.3.3 Upper Bari Doab Canal (UBDC)

The Bari Doab Canal, as it was known until the construction of Lower Bari Doab Canal (LBDC) during 1907-13, was designed to utilize the old Hasli canal built by Shahjahan but eventually the alignment of the old canal could not be extensively used.[1] Later on, some modifications were made and the canal was opened in 1859 with designed full supply discharge of 203 cumecs. Due to the partition of the country in 1947, a substantial part of area irrigated by UBDC and portions of some of its channels went to Pakistan.[1]

5.3.4 Krishna Delta System

Construction of 1,021 m long weir with head regulators and locks at both its ends, for the Eastern and the Western Canals[7] was commenced in 1852 and completed in 1855. Following a breach in 1952, a new barrage (Prakasam barrage) with the regulator was constructed during 1953-62.[1]

5.4 The Period of First Loan Works and Early Protective Works (1866-1901)

The new policy of financing productive irrigation works from public loans led to the inauguration of several new works, important among these projects were the following:

5.4.1 Mutha Canal System

India had already taken great strides in the construction of large irrigation canals and river diversion works and was well ahead of other countries in this field.[1] Mutha canal system marked yet another stage in the history of irrigation in India with the building of first great masonry dam 30.2 m high above the riverbed at Khadakwasla. Colonel Fife of the Royal Engineers was the originator of the scheme. Construction work began in 1869 and completed in ten years.[15] The object of the scheme was twofold, the protection from famine of a very precarious tract in the Pune District and the assurance of a supply of potable water to the Pune city and cantonments nearby. Although classed as unremunerative, the project has proved a thoroughly sound investment on the part of Government.[14]

5.4.2 Sirhind Canal System

The Sirhind Canal System was undertaken in 1873. It was financed from public loan funds to irrigate areas lying in British Punjab as well as in the Princely States of Patiala, Nabha, Jind, and three principalities of Faridkot, Malerkotla and Kalsia without any consideration of political boundaries and cost duly shared between beneficiaries. Sirhind canal had a design discharge of 271 cumecs, was opened for irrigation in 1882. The area irrigated is now in Indian Punjab.

5.4.3 Lower Sohag and Para Canals

These canals (1882-87) marked a new phase in Northwest India, viz., colonization of waste lands, which in due course developed magnificent agriculturists' colonies in the West Punjab and Sindh now in Pakistan. The canals irrigated crown waste lands and were pioneering works.[7] This canal was so well-administered and the demand for water for irrigation purposes was so great that it earned a revenue of nearly 45% on the capital outlay.[1]

5.4.4 The Periyar Project

The Periyar Project involved Inter Basin Transfer of Water (IBTW)from the west flowing Periyar River to the east flowing Vaigai River across the major water divide of the Western Ghats. Mullaiperiyar dam, a gravity dam of 52.6 m height above the riverbed, built in 1886-1895 enabled the diversion from its reservoir through a tunnel which was considered as an outstanding engineering feat.[1]

5.5 Status of Development of irrigation at the end of 19th century

The gross area irrigated in British India by public works at the close of the 19th century, according to the First Irrigation Commission, was about 7.5 million hectares. Of this, 4.5 million hectares was from productive and protective works and 3 million hectares from minor works like tanks, inundation canals etc. for which no separate capital accounts were maintained. The area irrigated by protective works was only a little more than 0.12 million hectares.[5]

The area irrigated by private works in British India around1900 was 5.7 million hectares, about 70% of it by wells and the remaining by tanks, streams, channels etc. Private works had been aided by the State from times immemorial, but a definite policy emerged only after the Famine Commission of 1880 recommended 'taccavi' loans for the construction of wells etc. In 1883, Government of India enacted the Land Improvement Loans Act, enabling it to advance money for specific land-improvement purposes. This was followed by the Agriculturists' Loan Act in 1884.[5]

Public works therefore accounted for 56% of irrigated area. The gross area sown was 82.2 million hectares of which about 16% was irrigated. Source-wise, canals irrigated 45% of the area, wells 35% tanks 15% and other sources 5%.[5]

5.6 Irrigation Canals Used for Navigation Purposes

When railway communications were absent, navigation through irrigation canals was considered feasible. Accordingly, navigation locks at canal falls were provided in Godavari and Krishna Delta Canals of the then Madras presidency, the UGC in United Provinces, the WYC and Sirhind Canals of Punjab etc., The navigation aspect of canals did not prove successful or remunerative and the concept was gradually abandoned.[7]

6. DEVELOPMENT OF IRRIGATION IN THE TWENTIETH CENTURY UPTO INDEPENDENCE

6.1 Administration and Financing of Irrigation Works up to Independence

The First Famine Commission of 1880 emphasized the need for direct State initiative in the development of irrigation particularly in the vulnerable areas. In 1901, the Government of India appointed the *First Irrigation Commission* presided over by Colin Scott Moncrieff, to report on its protective nature against famines. Its recommendations submitted in 1903 were adopted giving a great impetus to new irrigation works.[7]

The actual execution and management of irrigation works were the function of the State Governments.

However, until 1921, the Government of India and the Secretary of State in London exercised powers of superintendence, direction, and control on all irrigation activities of the State P.W.Ds., whether technical or administrative, through an Inspector General of Irrigation and a Public Works Secretariat of the Government of India, with an engineer of experience as its secretary.[16]

6.1.1 Constitutional Reforms of 1921 and 1937

In 1921, introduction of the Montagu Chelmsford Reforms brought about a transfer of powers to the provinces. Irrigation became a 'Provincial' but 'Reserved' subject. On 1st April, 1937 'Provincial Autonomy' was introduced and irrigation became a 'transferred' subject as per the Government of India Act, 1935.[1]

In 1927, the Government of India in consultation with the Provincial Governments had set up the Central Board of Irrigation as a coordinating body between the provinces.[1]The Government of India Act, 1935 made a radical change in the administration of irrigation projects. The act brought irrigation within the jurisdiction and control of the local Provincial Governments subject to certain contingencies. Irrigation was to assume a federal character only when there were any inter-State disputes.[1] Provincial Governments got exclusive powers over 'Water, that is to say, water supplies, irrigation and canals, drainage and embankments, water storage and water power.' The only items reserved for the Central list were 'shipping and navigation on tidal waters', and for the Concurrent Legislative List, 'shipping and navigation on inland waterways'.[17]

6.1.2 Post WW-II Reconstruction Programme

The water policy devised by the Labour Department during the post-war period visualized much greater role and participation for the Central Government than was permitted under the provisions of the 1935 Act. While the Policy Statement made it clear that it had no intention to interfere with the freedom of the provinces to devise and execute their own plans, it considered that irrigation and hydro-electric projects on inter-State rivers which involved more than one State and which required regional development of entire river valley basins the participation of the Central Government was necessary.[17]

Dr. B. R. Ambedkar, Member (Labour) in Governor General's Executive Council during 1942-46 was instrumental in evolving a policy framework for water resources sector which had three components, namely: (a) adoption of a concept of River Valley Authority or corporation for the management and control of projects on inter-State rivers; (b) adoption of the concept of regional and multipurpose development of River Valley Basin as a whole; and (c) establishment of administrative and technical expert bodies at the Centre.[17]

With the untiring efforts of the Labour Department, an agreement was finally reached between the Central Government and the Governments of Bihar and West Bengal (the Governments participating in the Damodar Valley project) to form an Authority on the lines of Tennessee Valley Authority. This was given legal force when the Constituent Assembly of independent India enacted in 1948 the Damodar Corporation Act to provide for the establishment and regulation of a semi-autonomous corporation for the development of the valley.[17]

6.1.3 Setting up of Central Waterways, Irrigation and Navigation Commission (CWINC)

In 1945, upon the advice of Dr. B. R. Ambedkar, the Government of India constituted the Central Waterways, Irrigation and Navigation Commission

(CWINC) to secure planned utilization of water resources of the country. It was to be a central fact finding, planning, and coordinating organization with authority to undertake construction work as per the requirement. CWINC was later reorganized as Central Water and Power Commission (CW&PC) and the present-day Central Water Commission (CWC). CWC has played a vital role in development of irrigation potential through major and medium projects by way of appraisal of projects for investment clearance, providing detailed design consultancy, monitoring of progress of projects, etc. during the plan period after the setting up of the Planning Commission in 1950.

6.2 Development of Irrigation during the early 20thCentury (1901-1921)

The findings and the recommendations of the *First Irrigation Commission* (1901) were mostly accepted by the Government, gave a great impetus to the construction of new irrigation works throughout the country.[1].

Several large projects were undertaken during this period and were successfully completed in spite of World War I. The more important of such projects included: the Punjab's Triple Canals Project, the Lower Jhelum Canal, and the Upper Swat Canal (now in Pakistan); the Godavari Canals, the Pravara Canals and the Nira Right Bank Canal in Maharashtra; the Sarada Canal and Wainganga Canal and Mahanadi Canals (CP).[7]

Protective works were taken up in Bihar, Bombay, Central Provinces, Bundelkhand and the Mirzapur-Allahabad area of United Provinces. In the princely State of Jammu & Kashmir, Ranbir and Pratap Canals from Chenab River were taken up and completed in the early 1900s.

The area irrigated by public works in British India (excluding the princely States) increased to 10.4 million hectares in 1920-21. The total area irrigated by both public and private works rose to 19.3 million hectares. The total irrigated area in the country, including the Princely States added up to 22.6 million hectares.[5]

6.2.1 Triple Canals Project

It was largest irrigation work executed in the pre-independence period and catered to Inter Basin Transfer of Water linking three rivers, viz. Jhelum, Chenab and Ravi. Three canal systems were constructed, and this enabled the waters of the three rivers to be utilized to the best advantage of the Punjab Province irrespective of the watershed boundaries. The new canals brought under command an area of four million acres.[15]

6.2.2 Godavari Canals Project

The Project (1907 -1916) was undertaken for protection against famine in Nashik and Ahmednagar Districts of Bombay Presidency (now Maharashtra). Although financially classified as 'unproductive', it transformed the drought prone area.[7]

6.2.3 Pravara River Canals Project

At the time of its construction in 1910, the 82 m high Bhandardara (Wilson)dam was one of the highest dams in the world.7Left and right bank canals from the reservoir irrigating a gross area of about 30000 ha.

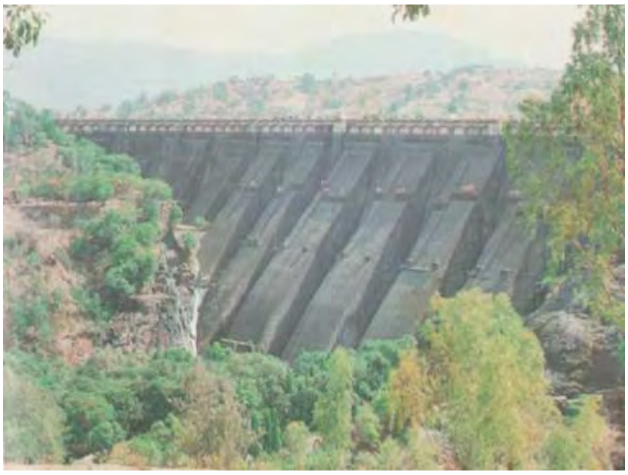

Figure 6: Bhandardara Dam

6.2.4 Sarda Canal Project

It was taken in hand in 1915 and completed in 1926. The scheme consisted of two parts, the Sarda Canal with a discharge of 226 cumecs and Sarda Kichha Feeder, with a discharge of 42.5 cumecs, taking off from the main canal near its 10th km. The headworkswere located at Banbasa few km below the point where the river debouches from Nepal hills at the boundary with agreement about some land transfer with the Government of Nepal.[7]

6.3 Development of Irrigation during the Period 1921-1935

An increase in the tempo of construction of new irrigation projects was witnessed during this period, not only in British India but also in some Princely States.1These included theCauvery-Mettur Project in Madras, the Sutlej Valley Project in Punjab,the Sukkur Barrage in Sind, the Nizam Sagar Project in Hyderabad Princely State andthe Krishnaraja Sagar Project in Mysore Princely State. Another project taken upduring this period was the Damodar Canal in 1926-27 in Bengal Province.[5]

6.3.1 Sutlej Valley Project

After prolonged negotiations, an agreement was reached in September 1920, among the Governments of the Punjab, and princely states of Bikaner and Bahawalpur, the three partners concerned, which formed the basis of the Sutlej Valley Project. The Sutlej Valley Project was, then, amongst the largest irrigation projects in the world and comprised four different head-works, all of them barrages, across the River Sutlej at Ferozepore, Suleimanke, Islam and Panjnad, and eleven big canals, both perennial and non-perennial, taking off from these head-works, which were operated as one unified system.[1]

6.3.2 Sukkur Barrage Project

This Project in Sind was unique, because seven large canals took off from a single diversion barrage across the Indus River. The project in its final shape was sanctioned in April 1923 and work on it was started soon. Later on, the project came to be designated as the Lloyd Barrage and Canals Project. The construction work of the Barrage was completed in 1932.[1]

6.3.3 Krishnaraja Sagar Project

Construction of Krishnaraja Sagar project was started in 1911 during the reign of Krishnaraja Wadiyar. The dam was designed by the late M. Visvesvaraya, Chief Engineer who subsequently became the dewan of Mysore State. The reservoir served two objectives: (i) to supply water for irrigation to about 30,587 ha of land in arid tract of Mandya District, and (ii) to ensure a steady supply of water for generating hydroelectric power at Sivasamudram. The dam located below the confluence of Cauvery, Hemavathi and Lakshmana-tirtha rivers is 2,621 m long with a maximum height of 42.7 m above the foundation. It was built in random rubble stone masonry in surkhi mortar, the facing being built of roughly dressed granite. The dam was provided with a large number of sluices of different sizes and at various levels, for flood disposal, for scouring silt, for irrigation and for power generation.[1]

6.3.4 Nizamsagar Project

Nizamsagar Projectwas executed by the Princely State of Hyderabad during 1924-1931. It comprised a dam across River Manjira, a tributary of Godavari and a canal with a full supply discharge of 96.3 cumecs irrigating gross area of 1,11,293 ha. The length of the dam is 3,901 m of which 2,286 m is built in stone masonry and the rest consists of earthen embankments faced with masonry. The height of dam is 48.1 m above the deepest foundation level. A hydroelectric powerhouse, generating 15,000 kW, was added during the First Five-Year Plan period (1951-1956).[1]

6.3.5 Cauvery Mettur Project

The Cauvery Mettur Project, was constructed between 1925- 1934. The question of improving the conditions of irrigation in the Tanjore Delta by storage of the Cauvery waters, was first considered in 1834 by Sir Arthur Cotton. After further prolonged negotiations between the Madras Government and the Government of the Princely State of Mysore, final selection of the site of the dam at Mettur was made in 1924.1It consists of a dam built in stone masonry, 1,615 m. in length and 65.1 m. maximum height. The project provided irrigation to about 1,21,815 ha of new areas, in addition to supporting &stabilizing irrigation in the delta. The water released at Mettur are picked up at the canal head located at the Grand Anicut, nearly 193.4 km downstream of the dam.[1]

6.3.6 Gang or Bikaner Canal

It takes off from River Sutlej at Ferozepur Barrage on left bank, upstream of head regulator of Eastern Canal. Its construction started in December 1922 and completed in October 1927. The main canal 135 km in length which was lined with hydraulic lime concrete for full length except 8 km, was the first large canal to be lined in India. The lime concrete lining was meant to cut down absorption losses in the first 117.4 km of main canal running through territory of Punjab State. No irrigation was done from it in this long reach. The portion within Bikaner state (now part of Rajasthan) was named as "Gang Canal" named after Ganga Singh, the then ruler of the state of Bikaner. The culturable commanded area of the canal was 2,83,290 ha and the gross area to be irrigated was 2,25,885 ha[1]

6.4 Development of irrigation during the Period 1935-1950

After GoI Act, 1935 the Provincial Governments set about execution of irrigation projects with vigour, but World War II in 1939 reduced the tempo for some time.7An exception was made in respect of two major projects in the Punjab viz. the Thal and the Haveli, the first of which had been recommended by the Irrigation Commission. Both projects are now in Pakistan.[5]

The Haveli Project was designed and constructed by Dr. A. N. Khosla, the founder Chairman of CWC would always be remembered with this project. The Trimmu Barrage was designed on sandy foundations in accordance with Khosla's theory of uplift pressures for structures on sandy foundations. Silt excluders were included in the design of the headworks following the experience gained elsewhere on silt induction. Extensive lining of canals with tiles in cement mortar was carried out to reduce seepage losses. There was close collaboration between field research by means of model experiments and the design office which paved the way for subsequent rapid development of irrigation research throughout India.[1]

Many river valley projects such as Damodar River Valley Projects, the Sone River Valley Projects, the Mahanadi (the Hirakud Project) and the Kosi and others on river Chambal and rivers of the Deccan were conceived by the Labour Department for multipurpose development with flood control, irrigation, navigation, domestic water supply, hydropower and other purposes.17They were taken up for execution after independence during the plan period.

7. DEVELOPMENT OF IRRIGATION AFTER INDIAN INDEPENDENCE, 1947

7.1 Aftermath of the Partition

The partition of India in 1947 dealt a severe blow to India's predominantly agricultural economy. 18% of the population of undivided India and 23% of its geographical area went to Pakistan. India lost 31% of the irrigated area on which the country had largely depended for cereals, fibers and oilseeds. Nearly half of 11,340 cumecs of water carried by all the canals of India before partition fell to the share of Pakistan. Some of the most impressive irrigation projects, like the Sutlej Valley Project and the unique Sukkur Barrage across the Indus with its extensive systems of canals, fell to the share of Pakistan. East Bengal, which comprises the fertile Ganga-Brahmaputra delta region and situated in the assured rainfall zone which produces good crops of Rice and Jute also went to Pakistan, now Bangladesh.[5]

The net irrigated area in the Indian sub-continent at the time of independence was about 28.2 Mha, the largest in the world. Partition resulted in division of the irrigated area between the two countries, India and Pakistan, as 19.4 and 8.8 Mha, respectively.7The corresponding net sown area was 98.5 Mha in India and 18.3 Mha in Pakistan. The percentage irrigated area to net sown area was 19.7% for India and 48.1% for Pakistan. This showed that the percentage of irrigated area dropped to 19.7% after partition from 24.1% in the undivided India.18The irrigation works which remained with India, barring some of the old works in Uttar Pradesh and in the deltas of the South, were mostly of a protective nature, meant more to ward off famine than to produce significantly higher yields. The loss of these major irrigation systems made an immediate and disastrous impact on India's already critical food problem, resulting in a deficit of four million tons in 1947. Large areas of cultivated land had been left fallow due to cross movement of refugees dislocated due to partition. In the aftermath of WW-II and dislocation of economy of many countries, the world was also passing through a food crisis in 1947. The country had, therefore, no option but to make heavy investments in irrigation in order to increase food production.[5]

7.2 Development of irrigation during the Five-Year Plans

In 1950-51, net area irrigated in India was 20.85 Mha, an area of 1.71 Mha was being irrigated in more than one crop season, the total extent of gross irrigation was about 22.50 Mha. Population of India was about 361 Million and annual food production was 51 Million tons which was inadequate.[7]

The Planning Commission recognized the crucial importance of developing irrigation to increase agricultural production, and accordingly assigned a very high priority to it in the Plans.[5]

7.2.1 Categorization of Irrigation Projects

Irrigation Projects are classified under three categories, namely, major medium and minor, depending upon the extent of Cultural Command Area (CCA). The details are as under:

Major Irrigation Projects:	Those having CCA of 10,000 Ha or more
Medium Irrigation Projects:	Those having CCA between 2000 Ha to 10,000 Ha
Minor Irrigation Projects:	Those having CCA of 2,000 Ha or less

The Ultimate Irrigation Potential from major & medium irrigation projects has been assessed to be as 58.46 Mha. These include large multi-purpose projects envisaging irrigation and other benefits such as hydro-power, flood control, water supply, navigation etc. The irrigation facility created through major and medium irrigation projects are more dependable with greater reliability ranging from 75% to 90%. The investment towards major and medium projects has been done by Central and respective State Governments.

The source for Minor Irrigation Schemes is both surface as well as ground water. The surface water minor irrigation schemes mainly comprise tanks, small diversion works and small lift irrigation schemes. The Ultimate Irrigation Potential from surface water minor irrigation schemes is assessed to be 17.38 Mha. The investment towards surface water minor irrigation schemes has been done mainly by respective State Governments.

The Ultimate Irrigation Potential from ground water minor irrigation schemes is assessed to be 64.05 Mha. These schemes mainly comprise of dug wells, shallow and deep tube wells. Ground water development got boost after the spread of rural electrification. For all practical purpose, these types of irrigation schemes are privately owned and managed. The use of ground water has been quite uneven in the country. Gujarat, Tamil Nadu, Punjab and Haryana are amongst the States where large ground water development has taken place whereas it is quite low in Eastern India.

7.2.2 First Five Year Plan (1951-56)

Many proposals had been investigated as part of the post-war reconstruction programme earlier and some were taken in hand for e.g., Bhakra-Nangal, the Damodar Valley and Hirakud projects. CWINC was entrusted with the construction of the Hirakud Dam project during 1948-49, on behalf of the Government of Orissa. An important event in the early years was the decision to have the Bhakra Dam built by Indian engineers. Another feature of the Bhakra dam construction was that it was done exclusively with departmental labor and no contractor, all labor having been recruited, trained, and supervised and paid directly by engineer officers of the Punjab Government. To avoid procedural delays in according sanctions, purchase of materials, appointments etc. Bhakra Control Board was set up to supervise and monitor the progress of the Project. Bhakra Control Board was chaired by Governor of Punjab and Chairman, Central Water and Power Commission was one of its members.

In the 1st Five Year Plan (FYP), there were about 267 major and medium schemes under implementation, of which 27 were major projects.5Several more projects were included in first plan which include Nagarjunasagar (AP), Kosi (Bihar), Chambal (Rajasthan & MP), Harike Barrage (Punjab), Tungabhadra (Karnataka and AP), Bhadra and Ghatprabha (Karnataka), Kakrapara (Gujarat), Lower Bhawani (Tamil Nadu), Matatila (UP), and Mayurakshi (WB). Simultaneously, minor irrigation schemes were also undertaken with financial assistance from the Government.[7]

On the pattern of Bhakra Control Board, Control Boards for other major projects viz., Chambal Project, Nagarjuna Sagar Project were established for quick decision making, speedy and efficient execution of works.

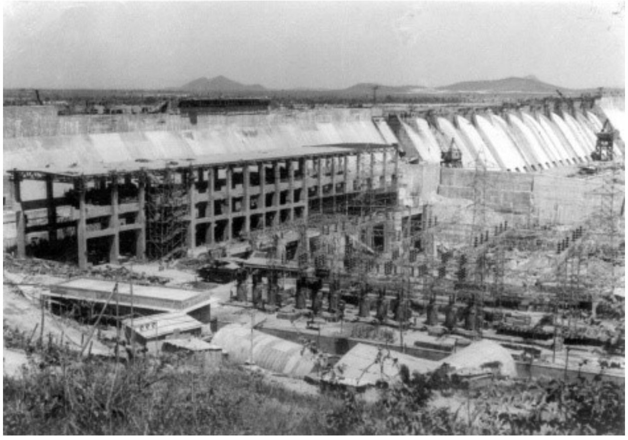

Figure 7 and 8: Hirakud Dam Project was the first Multipurpose Project in India. Completed in 1957, it provided irrigation to 2.51 lakh ha. Length of the dam (including dykes) is 25.5 Km (Water Resources Development in India, 1997, CWC)

Figure 9: Bhakra Dam, constructed in independent India across Sutlej River, irrigates 13.35 lakh hectares annually. Its hydropower generation (installed capacity) is 1204 MW. Height of the dam is 226 m (Water Resources Development in India, 1997, CWC)

Figure 10: Workers swarm over scaffolding to erect the Nagarjuna Sagar dam, large masonry dam across Krishna River (National Geographic, May 1963)

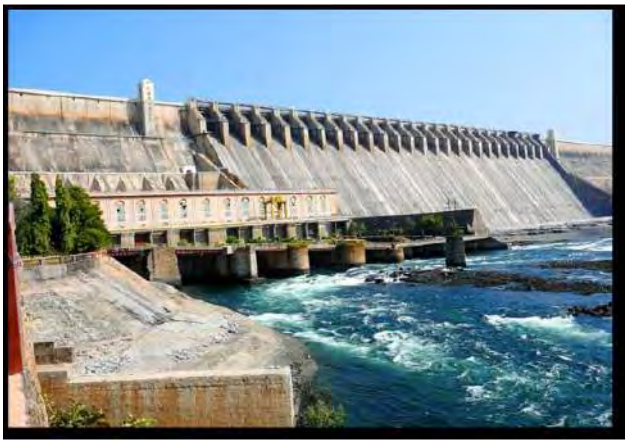

Figure 11: Nagarjuna Sagar Dam Project after completion (Bhagirath, Publications Division, GoI)

7.2.3 Second Five Year Plan (1956-61)

In the 2nd FYP, 195 major and medium projects were taken up, of which 25 were major schemes.5 Some important schemes of second FYP were Indira Gandhi Canal (Rajasthan), Gandak (Bihar &Uttar Pradesh), Tawa (Madhya Pradesh), Parambikulam Aliyar (Tamil Nadu), Kabini (Karnataka), Kansabati (West Bengal), Kadana (Gujarat), Ukai (Gujarat), Broach-Narmada (Gujarat), Koyna – Purna – Girna – Mula – Khadakvasla (Maharashtra).[7]

7.2.4 Third Five Year Plan (1961-66)

Due to inadequate finance, several schemes were delayed. In view of the carryover of many schemes, great emphasis was placed on their completion. Only 9new major and 86 medium schemes were taken up during the 3rd FYP.18Some of the important schemes were Beas (Punjab), Malaprabha (Karnataka) and Upper Krishna (Karnataka).[7]

7.2.5 Annual Plans (1966-69)

During the three-year period of Annual Plans, most of the States concentrated on large number of carry over schemes. Maharashtra, however launched six new projects, viz, Bhima, Jayakwadi, Krishna, Warna, Upper Godavari and Kukadi.[18]

7.2.5 Fourth Five Year Plan (1969-74)

During the 4thFYP, emphasis was shifted to the completion of ongoing projects, integrated use of surface and ground water, adoption of efficient management techniques and modernization of existing schemes.11 During the plan period, 9 major and 73 medium schemes were completed. Of the 9 major schemes completed, three were taken up in the first plan, three in the second plan and one each in third and fourth plans.[18]

The Second Irrigation Commission was set up in 1972 in the context of a rapidly expanding economy and an even more rapidly expanding population, and in the wake of rapid advances in agriculture, aptly called 'The Green Revolution'.5The Commission in its report inter-alia suggested the need for conjunctive use of surface and groundwater, preparation of complementary programmes covering engineering works, watershed management and ayacut development and recommended constitution of seven River Basin Commissions for the whole country to oversee all water resources development. Keeping in view the social urges and the demand for the removal of regional and social disparities, the Commission recommended construction of minor works in a time bound framework in under-developed area. In order that irrigation in India should pay for itself, the Commission recommended that the water rates should be raised to a level sufficient to cover the cost of maintaining and running the works and a reasonable rate of interest on investment. The concept of participatory irrigation management by constituting water users' associations was another important recommendation for economical and efficient use of water resources.[19]

7.2.7 Fifth Five Year Plan (1974-78)

The Irrigation Commission made specific recommendations that systematic development of commands of irrigation projects should be taken up to fully utilize the irrigation potential created. Government of India initiated a Centrally Sponsored Command Area Development Programme (CADP) in December 1974 to improve irrigation potential utilisation and optimise agricultural production from irrigated land through integrated and coordinated approach of efficient water management.

The 5th FYP also concentrated on completion of carryover schemes and very few new schemes were taken up in the plan period. Continuous shortfall in achievement of targets of creation of irrigation potential was evident by the end of fourth FYP. Urgent need for effective monitoring and evaluation of implementation of irrigation projects was felt. Accordingly, systematic monitoring of projects was started for their timely completion.

7.2.8 Annual Plans (1978-80)

This period also saw increased emphasis in completion of ongoing schemes. One major and 20 medium projects were completed.[18]

7.2.7 Sixth Five Year Plan (1980-85)

During the 6th FYP it was envisaged that 65 major projects started before April 1976 would be completed on priority. Factors which affected early completion of the carryover schemes were problems of land acquisition, rehabilitation, changes in scope of projects originally sanctioned etc., Notwithstanding the problems faced as mentioned, the sixth plan saw completion of 32 major and 158 medium schemes.[18]

7.2.8 Seventh Five Year Plan (1985-90)

There were 181 major and 433 medium schemes in the 7th plan which were continuing from the earlier plan periods. During the 7th FYP, another 18 major and 29 medium schemes were added. Reasons for non-completion of projects as planned and shortfall in the creation of potential targeted were deliberated for making the deficiencies good in the eighth and subsequent five-year plans.[18]

7.2.9 Eighth Five Year Plan (1992-97) & Ninth Five Year Plan (1997-2002)

At the end of 7th FYP, as many ongoing projects were on-hand, new schemes were generally restricted. Greater emphasis was laid on completion of projects at an advanced stage of completion (with expenditure of 75% or more). This policy continued during 1990-91, 1991-92 Annual Plans, 8th FYP (1992-97) and 9th FYP (1997-2002). Government of India during 1996-97, launched an Accelerated Irrigation Benefits Programme (AIBP) to provide Central Loan Assistance (CLA) to major/medium irrigation projects in the country, with the objective to accelerate the implementation of those projects which are beyond resource capability of the States or are in advanced stage of construction. While selecting the projects, special emphasis was to be given to Pre-Fifth and Fifth Plan projects. Priorities were also given to those projects which were benefiting Tribal and Drought Prone Areas.

7.2.10 Tenth Five Year Plan (2002-2007)

During 10th FYP, Central Government in January 2005 launched a pilot scheme titled 'Repair, Renovation and Restoration (RRR) of Water Bodies directly linked to Agriculture' for restoring the irrigation benefits from existing water bodies. The implementation of full-fledged scheme was started from 11th FYP.

7.2.11 Eleventh Five Year Plan (2007-12)

During 11th FYP, Government of India initiated scheme of National Projects with a view to expedite completion of projects identified as National Projects. So far, 16 projects have been declared as National Projects.

7.2.12 Twelfth Five Year Plan (2012-17)

During 12th FYP, Government of India launched the Pradhan Mantri Krishi Sinchayee Yojana (PMKSY) during 2015 with the motto of 'Har Khet Ko Pani' ensuring access to some means of protective irrigation to all agricultural farms in the country, to produce 'per drop more crop', thus bringing much desired rural prosperity. The programmes as being implemented by the Government of India, viz Accelerated Irrigation Benefits Programmes (AIBP), Repair, Renovation and Restoration (RRR) of Water bodies and Command Area Development and Water Management (CADWM) were subsumed in PMKSY.

7.2.13 Minor Irrigation

The area irrigated by minor works, prior to planning era was 12.9 Mha. The first three plans aimed at doubling area under MI works. The 3rd FYP laid greater stress including maintenance, repair, renovation, full utilization of the existing works, and the people's participation in new works. The progress was accelerated during the Annual Plans (1966-69). Large numbers of diesel pump sets were installed, along with thousands of electric pumps. There was also a significant increase in the number of both private and public tube-wells. From 4th FYP stress was laid on integrated use and efficient management of SW/GW resources. Suitable organizations were setup in the States to survey and exploit GW resource. There has been steady progress in adding to the area being irrigated through MI sector.[7]

The statement indicating plan-wise position of Irrigation Potential Creation in given on next page:

8. WAY FORWARD

India has made great strides in the creation of irrigation infrastructure since its independence. Presently, the country is tackling with major issues in respect of irrigation including (a) rising environmental concerns for creation of new irrigation infrastructure; (b) reducing storage capacities due to sedimentation; (c) increasing uncertainties of water availability due to increasing climate variability; (d) increasing urbanization and changing lifestyle; (e) increasing industrialization for economic development; (f) low efficiency of irrigation systems etc. Population is expected to stabilize to about 1.6 billion only around the year 2050 when the overall water demand is expected to exceed utilizable water resources.

To address these issues there is need for taking up all kinds of measures including that of creating groundwater recharge structures for water conservation at community end and to take-up Inter Basin Transfer of Water (IBTW) projects, to utilize surplus water, on large scale at national level. States are already coming up with the projects involving lifting of large quantity of water even up to 300 m and more for the purpose of irrigation. A few States have started taking up piped distribution network in place of conventional canal network which are reducing water losses substantially, reducing requirement of land resources and facilitating precise application of water using micro-irrigation

Plan	Irrigation Potential Created (Mha)				
	Major & Medium Projects	Minor			Total
		Surface water	Ground water	Total	
Upto 1951 (Pre-Plan)	9.70	6.40	6.50	12.90	22.60
I Plan (1951-1956)	12.20	6.43	7.63	14.06	26.26
II Plan (1956-1961)	14.33	6.45	8.30	14.75	29.08
III Plan (1961-1966)	16.57	6.48	10.52	17.00	33.57
Annual Plans (1966-1969)	18.10	6.50	12.50	19.00	37.10
IV Plan (1969-1974)	20.70	7.00	16.50	23.50	44.20
V Plan (1974-1978)	24.72	7.50	19.80	27.30	52.02
Annual Plans (1978-1980)	26.61	8.00	22.00	30.00	56.61
VI Plan (1980-1985)	27.70	9.70	27.82	37.52	65.22
VII Plan (1985-1990)	29.92	10.90	35.62	46.52	76.44
Annual Plans (1990-1992)	30.74	11.46	38.89	50.35	81.09
VIII Plan (1992-1997)	32.95	12.51	40.80	53.31	86.26
IX Plan (1997-2002)	37.05	13.60	43.30	56.90	93.95
X Plan (2002-2007)	41.64	N.A.	N.A.	60.10	101.74
XI Plan* (2007-2012)	47.97	N.A.	N.A.	65.56	113.53
XII Plan* (2012-2017)	N.A.	N.A.	N.A.	N.A.	126.73

* Data under confirmation with States Source: Planning Commission, P&P Dte, CWC
Source: Planning Commission / P & P Dte, Central Water Commission

thus overall increase in command area. Adoption of micro-irrigation in existing projects is also being taken up in mission mode. With these due measures taken and continuous systematic technological evolution in irrigation sector, the country is poised for water and food security in coming times.

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CHAPTER – 17

Historical Foundations for Sustainable Agriculture in Hungary and Some European Comparisons

László G. Hayde [a]

1. HISTORICAL BACKGROUND OF AGRICULTURAL DEVELOPMENT

In the 16th century the old Kingdom of Hungary surrounded by the Carpathian Mountains became the scene of recurrent attacks by the Ottoman Turks which distorted economic development toward adaptation to belligerent conditions. Under these conditions, one of the main sectors of agriculture was producing animals that can be taken away easily from danger while classic land cultivation was of lesser importance. The central geographical basin, most heavily affected by these military campaigns, was the flood area of two large rivers, that of the Danube or rather that of the Tisza (and their tributaries). The land that was made inaccessible by frequent flooding and turned into a marsh for long stretches of time was conducive to the survival of the small population and to animal husbandry despite the fact that public health conditions that used to prevail in those areas regularly decimated both the natives and the alien armies.

After getting rid of Turkish rule in the 17th century, not only political but natural conditions began to be pacified. German, Slovak and Serbian settlers were moved to the depopulated areas and the forthcoming more peaceful period that lasted for almost a century saw the beginning of water control works that laid the foundation for economic growth. Flood and river control operations that took place in isolation and hence turned out to be often unsuccessful were given true impetus in the 1840s, with flood control operations along the Tisza River spanning almost half century.

When a significant part of the Hungarian Plains was freed from the frequent floods of the Tisza and its tributaries, the landowners and peasants had to resolve a twofold task: cultivated land on the saved side of the dykes had to be protected from excess water which was unknown before but appeared whenever the weather turned unfavourable, and the yield of cash crops had to be maintained and even increased using irrigation, protecting them from draught.

It is generally believed that the Age of Reform, which began in Hungary in the 1820s, brought about plenty of change primarily in political and cultural life and undeservingly little is said about the underlying process which led to the transformation of the economic structure of the country in general (and that of the agricultural structure in particular) and the mentality of the landowners. This slow process did not have spectacular results; in most cases professionals who demanded change appeared to be lonely prophets. However, the champions of the rational farming obtained leading positions over time in the professional magazines and in professional literature as well (*Korizmics*, 1845).

Proposing the idea of irrigation and its usefulness was very important and promoting it in practice can be regarded as one of the essential conditions for progress; while emphasising all this, one must agree with the belief offered in 1935 according to which the emergence of irrigation farming must be traced back to the compelling forces of the economic conditions. Once these compelling conditions arise, agriculture must follow the road to which it is driven by economic pressure, whether we like it or not. Generally, this kind of pressure is felt when the population of a country specialising in agricultural exports increases to such an extent when surplus is no longer available using traditional modes of production (*Trummer*, 1935). So, the reason for irrigation to be applied in the first half of

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the 19th century in Hungary, only verbally rather than in practice, was to be found primarily in that the types of crucial crops at the time included those that required little irrigation or none at all.

2. FARMING METHODS IN THE EARLY 19TH CENTURY IN HUNGARY

Using some simplification, let us provide some specific outlines and summarise (classify) the features of the types of farming during the early years of the century because of the coexistence of the types of farming and dominance by one or the other in a broader region actually defined how the actors of agriculture related to irrigation.

1. ***Traditional farming in the flood area*** – Here the primary emphasis was on free-range animal husbandry where pastures were irrigated by nature (floods).

   Characteristic features included ability to support small populations only, diverse types of farming, but sets of farms isolated from one another.

2. ***Farming above the flood level –*** Farming based on crops requiring less water (grain and maize), irrigation used only occasionally, farming with a minimum of machinery but with plenty of water, both free-range and indoor livestock farming were pursued.

   Characteristic features included ability to support larger populations, the danger of exploiting soils, requiring relatively little knowledge about farming, and there were possibilities for extensive development.

3. ***Rational farming in the areas protected from floods and in the areas free from floods –*** Grain production on arable land combined with irrigation, increase of the land area under irrigated crops (vegetables and fruits), and replacement of the producing capacity of the soil with the help of indoor livestock farming was practiced.

   Characteristic features included ability to support large populations, production of cash crops embedded with market conditions, investments requiring significant capital and substantial farming culture was required.

With regard to the types of farming referred above, the first was dominant at the beginning of the 19th century, at least on the Plains; the second type was characterised mostly for the Dunántúl [Transdanubian area] and the Felvidék [Northern Hungarian Highlands]. The production of grain in the broad valleys of the large rivers was facilitated only when domestic flood control works progressed. The expansion of rational farming was postponed until the 20th century.

It becomes clear from this short explanation as to why the struggle of the farmers and the engineers of the 19th century was rather unproductive for the promotion of irrigation farming. Naturally, irrigation by flood water also had its extraordinarily important role in free-range farming. Once the huge spring floods were over, the places flooded by it produced the most wonderful vegetation. The rich meadows, the most beautiful spring crops, especially maize grow much better and even autumn crops including wheat and rye suffered from floods only if floodwaters remained in the fields for extended periods or the water flooding the fields was already warm. Generally, floods coming in February and March didn't damage the autumn crops.

However, it became increasingly clear that the development of agriculture should be spared the whims of flooding even if irrigation by flooding controlled in some cases by using certain traditional types of intervention could fit into river flats agriculture.

3. LAND AND WATER MANAGEMENT

3.1 Comprehensive Regulating Works in the Carpathian Basin

Since the Turkish wars by the end of the 18th century, there was significant population growth in the Carpathian Basin, there has been no major change in the agricultural productivity level. Intensification of the agriculture was shown by the increase in the area of grain crop cultivation, but still the land was abundant since the average population density hardly exceeded the half of the Western European average. The possibility of production increase was meant by breaking up pastures and abandoned lands and using cultivation methods that were utilising the soil capacity better. Increasing the plough-land area by flood protection was the principle task of the 19th century economic development (*Fejér, Hayde*, 2008).

Following the French revolution, wars brought prosperity in the agricultural development of the countries involved, so also in the Austro-Hungarian Monarchy. Grain production meant for export, also initiated the demand for the increase of the cultivated land area by land reclamation, flood protection and also the development of inland navigation. In 1802, the Ferenc-canal connecting the two big rivers of the country, the Danube and the Tisza had been opened, named after the emperor regnant, which shortened the navigation route by 226 Km (*Fejér, Hayde*, 2008).

Because forests were cut down over the centuries in the catchment area, flood levels rising relative to previous ones and damage done by them spurred Parliament to act. In response to the catastrophic icy flood on the Danube in Pest-Buda[1] in 1838 and the devastating damage often done in the river-system of the Tisza, an *Act on Regulating the Danube and other rivers* was adopted in 1840 and a committee was set up to

1 The two independent cities merged into the present Budapest only in 1872.

review the financial and the technical conditions of the task. This was the starting date of the comprehensive regulation works in the Carpathian Basin, before which only isolated activities had changed, locally, the picture of water conditions presented in *Figure 1.*

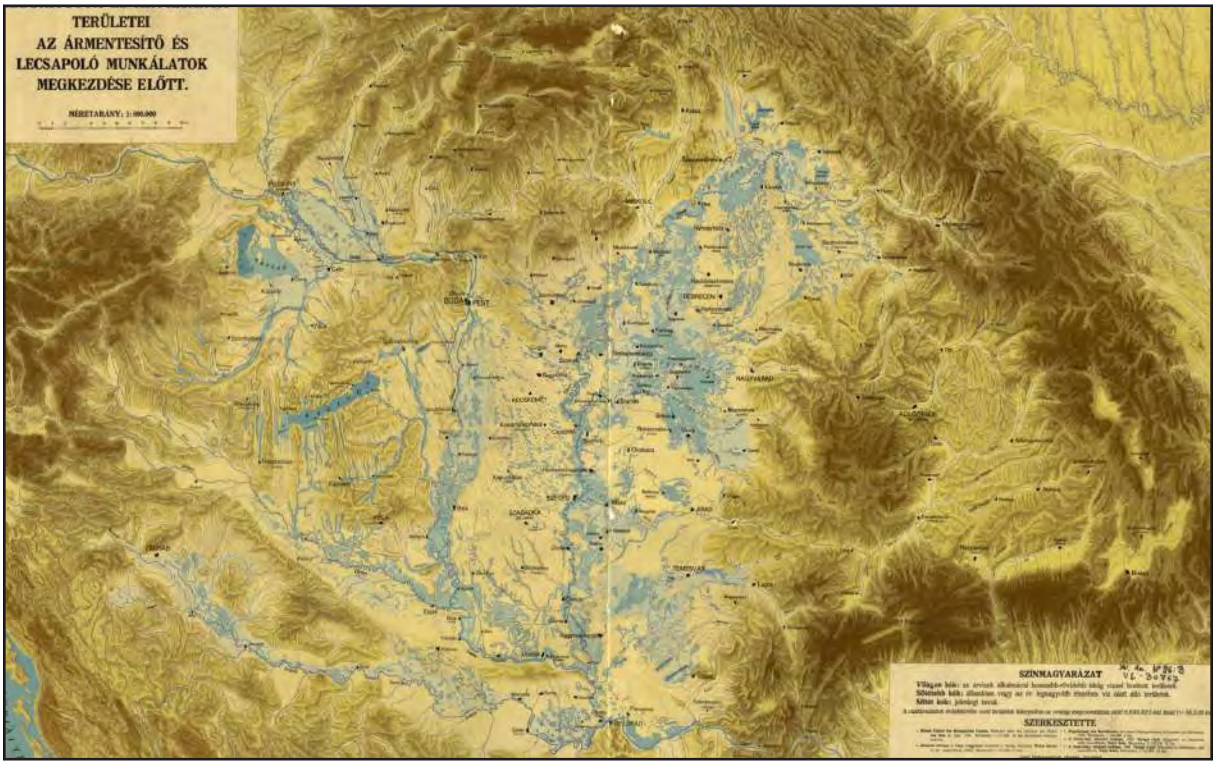

Figure 1. Water conditions of the Carpathian Basin before the beginning of comprehensive regulating works

The Committee found that regulating the River Tisza and its tributaries was a unitary task. River control works were started towards the summer of the year 1846. The concept for river regulation was elaborated by Pál Vásárhelyi (his picture can be seen in *Figure 6*), who directed the hydrological survey of the River Tisza but died in 1846. He wanted to save the approximately 26,000 Km^2 river flats from floods by cutting through the meandering river bends (*Figure 2*) of the flatland river (and its tributaries) and forcing the shortened river among dikes. It is to be noted that several versions of river control ideas were in circulation, and heated debates were conducted about this issue in the daily papers; however, those arguing agreed on one thing: the waters in the valley of the River Tisza needed to be regulated. It should also be noted that there have not been comparable examples of river control of a similar magnitude and nature in Europe at the time, which brought about uncertainty in many respects in elaborating the detailed plans (*Fejér, Hayde*, 2008).

Figure 2. Meandering river bends

When the landlords' increasing desire to have as much land as possible and their thriftiness about dike construction was mentioned with condemnation, it must not disregard a very important circumstance: the entire river control operation in Hungary differed substantially from similar operations in Italy, France or the Netherlands in terms of their economic foundation. River control in Hungary was characterised by the fact that it was not implemented by a well-capitalised agriculture in order to protect cultivated land or to intensify production; these operations were expected to trigger capital formation and strengthen Hungarian agriculture and ensure its development at a faster pace (*Fejér, Hayde*, 2007).

Besides the major fundamental flood management objective, several other equally important aspects of the comprehensive regulating works, such as agricultural, fishery, navigation and social aspects, could as well be identified.

Significantly drained and flood protected area can be seen in the comparative *Figure 3* of the Szeged region. The accomplishment of the 19th century flood control and reclamation works, as well as drainage of inland waters resulted in the following overall area (*Ihrig*, 1973):

- Considering the area of the historical Hungarian Kingdom, the country at that time, (the accomplishment of all the projects at that time):

– Tisza valley	2 583 000 ha
– Danube valley	1 246 000 ha
Total	3 829 000 ha

- Considering the area of the present Hungary, formulated after World War I. (the area lying on the present country from the above-mentioned total):

– Tisza valley	1 700 000 ha
– Danube valley	609 000 ha
Total	2 309 000 ha

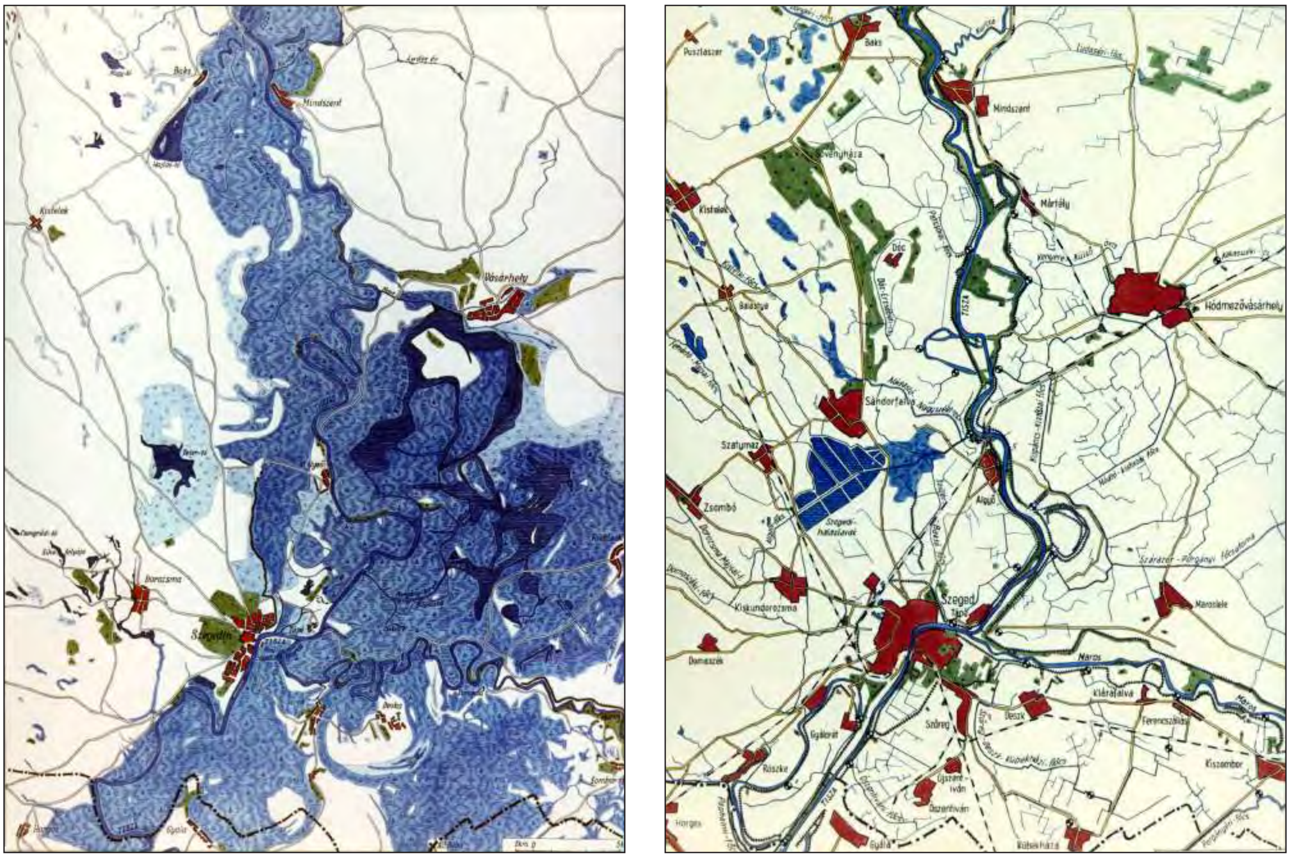

Figure 3. Water conditions in the Szeged region before and after the regulation

It can be stated that the comprehensive regulating works in the Carpathian Basin had been an unparalleled monumental task in Europe. Comparing these numbers to the total reclaimed land area of the Netherlands, traditionally considered to be gigantic land and water management activities, interesting results could be found.

3.2 Comparison to the Land Reclamation Works in the Netherlands

Major part of the Netherlands originally consisted of lagoon and delta type areas originating from the deltas of the Rhine, Meuse and Scheldt rivers. Due to transgressions and regressions of the sea, the land area decreased or was extended in different intervals. Different aspects related to the land and water management in the Netherlands, protection against the sea and the rivers have developed significantly and became of high importance.

Damming off various connections with the sea, for protection reasons, resulted in developement of canal systems. The polders drain their water into these systems, through which the water is transported to the sea to discharge during low tide. The topsoil surrounding the lot of lakes was mainly peat, so the banks were destroyed by the water during gales, as a result of which the lakes extended. Peat had also been used as fuel, so by digging the peat, more lakes were created.

The improvement of windmills, by the invention of revolving cap, made it possible from the middle of the 16th century to drain the lakes. In the beginning of the 17th century it has been discovered that by placing several windmills in series, large land reclamation works could be carried out. Most polders were made in the beginning of the 19th century.

The well known and world famous history of land reclamation in the Netherlands (*Figure 4*) has resulted in the following different polder areas (*Schultz, E*. 1983):

• Low lying lands	1 335 000 ha
• Drained lakes	315 000 ha
• Land reclaimed from the sea	350 000 ha
Total	2 000 000 ha

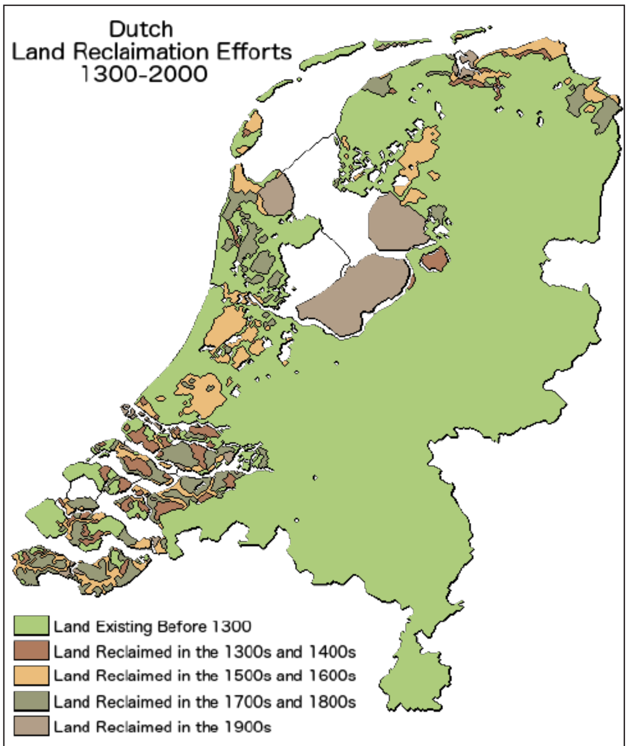

Figure 4. Land reclaimed in the Netherlands

(https://brilliantmaps.com/wp-content/uploads/netherlands-reclaimed-timeline.png)

Protection against flooding has always been priority in Dutch history with increasing environmental and ecological sensitivity. Areas in the Netherlands that need protection are shown in *Figure 5*.

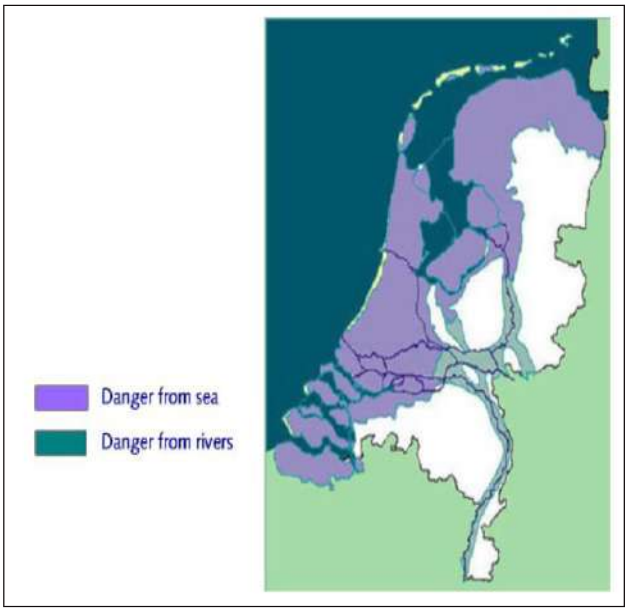

Figure 5. Areas in the Netherlands that need protection (Haas, A. de, 2003)

4. FLOOD MANAGEMENT IN THE 21ST CENTURY

After having seen some historical and geographical similarities between the two countries of The Netherlands and Hungary, we can find parallel or similar actions in the 21st century practices and plans, as well.

One and a half century has passed since the comprehensive regulating works in Hungary, the scientific knowledge and environmental responsibility has significantly increased and social demands have also changed. The most determining social elements of the 21st century river basin development are the optimal environmental management based on rural traditions, besides the reactivation of the flood plains and in some cases also the rehabilitation of the land surrounding the river. (*Kovács*, 2006).

Europe has experienced a series of severe floods with considerable damage e.g. along the Rhine, or Tisza rivers since the last decade of the 20th century. Both in Hungary and in the Netherlands simply heightening the dikes has not been considered as best solution, policies have been developed, projects and plans have been started for integrated management solutions.

Besides intensified endeavours for flood mitigation, these projects also concentrate on the potential for both nature conservation and human use integrating and satisfying the different ecological, economical and social issues.

4.1 The New Vásárhelyi-Plan

The update of the Vásárhelyi-Plan (*Figure 6*), adopted by the Hungarian government in 2003, aims to further develop the concept from 1846, in line with the changed socio-economic conditions to preserve and rehabilitate natural resources, to harmonize agricultural activity with local conditions, to promote eco-tourism and rural development, given the flood protection system designed by Pál Vásárhelyi. The update of the plan consists of two decisive parts, of which the most important one is the improvement of the conveyance capacity of the flood way, together with the rehabilitation of the floodplain areas. This approach shows similarities with the Dutch concepts. The methods are identical to improve the hydraulic conditions of the flood bed. The flood control measures should be planned individually for each river reach, selecting the most appropriate options (*Váradi*, 2003).

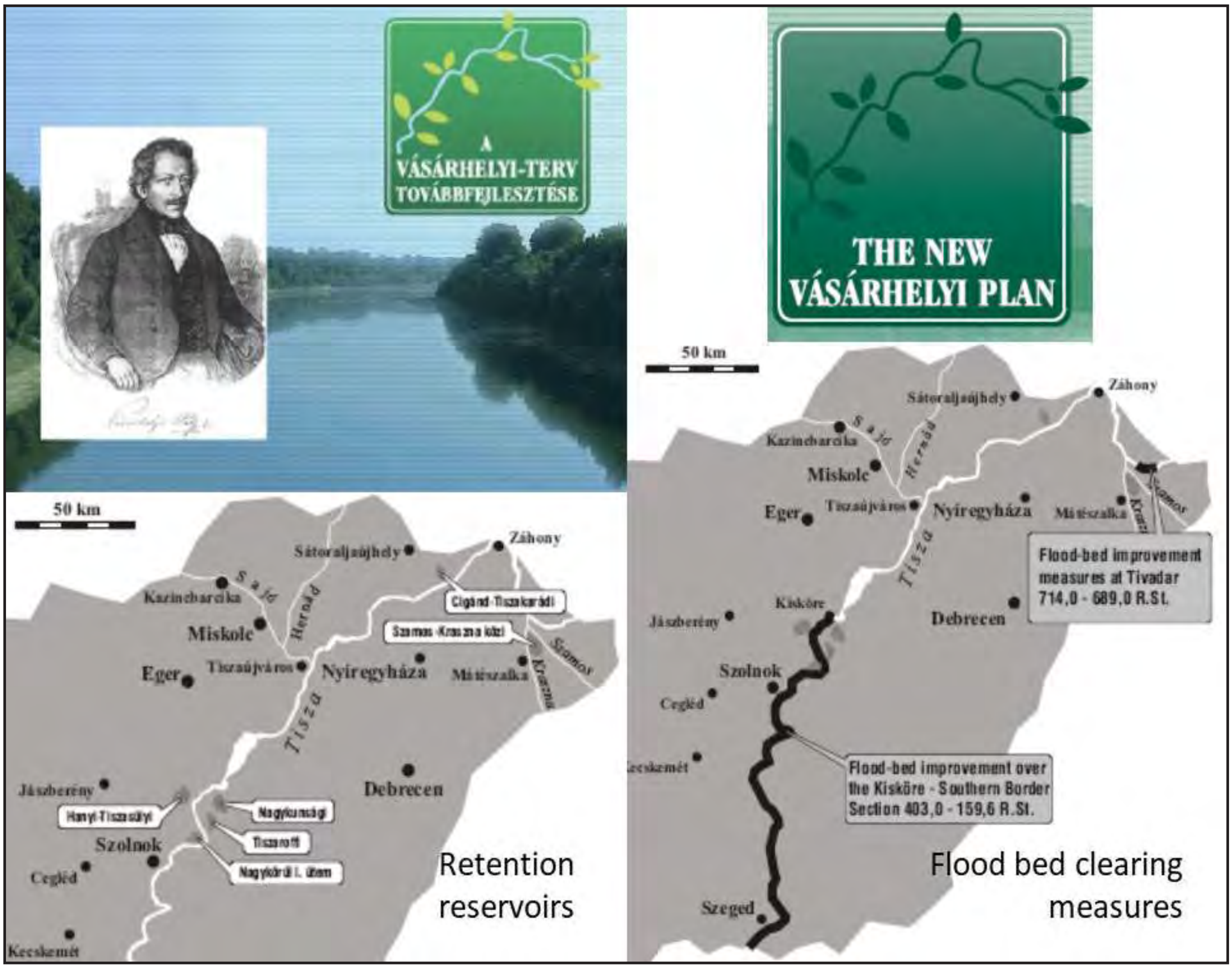

Figure 6. The New Vásárhelyi-Plan with the six retention reservoirs and river sections influenced by flood bed clearing measures, to be implemented in Stage I. (Rebirth of the River Tisza, 2004)

The works scheduled for the period 2004-2007, Stage I of the program include projects aimed at clearing the flood bed to improve its conveying capacity and the development of six reservoir sites for the controlled diversion and retention storage of abnormally high peak flood flows (*Figure 7*). These have been justified by the experiences, which demonstrated the inadequacy of the traditional approach of raising the levees.

Ecological assessments compatible with the European Union's "Water Framework Directive" have been completed on each of the affected river sections and the hydraulic engineering measures have been integrated into regional development concepts.

The complex project (*Figure 8*), the basic aim of which is to raise the living standards of the people in the Tisza Region, whilst ensuring a higher level of flood safety would be accompanied by a number of important infrastructural developments. These include land drainage and sewerage, afforestation, construction of cycling lanes, as well as environment management schemes. Construction work on the first retention reservoirs and on clearing the flood bed has been started in 2005.

4.2 Projects in the Netherlands

Very similar national programmes and plans are formulated along similar concepts in the Netherlands. After the 1993 and 1995 floods the reinforcement of the dikes had been accelerated by the Major Rivers Delta Plan in order to meet the normative discharge of 15000 m^3/s.

Up to the year 2001, the Normative High Water for the Rhine was 15000 m^3/s. Because of the two extreme high waters in 1993 and 1995, the statistics changed

Figure 7. Retention reservoir of Cigánd-Tiszakarád, implemented in 2008

Figure 8. The complex project, the new Vásárhelyi Plan is the key to development in the Tisza Valley. (Rebirth of the River Tisza, 2004)

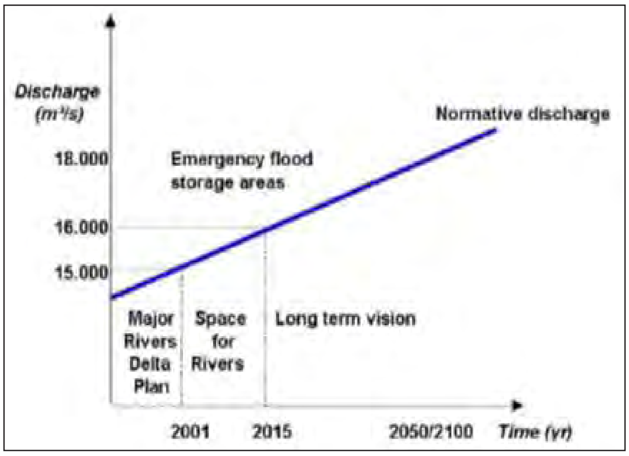

Figure 9. Overview of national programmes and plans for the Rhine (Sar, 2003)

so that the normative high water for the Rhine had to be increased to 16000 m³/s (*Figure 9*). To meet this demand, the decision was made to change the traditional approach of flood protection by dike reinforcement into a new approach called 'Space for Rivers'. The project Space for Rivers, next to meet the current safety standard, has also the second aim to improve the spatial quality along the Rhine branches. Two emergency flood storage areas were recommended along the Rhine and one area along the Meuse (*Sar*, 2003).

More projects, like the one on which German and Dutch organisations have been working on since 2003, are aiming the Sustainable Development of Floodplains (SDF) along the River Rhine, called 'Space for River, Nature and People'. The results and practical experiences have been published by the end of 2008 (SDF, 2008). Measures to protect against flooding and to upgrade nature and the landscape have been planned and/or implemented in twelve pilot projects along the Rhine.

Another example with similar intentions from the same time period 2003-2008 is the SAND project, meaning: **S**patial quality enhancement; **A**lleviation of flood damage; **N**ature expansion through **D**evelopment of mineral extraction sites along the rivers.

In the SAND project, Dutch, French and German partners have been working together for the integration of former, active or future clay, sand and gravel mining sites into flood mitigation strategies, (e.g. increasing retention capacity), which might offer new cost-effective win-win-opportunities between public and entrepreneurial interests (SAND BOOK, 2008).

5. IRRIGATION DEVELOPMENT AFTER THE COMPREHENSIVE REGULATION WORKS ON THE HUNGARIAN RIVERS

5.1 Impediments Hindering the Promotion of Irrigation

In the middle of the 19th century, the major impediments hindering the promotion of irrigation were seen by economic engineers in the following:

The first and most important problem was the lack of legal regulations. As a multitude of interests need to be co-ordinated to provide irrigation, the appropriate governing principles were not in place. Credit required to finance investment projects were also unavailable. There was little money available and interests were high. Large estates, cultivated extensively, may not require irrigation for a long period of time yet. The Hungarian farming community did not have appropriate experience in irrigation, therefore many feared to use it. Last but not the least, most of the rivers in the country were unregulated and the draining of the marshes had hardly begun.

As for the latter set of issues, it is a governing principle until today that good irrigation is based on good drainage and excess water control. In Hungary, comprehensive water control works had hardly begun by the middle of the 19th century – primarily in the Tisza valley – the whole of the work was far from being complete. The problem of the credit was typically not only for the Age of Reform but also for the economic life in the subsequent period. The lack of "initial capital formation" that did not take place in Hungary made it impossible for capital necessary for agricultural development to be available in the country. Actually, scarce capital accumulated from agriculture was also withdrawn from the sector which disappeared in the bottomless pockets of the businessmen, hoping to make greater benefits on railroad and industrial investment projects (*Fejér*, 2001).

Extraordinarily dry weather which hit the first half of the 1860s brought about the catastrophic drought of the century on the Hungarian Plain. Although the first angry assessments were made when the suffering of the farming population was obvious, which blamed the lack of rains on revitalizing the Tisza River. However, more rational observers had shown that water control works and the volume and distribution over time of precipitation were not directly related. At the same time, the arguments by experts made it clear, even to the lay, that only the expansion of irrigation could provide some degree of protection against recurrent droughts in the future.

In response to pressure from delegations of farmers, the government instructed the state organisation of engineers (the Central Authority in Control of the Regulation of the Tisza River), to make plans for irrigation to be used in the Tiszántúl [region East of the Tisza River] which was found most heavily threatened. Several scenarios were drawn up but none of them were implemented either for technical or financial reasons or primarily as a consequence of more rainy weather in the 1870s.

Despite the above, it was clear that irrigation and drainage were tasks that could be resolved together only. Consequently, the construction of the main works of the irrigation systems was the responsibility of the state, while those interested in using irrigation took care of the cost of the irrigation equipment (*Képessy*, 1867).

Even though grand ideas about irrigation failed to be implemented, local initiatives of lesser magnitude (*Figure 10*) – primarily in the Transdanubian area – were successful. Speaking about success, it has to be added that once an engineer or a farmer committed to use irrigation passed away, the cause of irrigation was easily stalled. It was typical for the era that while engineers for railroad construction were sought all over the country, engineers with plans for irrigation had to hunt for the customers.

Figure 10. Well for irrigation water with 'dolap', horse or human driven lifting device, so called 'Bulgarian Wheel', named after the Bulgarian farmers who introduced it in Hungary

5.2 Promotion of Irrigation

The situation changed substantially following the organisation of civil engineering offices in 1879. The establishment of the civil engineering services was justified by the fact that large river control works were coming to an end in the plain areas of the country and the amelioration of the soil of the drained areas had to be provided for, which was also demanded by the rapid increase of the country's population and the upturn in grain production in Europe. With very little exception, the soils of the Carpathian basin had a poor water balance. As a result of the frequent weather extremes, they were either excessively saturated with moisture or they dried out considerably. Therefore, controlling the water conditions of the soil and even out the impact of the anomalies of the weather became especially important using drainage pipes or irrigation and other technical interventions. The state-run water management services made every effort to accommodate demand for civil engineering works as it was in the government's interest to improve the income generating ability of agriculture thereby increasing tax revenues for the Treasury (*Csekő & Hayde*, 2004).

Figure 11. The first (1878) inland water pumping station at Sajfok, operated by steam engine

Albeit at the cost of heavy struggle, flood control works, drainage and excess water control were implemented in the 19th century, the situation was rather different regarding soil amelioration and irrigation. Being saved from damage by floods was popular enough among landowners, associations on these activities could be organised fairly easily. It was enough for a proportionate majority of the landowners of the area to join their forces. These works represented the first steps towards soil improvement. However, because individual farms were not at the same level in terms of farming and profitability, later on only more modern and richer landowners required soil improvement projects which were indispensable for the further development of their estates (*Péch*, 1894). Conversely to the case with the flood control associations, the provisions of the law did not provide any coercive assistance to achieve this, not even when most of the landowners in a given area announced that they had an interest in soil improvement. Although the legislator was familiar with the economic advantages of irrigation when drafting the 1885 Act on Water Usage, he did not want to change existing water usage arrangements and restricted the possibility for acquiring the necessary volume of water to a single day of the week which was Sunday. Of course, it was a completely different matter whether there would have been sufficient water for irrigation when all the landowners had decided to use irrigation (*Dános*, 1905).

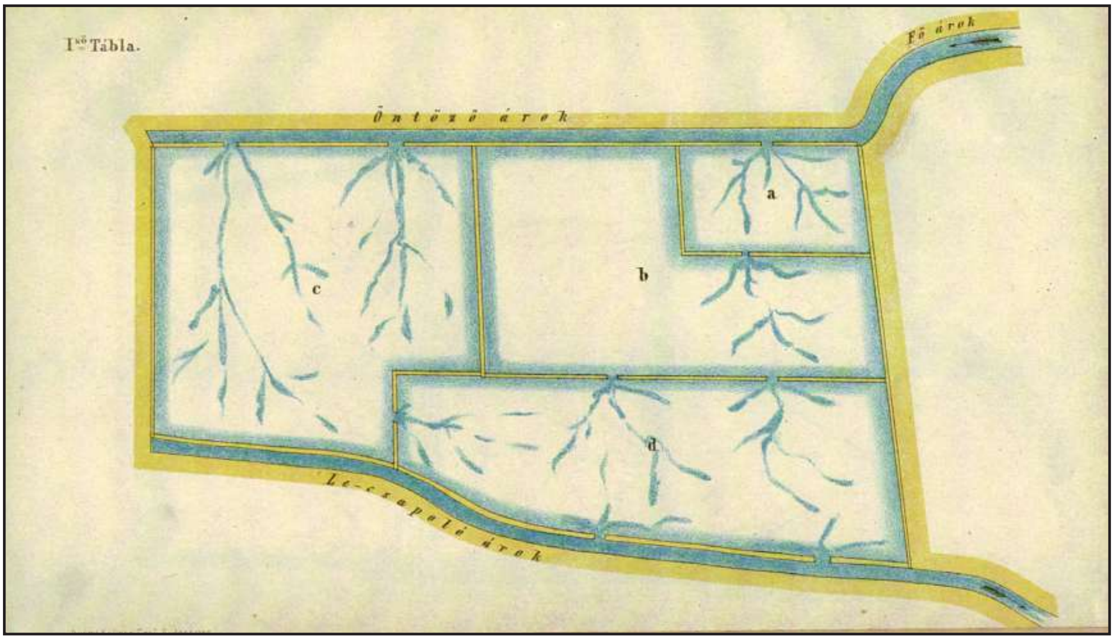

Figure 12. Rice irrigation plan from 1880. (Fejér, 2001)

Towards the end of the 19th century, as a result of recurrent grain crises followed by economic pressure, agro-social issues gained particular emphasis in the Hungarian Plain (*Figure 12*). Exceedingly broader use of irrigation farming appeared to be a way out from the crises which hit farms focusing on grain production in monoculture farming. Some politicians believed that intensive farming together with the construction of irrigation canals could be used to contain agricultural movements in the Plains.

In the course of the debate about this issue, the heads of the civil engineering offices cautioned against excessive optimism shown by politicians relying on their experience in this regard. In their opinion, while a landowner with 1000 acres could make a living, he does not need to set up a 50–60-acre irrigated plot (considered profitable at the time). On top of that, the irrigated plot cannot be left alone, it needs to be tended, and Hungarian farmers are not used to it. Of course, sooner or later they will have to get used to it too, but for the time being, they reject it as shepherds and herdsmen resisted indoor livestock farming. They believed that one must not go to the other extreme, irrigation should be implemented slowly and gradually, otherwise the entire matter would be regarded as infeasible. For the time being, irrigation of croplands should not even be mentioned and attention should rather be focused on irrigating meadows. The use of irrigation in Hungary should begin by irrigating pastures on large and medium-sized farms, then it should be extended to small farms and when it becomes part and parcel of everyday farming practices, irrigation of arable land can be raised (*Kvassay*, 1894).

It was obvious to the government that the development of irrigation farming simply cannot begin without state collaboration and financial assistance under deficient Hungarian conditions. The first Act about irrigation was adopted in 1900, held out the promise of government assistance. However, the Act failed to bring about considerable progress in the development of irrigation. It was obvious, after the first few years, that the conditions it specified for obtaining irrigation support made it impossible for small and medium-sized farms to submit successful applications. Only large farms were in a position to exploit the opportunity offered by the Act. And even they also ran into difficulty later on.

Irrigation is a highly labour-intensive agro-technical operation, but at the turn of the 19th and the 20th centuries, large farms did not have sufficient labour, let alone trained staff to handle it. They didn't care much about operating the system either. They believed that it was enough to let water onto the meadows and nothing else needed to be done to collect an abundant yield of hay. In the first few years, it actually worked like that, but then the productivity of the soil became low and even the irrigated meadows produced poor yields of hay.

However, other problems were also encountered in connection with meadow-irrigation. Because of the excessive focus on arable land grain production, animal husbandry lost its ground and fodder produced using irrigation could only be sold at a low profit. This also contributed to reducing eagerness for irrigation. It was not unexpected that the rector of the Technical University of Budapest, who was a civil engineer, emphasised, between the two world wars (1938), to review the history of irrigation in Hungary. The review revealed that "*...it was a fundamental truth that the excellence of technical implementation does not guarantee success for irrigation in itself; it also necessitates knowledge of factors including agro chemistry, crop production, transport, finance and sales as well as their successful application which turns the apparently simple task into a complex one."* (*Rohringer*, 1938).

The situation changed substantially after the First World War in which Hungary was on the side of the defeated powers. In addition to the substantial loss in human live, the Peace Treaty imposed on Hungary in Trianon significantly re-drew the borders of the country. Most of the country reduced to one third of its size was concentrated in the central part of the Carpathian basin which resulted in significant changes in its water management practices.

The problems faced by Hungarian agriculture on the Plains were not at all indifferent for the country living with new borders. Crop failures on the Plains in a dry year were offset by more secured yields in the areas in the Small Plains, Bánság [Banates] or Erdély [Transylvania]. After the war, when the protective tariffs of Hungarian agricultural products were dismantled outside the Austro-Hungarian Monarchy (which were in place since 1906), and an unprecedented fight had to be fought with competitors on well-paying Czech and Austrian markets, while Hungary lost its mountains and sources of industrial raw materials; in this situation funds for industrial imports had to be generated by increasing agricultural exports in terms of quality and quantity. So, in this respect, special economic and political attention was turned towards the Plains which were the basis of agriculture. After 1920, the Plains became economically appreciated from the country's viewpoint which also meant increased sensitivity towards water management problems along the Tisza River and the area of Körösök.

It did not take long, however, to find a solution. The droughts in the Plains in the first half of the 1930s (1934, 1935) provided the social pressure which forced the government to take action in order to promote the issue of irrigation (*Figures 13*). Owners of small and large estates alike demanded irrigation water to cope with dry weather. The state water management services developed technical ideas (*Figure 14&15*), one after the other, and put them on the table of subsequent governments for review. Considerable results could be achieved through the Irrigation Act of 1937 which specified the tasks of the state and the organisations to implement them as well as the framework of state support to be granted to landowners.

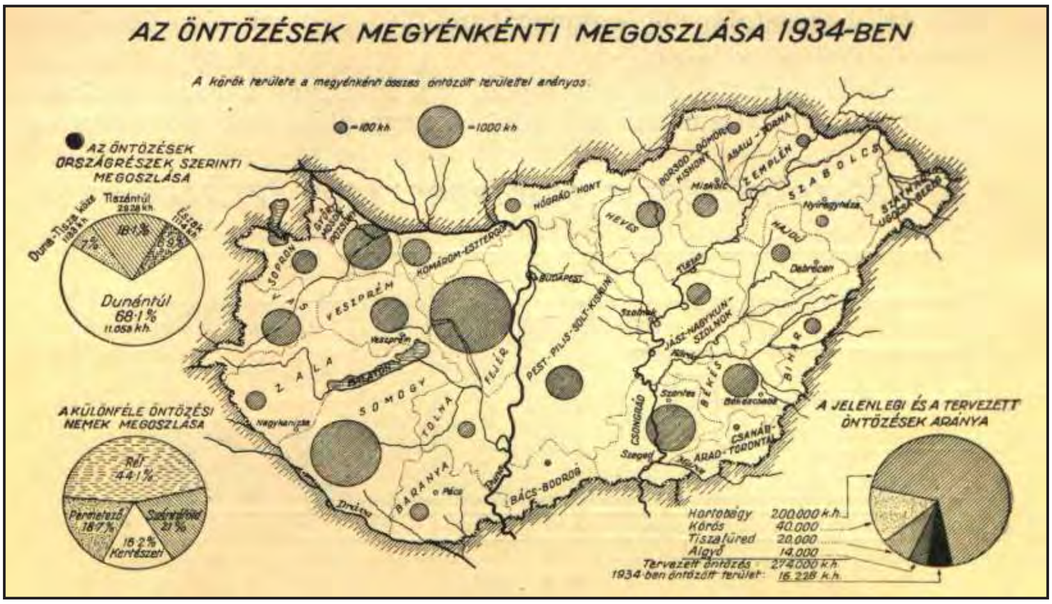

Figure 13. Irrigation in the Counties of Hungary in 1934
(The area of the circles is proportional with the irrigated area of the county)

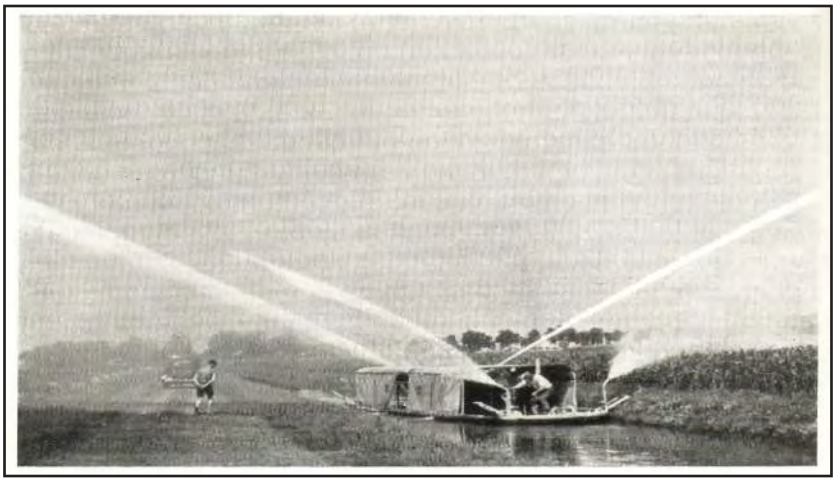

Figure 14. Irrigation canal with irrigation boat in the 1930s

Figure 15. River barrage construction (starting in 1936) at Békésszentandrás, creating navigation and irrigation opportunity in the Körös valley

At the dawn of the new world war, main works implemented by the state gave significant impetus to the cause of irrigation. Dynamic growth in food production by agriculture was also facilitated by huge German wartime orders. It was not unexpected that Hungary's agriculture reached peak performance not in the last year of the peace (1938), but in 1940. It is a completely different issue, however, that farmers tried to utilise opportunities for irrigation by growing rice (*Figure 16*) in the first place because at the time that appeared to be the most profitable investment. The fact that this water intensive crop exploits soil and poses other dangers became increasingly obvious only after the war in the socialist era (*Lászlóffy*, 1982).

Figure 16. Experimental rice basins at Hortobágy in 1941

However, Hungary's entry into the war took away central funds from the further development of irrigation and therefore their implementation could only take place in the decade after the war, in a socio-political environment in which agricultural ownership relations were radically changed.

6. CONCLUSIONS

Agriculture is strongly related to water management; therefore, the sustainability of agricultural production is strongly linked to the development and sustainability of water management.

In Hungary the comprehensive regulation works of the two major rivers, the Danube and Tisza Rivers are excellent examples for this strong link. The need for the Tisza regulation in the great plane area (Alföld) was brought up by the structural change in agriculture, the change of the ratio of the plough-lands and grazing-lands. The developing cereal cultivation required more land area to be dried. In the original, mid-19th century, Tisza regulation plans of Count Széchenyi not only flood protection and the drainage of marshes have been planned but also the artificial water supply, irrigation of the drained areas already suitable for agricultural production.

Compared to the Western European countries, where this kind of hydraulic engineering activities were related to the industrial development, helping also higher productivity in the financially strong agricultural sector, in Hungary, this development of the food production started in an agricultural sector in shortage of capital.

The comprehensive regulation works resulted in significant drained and flood protected area, which can be compared to results of the land reclamation works in the Netherlands.

The ups and downs of the irrigation development, following the comprehensive regulation works on the Hungarian rivers, are also discussed in general historical context of this interesting period of the country. All these aspects, such as - spatial river planning, flood mitigation, the potential for both nature conservation and human use, integrating and satisfying the different ecologic, economic and social issues have been discussed which characterized the historical background of the sustainable agriculture in Hungary.

Since sustainable development being considered as a dynamic process, interesting comparison can also be discussed in the 21st century developments of flood management in the Netherlands and in Hungary and the analysis of the historical development in several linked aspects provide an overview of the foundations leading to the actual results.

Through these analyses, interesting observations could also be made on historical area gaining actions and also on the 21st century developments of flood management in Hungary, showing also the need of corrections through the dynamic process to maintain or further develop the sustainability of agriculture. The ups and downs of the irrigation development following the comprehensive regulation works on the Hungarian rivers are also showing the dynamics of the process keeping the direction towards sustainability.

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During his professional life, he gained a vast and sound experience, most of his work being dedicated to water resources development. He has been involved in the planning, design, and supervision of hydraulic infrastructures as part of major international cooperation projects on land reclamation and irrigation, especially in developing countries of Africa and Asia.

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He is working in the field of water resources sector since last 35 years in various capacities. He looked after climate change issues pertaining to water resources in India, for about 10 years as Director in Central Water Commission. He has been instrumental in preparing National Water Mission document of GoI. He has drafted "Preliminary Consolidated Report on Effect of Climate Change on Water Resources" in June 2008. He has co-authored "Water Resources Assessment – A National Perspective" – A technical guide to water resources engineers and planners published by NRSC, Hyderabad. He has completed studies on "Operational Research for Integrated Flood Management" with ADB. He has drafted Handbook for "Flood protection, anti-erosion and river training works" a CWC's publication and ToR for "Water Use Efficiency Studies and Preparation of DPR for Improvement of WUE in Irrigation Projects" a NWM Secretariat's publication.

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