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A history of water issues

A history of water issues: Lessons to learn

Edited by Richard Coopey, Henning Fahlbusch, Nobumasa Hatcho and Libor Jansky

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Richard Coopey
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List of acronyms

ASEAN	Association of South-East Asian Nations
CBD	Convention on Biological Diversity
CFD	computational fluid dynamics
DAC	Development Assistance Committee (of the OECD)
FSC	Farmer Services Centre (Nigeria)
ha	hectares
HJRBDA	Hadeija-Jama'are River Basin Development Authority (Nigeria)
IIMI	International Irrigation Management Institute (Nigeria; now IWMI)
IWMI	International Water Management Institute (Nigeria; former IIMI)
JBIC	Japan Bank for International Cooperation
JICA	Japan International Cooperation Agency
KRIP	Kano River Irrigation Project (Nigeria)
LID	Land Improvement District (Japan)
LIL	Land Improvement Law (Japan)
MDG	(UN) Millennium Development Goal
NGO	non-governmental organization
O&M	operation and management; operation and maintenance
ODA	Official Development Assistance
OECD	Organization for Economic Co-operation and Development
PAWN	Policy Analysis of Water Management in The Netherlands
PDRK	People's Democratic Republic of Korea (aka North Korea)
PIM	participatory irrigation management
P&T	Pamenoekan and Tjiassem (lands; Netherlands East Indies)
RBDA	River Basin Development Authority (Nigeria)
SDF	Self-Defense Forces (Japan)
TVA	Tennessee Valley Authority (USA)

UFW	un-accounted for water
UNU	United Nation University
WLV	Wildbach- und Lawinenverbauung
WMA	Water Management Association (Japan)
WSSD	World Summit on Sustainable Development
WUA	Water Users Association (Nigeria)

1

Introduction

Richard Coopey

The study of water resources covers many areas and embraces various disciplines. Because water has a multiplicity of uses, it poses a range of questions in terms of ownership, management and technological development. Water is a basic commodity of life, both for consumption and as an input to agriculture and fishery – all food depends on water. Water is also a power source, from the most basic water wheel to the largest hydroelectric turbine.

Issues relating to the ownership, supply and management of water resources range from predictions about the natural cycle of river-flooding to the construction of elaborate systems of dams, dykes, ponds, reservoirs, irrigation and piping. Water also provides transportation opportunities, through rivers and canals, again employing a complex inter-play of natural features and technologies. The range of people involved in the control of water is correspondingly kaleidoscopic, historically stretching from individual farmers to despotic rulers, and embracing politicians and civil engineers. Although the history of water resources is complex, there are perhaps a few essential factors to be borne in mind. For example, throughout history, there always has been (and for the foreseeable future, will be) change and reform. In this atmosphere of change, it is essential that experts and policy makers be sensitive to the structures of the past.

Often, during the evolution of water systems and through generations of stewardship and control, key elements are accreted into the very technology of the system itself, with the social and technological becoming almost indistinguishable. Reflecting its origins, this book contains an extended case study of the rice cultivation irrigation system in Japan. In their case study of the Sayama-Ike irrigation and land improvement system, Ogina and Mulenga locate more recent history against the long-term development of irrigation and farming in Japan. The Sayama-Ike "mother pond" and its 80 "daughter ponds" currently support over 2,400 farms and households. The system had its origins over 2,000 years ago, and has undergone many phases of restoration and rebuilding. In the 20th century, major engineering work was undertaken in the 1920s. Organizational reform took place following the 1949 Land Improvement Act, which led to the establishment of Land Improvement Districts (LIDs), of which Sayama-Ike became one. Ogina and Mulenga outline the delicate structure of control that was established in post-war Japan, and the cooperative organizations which emerged in the LIDs.

Farming communities (*mura*) must deal with a range of matters beyond the simple allocation of water. These include the raising of capital for maintenance and improvements (via low-interest loans), and flood prevention and control. The transition to this modern system is not necessarily as straightforward or technical as it seems, however. As Kinda's chapter shows, the Sayama-Ike system, in its original conception (certainly from the 7th century onwards), relied on a fundamentally different organization of distribution within the system. Water would not be channelled directly from mother to daughter ponds, but rather would be used and reused in a hierarchical fashion, flowing into one paddy, then from there to the next paddy, in sequence. Such a system had profound ramifications for farmers, not only in terms of the timing and quantity of irrigation water availability, but also in terms of the quality of water that could be expected. Those at the end of the ladder of paddies had to time their crops accordingly, and were both vulnerable to and reliant on cooperative organization. On the other hand, the re-used water picked up fertilizer and nutrients in its cycle that might otherwise have been wasted. The old system also had its many drawbacks however, not least the difficulty, as Kinda shows, of utilizing machinery in smaller, relatively isolated paddies.

Modern reformed systems need to take full account of both the disadvantages and the advantages of the old. As Kinda notes, larger, directly irrigated paddies and the fertilizer regime that they incorporate often fracture a more organic, less pollution-ridden cycle. More recently still, sensibilities have been raised in terms of these issues. It is here that we encounter another cycle, or phase, in the management and control of water. Taking the long-term perspective, Hatcho and Matsuno track these different phases of thinking in Japan. Many scholars (notably, perhaps, Marx and Wittfogel) have sought to connect water control to political systems and ideology. In Japan, a major change took place following the Meiji restoration, as Japan sought a rapid path to modernization which incorporated state direction and the importation of foreign expertise. Water was no exception to this general programme, as large-scale works were undertaken, but an ethos of ''top-down'' management was also incorporated. The LID approach in the post-war period sought to redress evident shortcomings in this system, and participation was incorporated in a systemic way. Hatcho and Matsuno stress the importance of history in this: the recognition that communal benefits, and not profit maximization, should be given primacy. Arguably, the LID system reincorporated local managerial prerogatives that had existed in one form or another since at least the 3rd century.

The above cases highlight developments and lessons in Japan (though some of the issues can be said to be almost universal in application). These lessons should certainly be taken on board by national governments, or international agencies, such as the United Nations or World Bank. The importance of localized management of resources, for example, is also emphasized in Sani Bala, Musa and Abdulkadir's study of the Kano River Irrigation Project (KRIP) in Nigeria. Here, we can see an economic, political, social and cultural background that is widely divergent from that of the Japanese example. Yet, many similarities emerge.

Sani Bala et al. describe the origins of KRIP in the 1970s when, despite large amounts of investment, results were disappointing. This situation was redressed with the formation of the River Basin Development Authorities (RBDAs), which were predicated on the idea of cooperative management of public sector schemes. A combination of agency staff and local farmers were to be responsible for the management and resource mobilization. In this scheme the users, formed into Water Users Associations (WUAs), gained a significant degree of control. Water scarcity had, by this time, become the primary issue, and maximized utilization was a priority. Before the RDBA/WUA system had been established, it was seen that too many institutions and a lack of coordination were leading to stasis or inefficiency. Once the WUAs were formed, they embarked on efficiency measures such as de-silting and plant and bank management, as a result of which, irrigation worked effectively and distribution was more equitable, to the inclusion of ''tail end'' farmers who previously had been marginalized. The WUAs also had an important role to play in riparian issues by resolving and enforcing water property rights in the system.

Riparian rights form a central issue in water resource control, and have for a very long time. Salamat, for example, highlights the ways in which water shares and divisions were – according to the 17th-century Sheikhbahaei scroll – administered by "trustful" people. This was extremely important in times of low availability.

Returning to the example of the Kano River, we can see that the efficient running of the system rested on a sense of trust and became a source of pride among WUA members. Sani Bala et al. have another important message, however. Revisiting the WUA ten years after its inception, the authors found that the initial gains had begun to fade. Meetings were less regular, and lack of funding was seen to be a problem. The authors suggest a new framework designed to reinvigorate the system, but the message is clear: While the establishment of a system such as this is an important step in equitable and sustainable resource management, resources and support must be forthcoming in order for such a system to work with long-term, sufficient commitment.

Technologies, in common with organizational reform, are often perceived as progressive, as modernization and new science replaces old. If this were true, then history would be simply for the curious, the antiquarian – interesting in itself, but with no practical application, no lessons to learn (or, rather, re-learn). Studies of science and technology have long realized that development is not necessarily unilinear. Science and technologies are anchored in social, political and cultural contexts, and it is folly to regard developments as somehow neutral and insulated from these wider pressures, or progressive in a straightforward way.

A good example of this is highlighted in the chapter by Ortloff, which examines the Roman siphon at Aspendos and the pre-Columbian Chimu hydraulic system. The design strategy of the Chimu architects is outlined and examined in fine detail, in order to understand the ways in which advanced hydraulic control technologies were built into the system of canals and aqueducts in order to optimize performance and protection. The system had to interact effectively with the local topography and dissipate stream energy in order to protect the works at vital places, such as aqueducts. The Roman system used many ingenious techniques to ensure reliable, efficient and steady flow rates (very important at the start up of the system to avoid air locks, for example). In both cases, examination of the artefacts – the historical technologies themselves – is most revealing. We do have written sources, such as Vitruvius, but as Ortloff notes, "much more was known, but not recorded by the field practitioners of Roman civil engineering."

The longevity of some of these ancient water technologies speaks for itself in assessing technical efficiency. A wealth of tacit knowledge resided in the builders of these and similar works. (We now understand the importance of tacit knowledge in application to the most sophisticated technological modelling and design.) Empirical understanding of the ways in which water flows, the effect of pressures, etc. cannot necessarily be replicated by the most sophisticated fluid mechanics models of today.

Kessener's chapter underlines this point in a most graphic way. He estimates that in modern water piping systems, air entrapment causes inefficiencies above 30 per cent. By studying Roman and Greek systems, lessons can be learnt. There are plenty of existing technologies to study in this respect – a testimony to the craft of their builders and also the centrality and importance of their work; there were, for example, over 300 aqueducts built in Gaul alone. A range of techniques and materials were used in the construction of these elaborate systems, including lead, stone, concrete, ceramics and terracotta. Seals could be lead solder or various mixtures of lime oil. Materials and methods were carefully selected to deal with a range of factors: static pressures, flow pressures, air pockets, bend radiuses, etc. Kessener's study underpins the importance of understanding the methods embedded in technologies and systems such as the Madradag siphon, which allowed water to flow ''uphill'' to the Acropolis, or the different design of the Yzeron siphon, which utilized open tanks and towers to obviate the problems inherent in a very steep pipeline. As the author states, ''physics has not altered in 2,000 years.''

A similar lesson is highlighted in the chapter by Sakitani, Nakai and Shinohara. Their work again highlights the considerable empirical knowledge employed by engineers such as Nonaka Kenzan in the 17th century in the construction of river weirs. The curvilinear oblique design developed during this period is found to optimize the characteristics of the river flow itself. Built to take advantage of riverbed forms, including alternating bars, the weirs were placed to maximize intake and outflow functions across a range of conditions. River characteristics (during flood and normal flows), geology and topography were all meticulously observed before the design and placement of the weirs. The authors state that, in spite of modern materials and construction methods, ancient methods may have been superior due to a synergy between the designers and the natural environment. ''Our ancestors had sharper eyes and more wisdom . . . [and] lived their lives somehow in harmony with nature.''

Jansky and Jakubis produce a complementary pair of studies of water management systems in Central Europe in the 17th and 20th centuries. Work on the mining ponds of Banská Štiavnica in Slovakia outlines the way in which over 50 reservoirs were combined into a ''unique water management system'' from the 12th century onwards. By the 17th century, this was the largest area of reservoirs in support of mining anywhere in Europe. Advanced design features were apparent, such as the steep-gradient earthen dam at Rozgrund.

A similar tradition of innovation and cutting-edge design can be found in the Jelenec torrent control system, constructed in the Slovak Republic between 1926 and 1927. This system implemented revolutionary flood control methods to prevent erosion, reduce pressure on river beds and control flooding. Jansky and Jakubis provide exhaustive detail of the development of these systems and their revolutionary nature and, in so doing, shift the focus of water history away from more traditional areas of study. Much historical study in these periods has focused on the example of the Dutch in the 16th and 17th centuries, and on the USA in the 20th century – perhaps with some justification, given the vibrant culture of water management and water-related technology that arose in these countries. Nevertheless, innovation can be found across a range of global sites, in wide-ranging contexts; water historians and practitioners should be aware of this.

That said, no collection on water history would be complete without some focus on Dutch history. Perhaps no country or society has lived in symbiosis with water to the extent of the Dutch. De Bruin and Schultz provide a comprehensive overview of the way in which the Dutch have used technological systems and management and organizations, both to establish an economic system and to protect and perpetuate it. From at least the 14th century onwards, digging and collective dyke construction enabled agriculture to thrive in a "hydraulic and hydrological chain reaction" that drove Dutch expansion. The chapter takes us through successive waves of development and technological rationalization, from wind to steam to electric power, and through land reclamation programmes to flood control systems. The chapter also tracks the concomitant change in political regimes, the command and control structures as they change, and the unfolding debates about the political economy of water (an issue which we shall return to below).

The central message or lesson that emerges concerns the ways in which control and rationalization change the environment. But also there are wider environmental pressures that reshape responses; there is a constant interplay and shifting of boundaries between technologies, markets and the environment. Drainage affects land levels, river flooding changes with enclosure, population and industry pressures shift, and broader climatic patterns become increasingly unpredictable. Problems have emerged for each age in Dutch water management, from the pile worms that destroyed wooden dykes in the 18th century, to high 19th-century river levels.

Early drainage systems were expected to double as military defences, whereas more recent priorities have been towards issues such as soil ripening or desalination. If we consider policy at a national level, the major issues of concern from the 1960s onwards shifted towards water quality issues, and more recently to integrated water and environmental management. As the authors take pains to point out, however, the issues that must concern planners in the 21st century may mark a return to older twin threats of tidal surges and river flooding, given the uncertainty of the global water environment and the vulnerability of coastal nations.

The Dutch, as noted, are emblematic of a nation suffused with a tradition of water management and water resource expertise. The wider influence of the Dutch cannot be underestimated. Dutch engineers brought many of their innovations to Britain, for example, on the eve of economic expansion there from the 18th century onwards. The Dutch were also, of course, an expanding and colonizing economy, anchored in world trade from an early period. The Dutch were the only Western nation to establish a presence in Japan, for example, before the late 19th century, and the Dutch East India Company established a model for trade between Europe and Asia.

In common with many formal imperial powers into the 19th century, the Dutch led their colonization programmes through their mastery of technologies. Just as guns would provide an overwhelming military advantage, so a broader range of civil engineering technologies would provide the basis for a consolidation of political power and control. Ertsen provides us with a very good example of this process in the development of the Tjipoenegara system in West Java. Dutch engineers envisaged and constructed an irrigation system designed to facilitate not only the growing of rice, but also sugar cane. They used a scientific method to calculate the functioning of the system, replacing or ignoring older experiential methods. The designers of this system hoped that investors would favour sugar growing, changing the socio-economic profile of the region. Although market prices intervened to scupper the system, Ertsen provides some fascinating insights into the ways in which engineers are involved in decisions that ostensibly are technological, but that in reality are deeply political, and the ways in which they and their administrative and political counterparts interact.

The relationship between political control, authority and technological systems is, of course, a complex issue. From Wittfogel onwards, scholars have pointed to the links between the control of water resources and political control.

Water-rich countries may not necessarily escape debate and controversy. The history of Swedish water resources, for example, is replete with debates about the over-exploitation of the nation's rivers for hydroelectric use at the expense of natural flow. One of the biggest contemporary debates is that which rages around the political economy of water: whether water is a commodity and, like other commodities, should be subject to pricing and market dynamics. Current thinking at the World Bank, for example, favours the inclusion of a pricing mechanism in water provision, marking the supremacy of market forces economics throughout the globe. History shows, however, that the debate over the pricing of water has a very long lineage. The chapter by Hukka and Katko provides a very illuminating cameo in this respect. They recreate the early 20th-century debate between Finland's Bernard Wuolle and Britain's Lord Avebury over the best place for water resources: in the private or public sector? British water resources in the late 19th century had undergone a profound revolution with the transfer of ownership to local municipal authorities, effectively putting its control in the hands of politicians. British politicians certainly had an eye for political as well as economic expediency when they took over the running of water companies and embarked on a number of very large civil engineering projects. The debates re-emphasized by Hukka and Katko ran throughout the 20th century and, indeed, continue to run (as they demonstrate through their commentary). Water remains for many a special commodity, imbued with emotional capital that places it beyond the scope of ''normal'' economics.

Returning to, and completing, the phased analysis of Japan's water resources management, Takahashi takes a broader view to examine national attitudes and strategies against the background of industrial and urban change. Few can be unaware of the meteoric rise of the Japanese economy from the 1970s. This growth posed a series of problems in terms of increasing demand for water resources and qualitative pressures on those resources. In the fifty years following World War Two, for example, Japan constructed over 1,500 multi-purpose and power-generation dams. Interventions such as these, along with new building and industrial programmes, enhanced the instability of the system in terms its vulnerability to flooding or pollution. Takahashi outlines four key phases: until 1960, when flood control and management were the prime issues; the 1960s and early 1970s, when industrial growth put severe pressure on water availability; post-1973, when the oil shock pushed conservation measures to the top of the agenda; and, finally, from the 1990s onwards, when broader environmental measures have come to be the primary issue. It is well known that Japan is seeking to place itself at the head of the international governmental movement for environmental sensibility. Domestic water policy, as Takahishi shows, is very much driven by this new political agenda, which seeks to balance productivity with sustainability, and to harmonize environmental exploitation with conservation.

Turning next to foreign policy, Murakami's chapter looks at the history of Japan's official development assistance (ODA) policy in the water sector. Murakami divides Japanese assistance to international development projects since the 1920s into three phases: the pre-war and war years stage (1920–1945), the post-war stage (1945–1954) and the stage of international cooperation (1955 onwards). He then tries to identify some alternative strategies to resolve water and poverty problems by fostering peace initiatives in the developing world, and examines the paradigm shift of Japan's international development policies.

Not all studies of water technologies can provide instant lessons in terms of the ways in which modern systems might be designed or function. Nevertheless, the studies themselves may contain valuable lessons of a different sort. Archaeological methods and epistemology may be advanced through the study of ancient and more modern water technology artefacts. Fahlbusch's elegant study of the Sadd el Kafara dam is a perfect case in point. The Sadd el Kafara has been identified as the world's oldest high dam. Standing at 15 metres in height, the dam was constructed over 4,000 years ago in the Wadi Garawi to retain flash flooding, which is endemic in the region. Falhbusch painstakingly recounts the story of the discovery and examination of this dam, its construction, its destruction when only partially completed, and subsequent deconstruction by the elements. Using almost forensic archaeology, he interrogates a variety of theories explaining the dam's purpose, from irrigation, flood protection or water supply for nearby slave labour in the alabaster quarries to, most ingenious of all, the provision of water to lubricate the sliding transport of stones from the quarry.

Similarly, Vogel's chapter on the fluming dams around 18th-century Vienna illuminates a similar hidden history using archaeological evidence. He reveals how a complex system of dams was constructed in order to generate and control annual flooding and transport over 50,000 cubic metres of timber annually down the river system. The fluming dams acted as a storage device, particularly during the snow melt season, which could be used by a controlled release to float logs through difficult terrain to the central Viennese market. The dams incorporated in this system comprise a range of designs and provide evidence of complex management and coordination. Evidence comes predominantly from ruined dams, in which the author has rediscovered a recondite, hidden technology.

While some areas of water resource control and management have been well documented, and the origins and anatomy of technologies studied in depth in this volume, other areas of study are still comparatively neglected. Many of the studies detailed herein have revealed that the past can provide valuable lessons, if studied in the correct way – and if the right questions are addressed. One example of such an area that would surely repay further research is highlighted by Kobori. His work on qanats shows how they have been superseded by newer technologies (pumped wells in particular). The social and labour formations upon which these systems depended have been eroded and are increasingly untenable. Nevertheless, valuable information may well be forthcoming if a systematic and rigorous programme of research into the nature of qanats is undertaken.

The studies collected here demonstrate the diversity of history that needs to be studied in order to understand the integrated and complex way in which the development of water resources has taken place. What is clear is that many of these studies point to ways in which tradition and history can give valuable lessons – whether in terms of organization and control at a local level, or in terms of exact engineering principles. In a changing environment, at a local as well as a global level, these lessons should be taken very seriously.

I

Investment and management of water resources

2

The mining ponds of Banská Štiavnica: Large-scale technology transfer 300 years ago

Libor Jansky and Matúš Jakubis

The fourth meeting of the Conference of the Parties to the Convention on Biological Diversity (CBD), held in 1998 at Bratislava, recommended the adoption of integrated land and watershed management approaches based on watersheds, catchments and river basins for the protection, use, planning and management of inland water ecosystems. (CBD 4, Doc. 27). It further emphasized the restoration or improvement of the quality and supply of inland water resources and the economic, social and hydrological functions of inland water ecosystems. Thus, to carry out the recommendations of the fourth Conference of the Parties, it is important to understand the history of the various inland water ecosystems and their formations, before we can really look into their management aspects.

Not far from Bratislava, where the convention took place, is the small mining town of Banská Štiavnica (figure 2.1). It was here that the remarkable beginning to the history of water management in Slovakia started, with the formation of 54 reservoirs that laid the first foundation of dam building in Slovakia and Central Europe in the 17th century. Many of the reservoirs are functional even today and, in spite of their age, serve both to supply water and for recreation and fishing. The system of dams and reservoirs is unique because of its technical parameters and the extensive water management system that utilizes water from another watershed with interconnection of the respective reservoirs by an arrangement of shafts, ditches and galleries.

In 1950, Banská Štiavnica was declared one of the first Urban Conser-

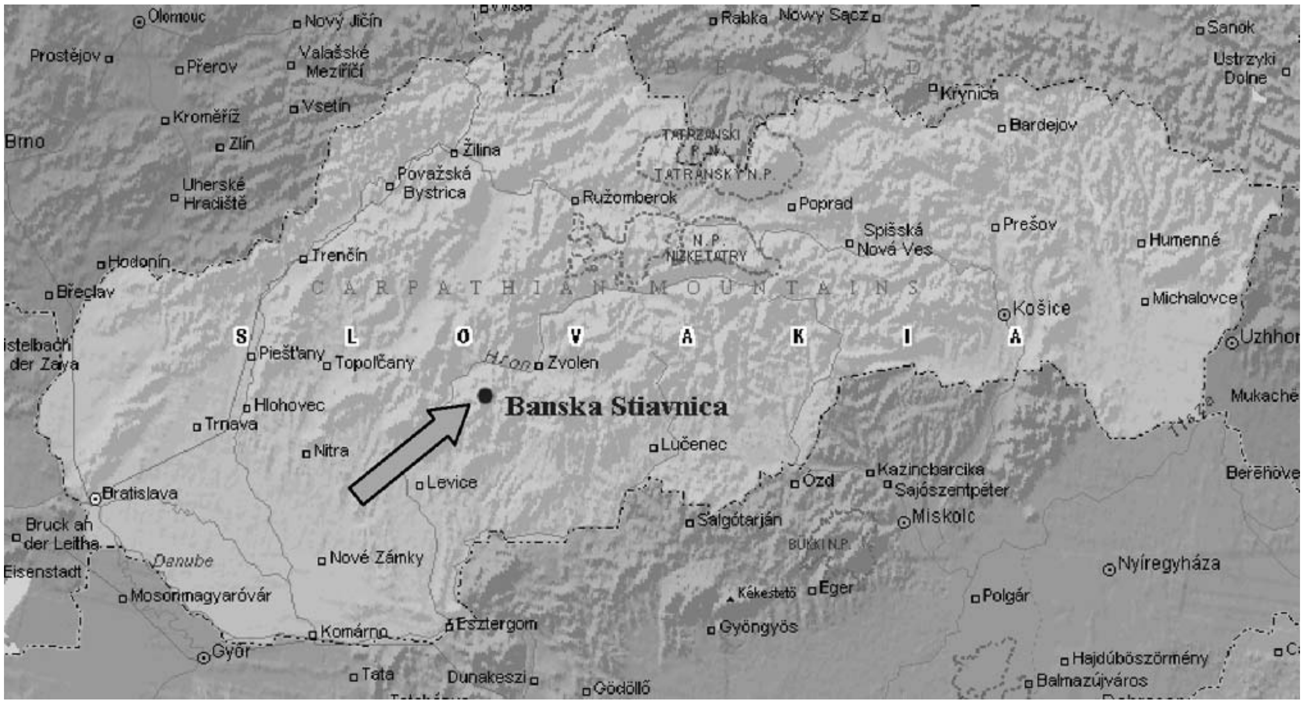

Figure 2.1 A map of Slovakia highlighting the location of Banská Štiavnica

vation Areas in Slovakia. The uniqueness and contribution of Banská Štiavnica's water management system, which led to the progress of world civilization, was also recognized by UNESCO in Cartagena in 1993, when the historic town was inscribed in the World Cultural and Natural Heritage List.

The history of water management in Banská Štiavnica

The history of water management in Banská Štiavnica begins with the era of mining and ore exploration, and dates back to 1156. In the first-known written document from this period, the region was called the "land of miners" (*terra baneusium*).

King Belo IV of Hungary granted free-town privileges to the royal town of Banská Štiavnica in 1238. A milestone in the history of the town was the establishment of the world's first Mining Academy in 1762; the town soon became the centre of mining technology for the whole of Europe.

The first reference to the water supply reservoirs in the region was in 1510 and 1511 (Abaffy et al., 1995). The mining activities in the Banská Štiavnica ore region reached their height in the 16th and 17th centuries, followed by a mining depression that culminated in the late-17th and early-18th centuries (Lichner et al., 1997). The main cause of this depression was the intrusion of groundwater into the mines; because the water pumping technology and energy resources of that period were limited, the problem escalated into a very serious situation. In 1687, the situation was so bad that as many as 720 of 2,173 mining workers (as well as 196 horses) were pumping water. After a long and complicated development of mining and mining technology in this region, a sophisticated mining water management system was created in the first half of the 18th century. This system not only saved Banská Štiavnica's mining industry but also served as a model for other mining districts in the world.

The adoption of hydrological methodology and technical parameters

In the first half of the 18th century, the advanced technologies consisted of 54 reservoirs, 130 kilometres of water ditches and 8 kilometres of connecting galleries. The Harz's water management system in Germany was the largest mining water management system in Europe at the end of the 18th century, but Banská Štiavnica's system was noted for the remarkable technical parameters of its reservoir. Of the 13 largest mining reservoirs in Europe at the end of the 19th century, more that half – seven – were in the Banská Štiavnica ore district. Furthermore, the three highest dams of mining reservoirs constructed in Europe before the middle of the 19th century were located in the surroundings of Banská Štiavnica: Rozgrund (30.2 m), Richnavský tajch velky (23.4 m) and Pocuvadlo (22.5 m). Only one of the ten highest dams built in Europe before the end of the 18th century was outside this region (Oderteich in Harz, Germany).

The height of dams built from the local debris clay materials ranged from 8.5 to 30.2 metres. According to Abaffy et al. (1995), these dams were also interesting with regard to the economical design of their cross-section, namely the slopes of the upstream and downstream faces. Among all dams, the Rozgrund dam is unique in its height and inclination of slopes, which have a gradient of 1:1.5 on the water side and approximately 1:1.35 on the outer side, making it is the most economically constructed dam in Central Europe. These parameters outstrip even the French dam Meurad (27.5 m high, constructed in 1859 with gradients of 1:1.35 and 1:1.6), which is regarded as the most courageously designed earthen dam in the world. Table 2.1 lists the most important dams and reservoirs in the Banská Štiavnica region.

The originality of this extensive water management system of dams may be considered for its construction solution as well as from the hydrological viewpoint. The original approach to water management and hydrologic issues may be seen in the utilization of water from a so-called ‘‘foreign’’ basin, and in the interconnection of reservoirs by means of a system of ditches, tunnels and shafts. Since majority of reservoirs are characterized by a small area of the basin, civil engineers and designers – among them Matej Kornel Hell (1653–1743), Saumel Mikovini (1686–1750) and Jan Lill (1751–1817) – were aware of these circumstances. To improve the hydrologic conditions in their own territories, they constructed interception ditches close to reservoirs to lead water into the reservoirs. The purpose of these interception ditches was to bring water from the foreign basin, which would naturally drain rainfall water into river, downstream of the reservoirs. The interception ditches were built at elevations following the approximate contour line. The most extensive system of such ditches were for the reservoir Počúvadlo (over 28 km) and Richnavský tajch velky (25 km).

The most remarkable personality in the history of mining technology in Banská Štiavnica was the principal mining machinist, Matej Kornel Hell. Hell came to Banská Štiavnica around 1693, after working in Kremnica. Just three years later, in 1696, he constructed a horse-drawn device for vertical transport that did not require a crankshaft. There was a special appreciation for this device, since crankshafts often broke and were expensive to produce.

Table 2.1 An overview of the fundamental characteristics and parameters of weighty water reservoirs

Reservoir	Built In (year)	Altitude (m)	Area (10^3 m^2)	Total capacity (10^3 m^2)	Maximum depth (m)	Dam wall (top) Length (m)	Dam wall (top) Width (m)	Dam wall (top) Height (m)	Purpose Previous	Purpose Contemporary	Reconstruction (year)
1	2	3	4	5	6	7	8	9	10	11	12
Bakomi	1738	711.27	12.00	183.2	14.4	113.8	13.3	15.6	M	R	1792
Beliansky tajch	1747	556.75	18.20	146	18	130	9.0	19.0	M, I	R	–
Evička	1638	662.81	20.21	211.6	10.4	165	12.5	11.4	M	R	1714, 1729
Halčiansky t.	1770	472.4	45.46	257	13	123	8.6	11.5	M, DM	R, FB, I	1798
Hodrušský t. dolný	1743	528.23	–	641	20.3	199.1	5.7	21.7	M	–	–
Hodrušský t. horný	1705	532.7	48.75	255.8	14.2	244.7	7	15.7	M	R, FB	1958
Klinger	1765	682.83	21.0	157.9	21.3	127.1	6.3	22.4	M, I	R, I	1829–1833
Kolpašský t. vel'ký	1730	598.5	113.3	798.9	13.5	182.1	20.9	14.2	M	R, I	1746
Počúvadlo	1775	677.64	117.30	745.3	10.8	195.3	19.0	29.6	M	R, FB	–
Richňavský t. malý	1746	725.51	10.0	553.7	14.2	187.8	6.3	17.3	M	R	–
Richňavský t. vel'ký	1738	725.51	81.0	960.0	21.1	268.9	24.7	23.4	M	R	–
Rogrund	1743	703.83	57.25	960.0	22.3	138.4	7.6	23.2	DW, I, M	DW	1749–1760
Vindšachta vel'ká	1712	687.48	44.0	533.7	14.2	237.1	4.4	15.2	M	R	1729
Vodárenská vel'ká	1510	820.50	8.5	34	14	87	16	10	DW, I, M	DW	1725

Notes: M = mining; R = recreation; I = industry; DW = drinking water; DM = drive of the mills; FB = fish breeding.

In the second half of the 19th century, the significance of reservoirs for mining decreased (due to limitations on and suspension of mining activity). Unfavourable conditions of the appurtenant structures of dams (as well as the fact that they did not meet current safety requirements) prevented a more extensive exploitation of some reservoirs. Failures and breakdowns occurred at some dams in the 20th century, requiring cautious operation with gates of bottom outlets.

Of the 54 reservoirs existing at the beginning of the 20th century, 28 have so far been registered. All are used for recreation, and some for fish breeding, fishing and drinking water supplies.

Conclusion

Banská Štiavnica's history has shown the world, through some classical examples, how excess water could be managed in a very sustainable manner during a time when there was little hydrological advancement. The history of the mining ponds of Banská Štiavnica paved the way for inventions in controlling excess water in mining fields and, later, led to improved hydrological technologies culminating in the construction of dams and reservoirs. During that time, the major need was to control the excess groundwater seeping into the mining ponds; as the city was totally dependent on the resources from the mining fields, it was important to find a solution to this problem. Though the solution took more than a century to achieve, it helped to advance knowledge about hydrological engineering, and is one reason why the region has produced some of the world's best hydrologists.

It is important for us to learn from this history and understand the problems in a much better way. Water conflicts regarding the sharing of the Danube remain, and water conflicts around the world are a never-ending problem. We can learn from examples of history about how science and technology has been instrumental in achieving a better understanding of situations such as the Banská Štiavnica experience. As we draw recommendations from the fourth meeting of the Conference of Parties to the Convention on Biodiversity, we should realize that many of these conclusions originated some 300 years, at the mining ponds of Banská Štiavnica.

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3

General perspective of the Sayama-Ike Land Improvement District

Yoshihiko Ogino and Barnabas Mulenga

After the Second World War, the Japanese Government enacted land legislation and replaced outdated laws in order to improve and enhance irrigated agricultural production and land productivity. In 1949, the Government of Japan promulgated the Land Improvement Act, replacing the Arable Land Readjustment Law and Irrigation Association Law. Previously, arable land was inequitably distributed, with much of it in the hands of individual landlords, thus hindering rapid agricultural development and harmonization of the labour force to boost land productivity. The Land Improvement Act paved the way for the establishment of Land Improvement Districts (LIDs) as irrigation associations throughout Japan, taking over control of infrastructure and associated irrigation functions from the *Suiri Kumiai* (Irrigation Association) whose experience in irrigation dated back for many generations (more than 400 years). This opened a new chapter in irrigation and led to establishment of the Sayama-Ike Land Improvement District, which took over the functions and activities of the former Sayama-ike Suiri Kumiai.

The effective distribution and utilization of irrigation water in areas where water is scarce is one of the many challenges that irrigation project engineers have had to face. Lessons drawn from experience in paddy irrigation projects in the Asian monsoon region, coupled with the vast and generations-long experience in paddy irrigation in Japan, indicate that construction of large-scale irrigation facilities – such as reservoirs, barrages and main canals – is insufficient in itself to achieve effective distribution and utilization of irrigation water. Farmer-based water manage-

Figure 3.1 An aerial view of the mother pond of Sayama-Ike Land Improvement District

ment organizations with on-farm water distribution systems – such as secondary and tertiary canals and ditches – are vital components of an irrigation project.

The command area of the Sayama-Ike LID is located in Osaka Prefecture (central Japan) and, until recently, its irrigated acreage was 2,700 hectares (ha). The current total command area under the scheme has been reduced to 484 ha, with a total membership of 2,438 (farmers or households). The scheme comprises a mother pond, the Sayama-ike (see figure 3.1), and more than 80 small ponds (called daughter ponds,) including 5 weirs, 2 main canals and several sub-main (lateral) canals with a total length of 18 km. The scheme comprises 33 local irrigation associations.

A brief historic view of the Sayama-Ike LID

The Sayama-Ike pond-fed irrigation association was founded some 2,000 years ago, and is one of the oldest in Japan. Through the centuries, the scheme underwent several rehabilitations, but modern engineering work was first carried out in the period 1925–1931. In 1949, the Government promulgated the Land Improvement Act; based on this Act, the Sayama-Ike LID was established as a water users association in 1950. The Sayama-Ike LID succeeded the command area, functions and activities of the former Sayama-Ike Irrigation Association. Further rehabilitation and modernization work was carried out from 1962–1964, and again in 1988–2000, for flood prevention and modernization purposes.

Japanese farmers have a long history of paddy irrigation management through farmer organizations in which they have cooperated in the construction, operation and maintenance of irrigation facilities. In the past, beneficiaries of the Sayama-Ike and associated facilities belonged to two hierarchical farmer associations: the Sayama-Ike Irrigation Association and a number of *mura* (village) irrigation associations. The Sayama-Ike Irrigation Association, formally called the Sayama-Ike *Suiri Kumiai*, is the one now called the Sayama-Ike LID and has continued to perform the same functions and activities related to irrigation water management.

Each *mura* irrigation association – a local irrigation water management organization of farmers in a rural community – is obligated to cooperate in water management in the command area of a daughter pond. Sometimes, a single *mura* may have two or more daughter ponds, while in other cases a daughter pond may be shared between two *mura*.

Figures 3.2 through 3.7 show historic moments and functions of the

Figure 3.2 Labour farmers with compaction tampers (in 1925)

Figure 3.3 The rehabilitation of Sayama-Ike (in 1925)

Figure 3.4 Old wooden intake structures

Figure 3.5 ‘‘Thanksgiving ceremony’’ at the site on 1 June by the president and board members of Sayama-Ike Land Improvement District

Figure 3.6 Water master in intake tower

Figure 3.7 Gate-keepers and farmers operating an old intake

Sayama-Ike, such as rehabilitation and modernization by using labour farmers, an old wooden intake structure built in the 7th century (revealed during reconstruction of the embankment), a traditional "thanksgiving" ceremony and operation of intake structures in the old days. Figures 3.8 and 3.9, meanwhile, show old paintings of the Sayama-Ike and the command area in 18th century.

Organizational structure of the Sayama-Ike LID

The Sayama-Ike LID is organized as a central office with several functionaries and special standing committees that carry out executive, policy-making, and inspection and auditing functions. The central office consists of a Board of Trustees, auditors and the president as well as various sections dealing with administration, finance, engineering and management. In addition, there are special standing committees for engineering and operation and management (O&M). (See figure 3.10.)

The tenure of both the president and the board of trustees is 4 years, and meetings are held at least every 2 years. The tenure of the farmer

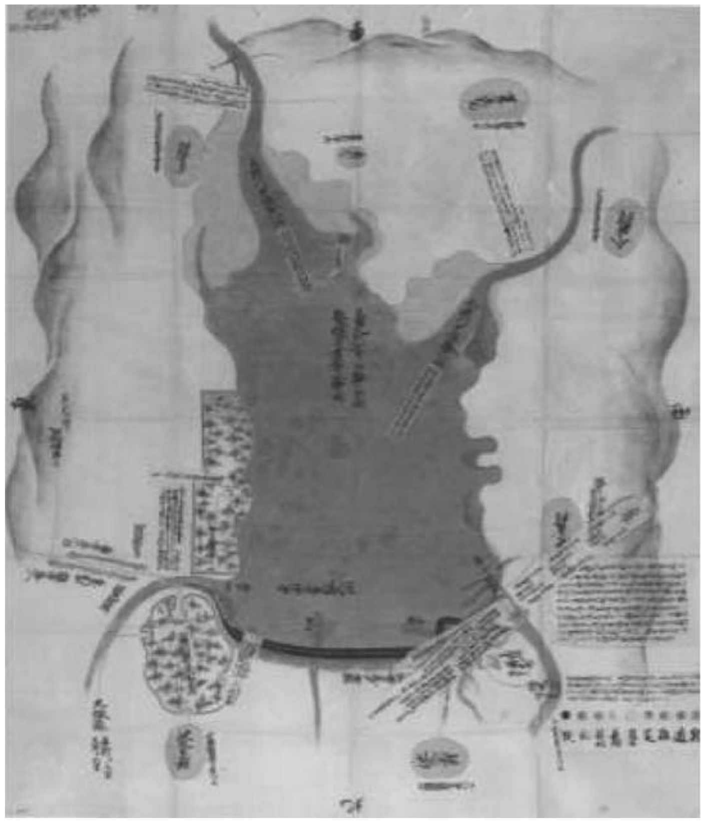

Figure 3.8 A painting of the Sayama-Ike mother pond in the 1700s

representatives is also 4 years; 42 persons serve as representatives of *mura* irrigation associations affiliated with the Sayama-Ike LID. These farmer representatives meet in a General Assembly once a year (in March).

Functions and activities of the Sayama-Ike LID

The Sayama-Ike LID undertakes a wide range of activities, including the promotion of irrigation projects and the operation and maintenance of irrigation facilities.

Promotion of irrigation projects – In Japan, planning, design and construction (including rehabilitation) of irrigation projects are carried out by irrigation engineers from the central and/or local governments at the

Figure 3.9 A painting of the Sayama-Ike Water Users' Association in the 1700s

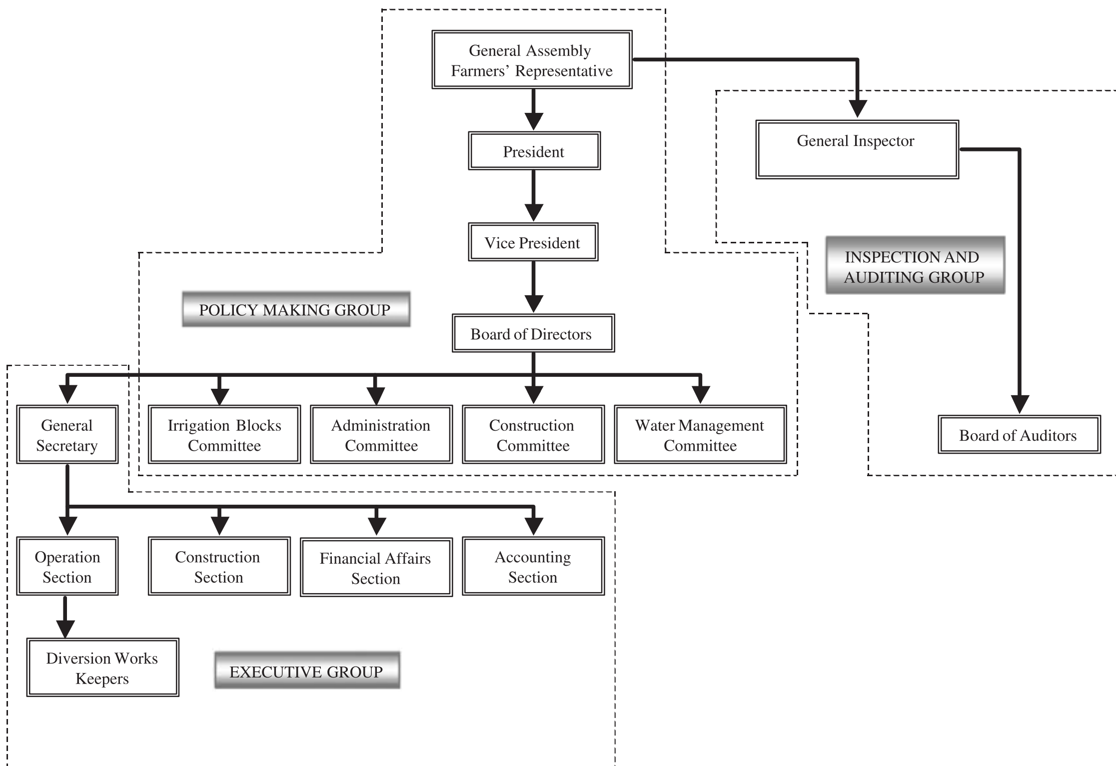

Figure 3.10 The organizational structure of the Sayama-Ike Land Improvement District

request of the LIDs – since the high level of technical expertise required for planning, designing and constructing large-scale irrigation facilities is generally beyond the capacity of LIDs. The Sayama-Ike LID is responsible for promotion of irrigation projects in the district, which is done through community sensitization and awareness campaigns. Needs assessment and identification of irrigation facilities are done by central or local government engineers, who then make recommendations to the executive members of the LID. A project may then be approved for promotion on the basis of the advice and recommendations of the official engineers.

Operation and maintenance – Generally, in Japan today, a reservoir constructed as an element of an irrigation project is a multi-purpose reservoir, operated and maintained directly by engineers and technicians specializing in hydroelectric power generation and flood control. The operation and maintenance of other irrigation facilities – such as barrages or diversion dams, pump stations, irrigation canals and turnouts – are carried out by farmers themselves. The Sayama-Ike LID is responsible for fixing and management of irrigation schedules through its board of trustees, flood prevention through timely regulation of water in the ponds, and collection of revenue from affiliated local irrigation associations (which are essentially membership fee-based groups of subscribing farmers). Major irrigation facilities – such as large-capacity pumps, barrages or diversion dams, and main and secondary canals (above tertiary level) – are operated and maintained by the LID; at and below the tertiary level, operation and maintenance of irrigation canals and ditches (including minor turnouts) are the responsibility of organizations of rural farm communities (the *mura*).

Each *mura* undertakes on-farm water management activities and also participates in the maintenance of village roads and the organization of local festivals, in addition to cooperative O&M of on-farm irrigation facilities. Furthermore, the land improvement district also leases and converts agricultural land for non-agricultural use, such as residential or industrial purposes. Planning, design and construction of irrigation facilities are executed and supervised by official engineers; once a project is completed and commissioned, all administrative and management functions are transferred to the LID.

Budget and financing of the Sayama-Ike LID

The Sayama-Ike LID has an annual budget of about ¥28.6 million. Of this, some ¥0.6 million is derived from membership fees, while part of the remaining ¥28.0 million is covered by assets that the LID holds as capital through the transfer of real properties. There are also small donations from the local government.

Expenditures include recurrent, capital and investment costs of the scheme. In general, financing of the LID comprises two main components: construction costs and O&M costs.

Construction costs – The central and local governments subsidize as much as 70 to 80 per cent of the construction costs for major and minor irrigation facilities, including reservoirs. To cover the remaining (unsubsidized) portion of the total construction cost, the LID can obtain a loan at a low rate of interest, payable in annual instalments by beneficiary member farmers. A 5-years grace period is often provided, and the loan is redeemable in 20 years with an annual interest rate of 5 per cent.

Operation and maintenance – The funds necessary for day-to-day operation and maintenance of major facilities, and for the management of the central LID office, are collected from member farmers. All the cost for O&M may be regarded as the responsibility of the farmers, since there are no provisions for subsidies from central and local governments.

Typically in Japan, the annual payment by a farmer to an LID for O&M is about ¥40,000/ha (US$360/ha), or 4 per cent of the domestic paddy price/ha. The total is based on calculations of the paddy field acreage owned by the farmers in the LID command area. Hence, farmers' contributions towards O&M costs are calculated on an acreage basis rather than the on accumulative volume of irrigation water delivered (this is regarded as a membership fee or dues) or as a water charge on acreage basis.

Operation and maintenance costs of the LID are further minimized by engaging farmers to operate turnouts and pumps without pay, including the tending of ditches, instead of hiring full-time, salaried central office personnel. In addition, farmers voluntarily carry out cooperative maintenance work without pay, such as removing canal sediment and mowing grass on embankments.

Distribution of irrigation water in the Sayama-Ike LID

Effective distribution and utilization of irrigation water in areas where water is scarce is one of the many challenges that irrigation project engineers have to face. The two most common systems of delivery and distribution of irrigation water in Japan are pond-fed irrigation systems and river-fed irrigation systems. Pond-fed irrigation systems are popular in four prefectures (Osaka, Nara, Hyogo and Kagawa), while river-fed irrigation systems are preferred in most regions of Japan. The latter are sometimes referred to as gravitational irrigation systems, because water diverted from rivers flows through open channels. Generally, water diverted from barrages or diversion dams is distributed to paddy field plots in the command area simultaneously through main-secondary-tertiary-quaternary canals and ditches.

In the Sayama-Ike LID, irrigation water is uniquely distributed using a pond-fed irrigation system. Characteristically, a pond–fed irrigation system is a rotational irrigation system that involves impounding water in a reservoir (referred to as the ''mother pond'') located upstream of the command area. Two types of ponds exist: on-stream reservoirs and off-stream reservoirs; the Sayama-ike ''mother pond'' is an on-stream reservoir. A series of smaller ponds (referred to as ''daughter ponds''), which are off-stream, are located inside each irrigation block and linked to the ''mother pond'' by canals within the command area. During a dry spell, or an abnormally dry season, the mode of water distribution is occasionally interchanged between rotational and simultaneous systems in-order to equitably and effectively distribute irrigation water to all plots of paddy fields in the command area.

Pond-fed irrigation systems – The rotational-based pond-fed irrigation system is the classic model in Japanese irrigation for effectively distributing and utilizing irrigation water during dry spells or in peak irrigation periods. In essence, this is a rotational irrigation system; during a normal irrigation season, with no extreme dry spells, all the water stored in each daughter pond is distributed on a rotational basis to paddy fields for puddling and transplanting at the beginning of the irrigation season (May to June). This water is generally collected in a daughter pond's catchment area in the winter prior to the irrigation season (spring to summer).

Figure 3.11 shows the Sayama-ike mother pond interlinked with daughter ponds by canals in the command area. Figure 3.12 is a schematic diagram of the rotational water distribution of the pond-fed irrigation system, including names of *mura* or local irrigation associations, acreage of paddy fields and allotted time for each association.

The stored water from the mother pond is released and distributed to each daughter pond rotationally as a supplementary contribution towards replenishing water used from the daughter ponds (which otherwise would have to be replenished entirely by rainfall and run-off from daughter pond's own catchment area). This rotational distribution of water into daughter ponds takes about twenty days.

The distribution and conveyance of water ponded in the mother pond is supervised by a director of the Sayama-Ike Irrigation Association. Water is distributed simultaneously and continuously during the 20 days of the rotational period into two main canals (the eastern and the western canals). The water is then diverted at each main canal turnout rotationally from upstream. Turnouts and ancillary devices are usually

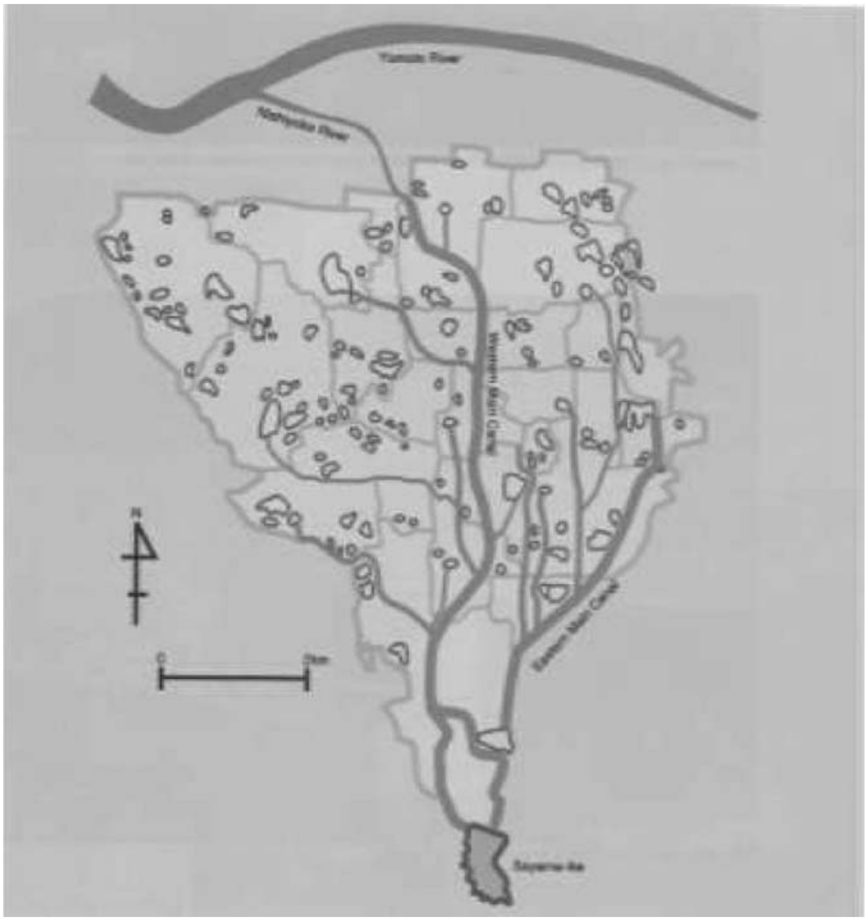

Figure 3.11 The command area of the Sayama-Ike Land Improvement District

controlled by a technician from the central office under supervision of the director who is responsible for a main canal turnout and its laterals and sub-laterals. Each lateral turnout is managed by a ''sub-lateral manager,'' who also supervises representatives of daughter ponds to follow the allotted hours (time table) endorsed by the central office director.

Conclusion

In pursuit of sustainable irrigation development and food self-sufficiency, regional-based irrigation organizational structures similar to the Land

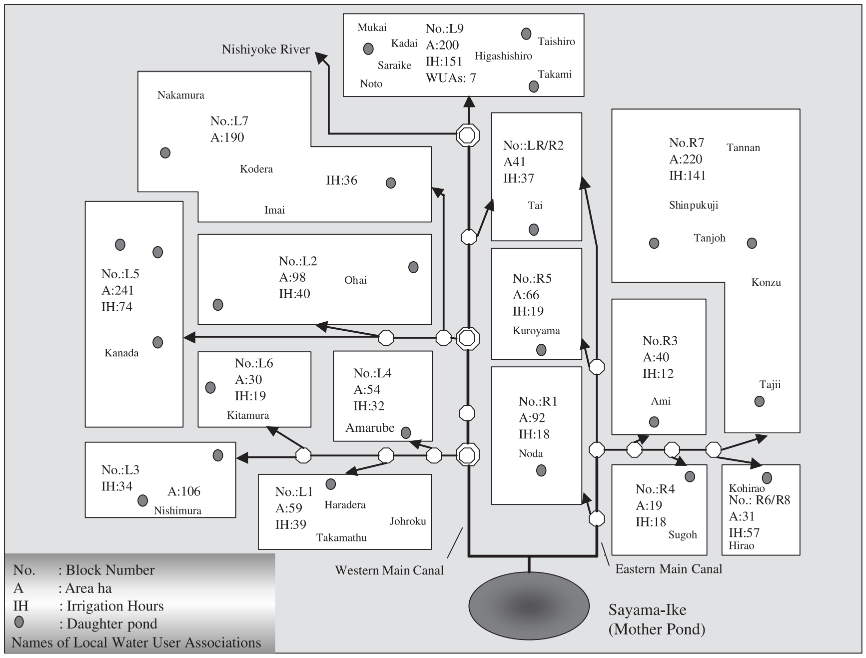

Figure 3.12 A schematic diagram of the pond-fed irrigation system

Improvement Districts are vital for ensuring development for irrigation as well as increasing productivity of available labour, land and water resources. Sustainable irrigated agricultural development is not attainable merely by providing irrigation facilities and infrastructure, but through farmer-based water-user or irrigation organizations with policy support at government level.

Irrigation development requires the government's lead in planning and implementation, particularly with regards to provision of incentives and partial financing of construction costs. The planning aspect in irrigation includes identification of suitable land for irrigation so that farming communities do not continue to rely on rain-fed crop production. This is the essence of land consolidation, which can only be implemented or driven effectively by government.

It is necessary for farmers and beneficiaries to contribute towards the costs of construction in order for them to develop a sense of ownership, commitment and responsibility. This could be achieved by farmers contributing through labour, funds, materials, etc.

Acknowledgement

This study could not have been accomplished without the unfailing support of the staff members and chairman of the Sayama-ike LID. Their kind support and patience in providing valuable explanatory information and data is gratefully acknowledged.

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4

Sayama-Ike and the Japanese experience: Traditional irrigation systems and problems of modernization

Akihiro Kinda

Traditional irrigation systems in Japan

Rice cultivation began in Japan in the fourth century B.C. Many rice paddies excavated by archaeologists show the presence of irrigation channels, although they were not long or wide.

From the second half of the 7th century, a system for constructing and maintaining irrigation channels was regularized by law. A manorial map drawn in the 8th century vividly represents many irrigation channels, including one coming from a river more than 5 kilometres away (figure 4.1).

In the 7th century, reservoirs for irrigation were also constructed. Another manorial map from the 8th century shows a reservoir that has a bank with a sluice gate on one side (figure 4.2) Sayama-Ike has a similar structure – a reservoir that dams up a narrow valley (figure 4.3). Such a reservoir can be categorized as a *tani-ike* (valley reservoir). In flat plains, there are numerous reservoirs of another type, many of which show a rectangular shape with banks on all sides of the paddies (figure 4.4). These are usually very shallow (a few metres in depth) and are used temporarily during spring and summer season, when plenty of irrigation water is needed to supply their rice paddies. This type of reservoir can be categorized as a *sara-ike* (shallow reservoir).

There were more than 1,500 reservoirs in Nara Basin, mainly of the *sara-ike* type in the flat plains, with some of the *tani-ike* type at the foot

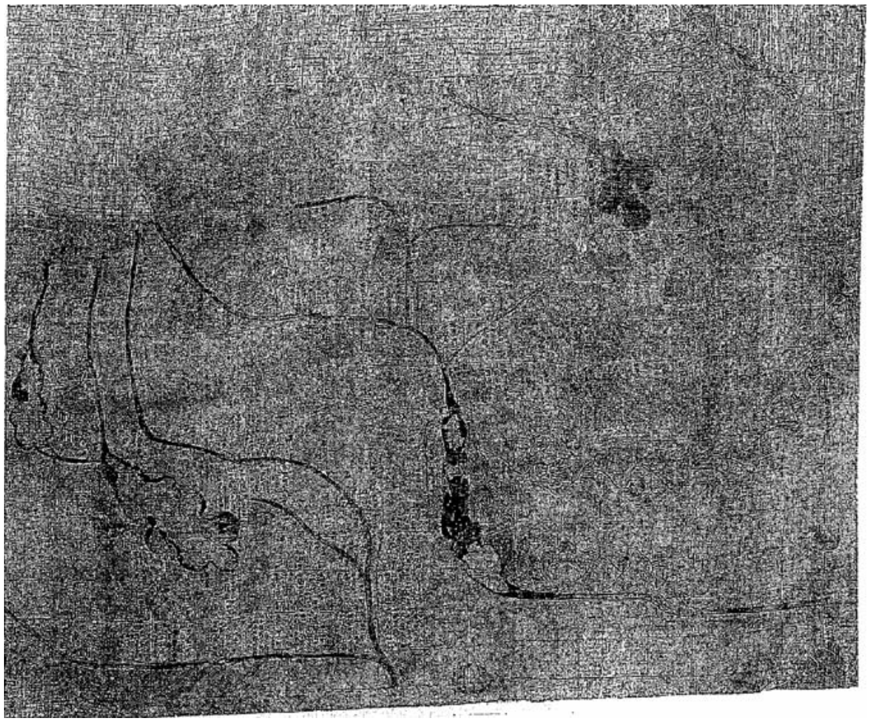


Figure 4.1 Irrigation channels drawn on an 8th-century manorial map

of surrounding hills and mountains (figure 4.5). Most of the *sara-ike* were constructed in and after the 12th century; the most active period of constructing *sara-ike* was from the 17th to 20th centuries for intensive rice cultivation. The *sara-ike* usually has a supplementary function, serving not only for irrigation but also as a "water tower" for a water supply system.

Sayama-Ike, a typical reservoir system

Sayama-Ike was first constructed at the beginning of the 7th century, and was repaired or reconstructed several times after its destruction by disasters. A pictorial map drawn in the 17th century (figure 4.6) shows a *tani-ike*-type reservoir into which two rivers flow, with a bank on one side from which three irrigation channels flow out. In that era, the

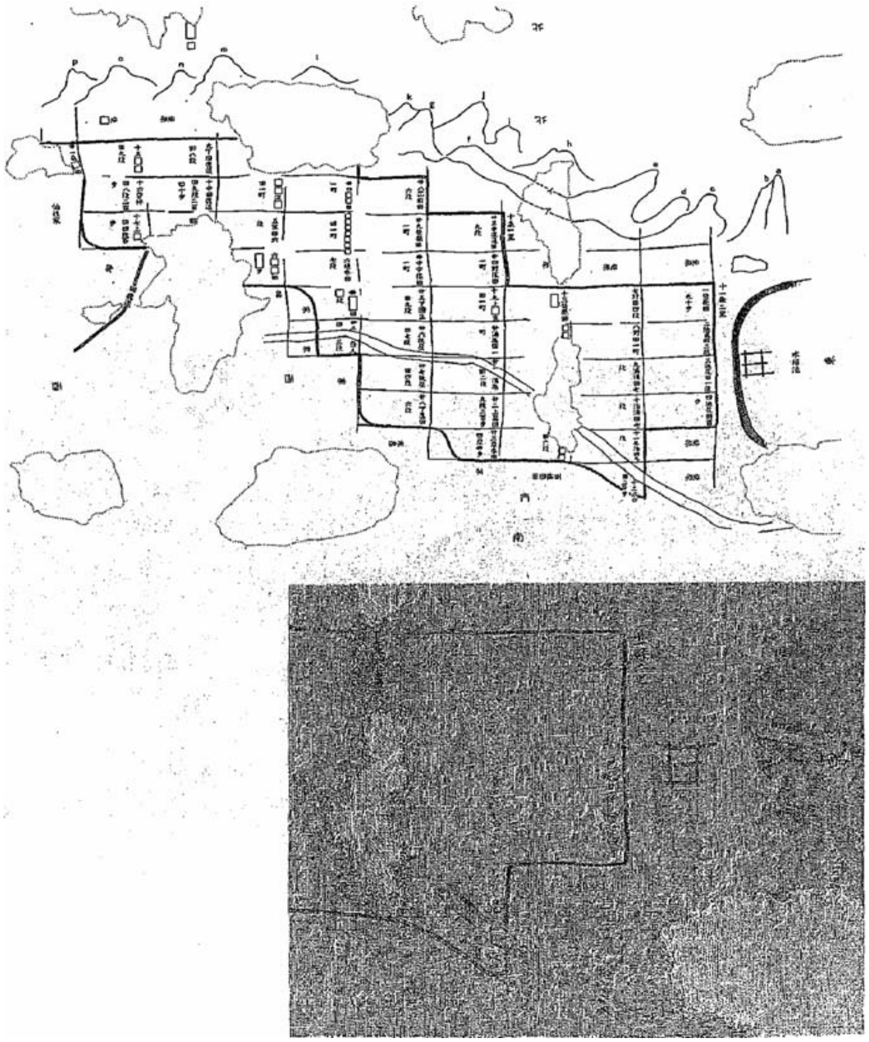


Figure 4.2 A reservoir for irrigation with a sluice gate drawn on an 8th-century manorial map

reservoir had an area of approximately 52 hectares and irrigated 1,247 hectares of paddies in the 81 downstream villages. Sayama-Ike was the mother reservoir, with other *tani-ike* and, as downstream smaller reservoirs, many *sara-ike* (as shown on a pictorial map from 1669; see figure 4.7). Sayama-Ike's reservoir network not only supplied irrigation water

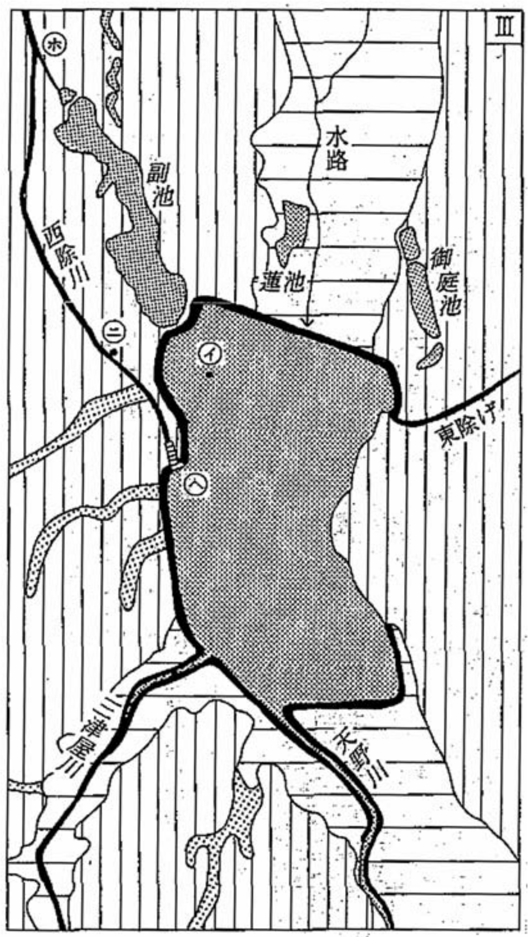
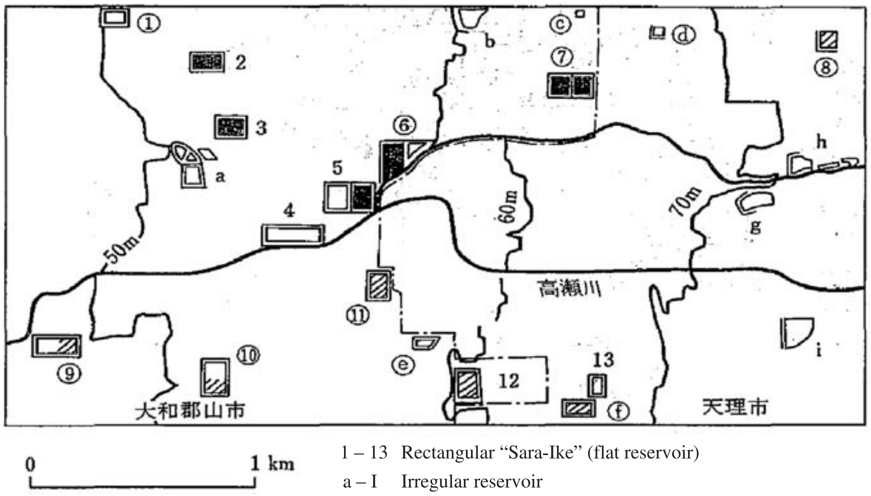


Figure 4.3 Location of Sayama-Ike: a reservoir that dams up a narrow valley

into those reservoirs but also provided plenty of groundwater into the downstream region.

The purpose of the reservoirs and irrigation channels was to improve the productivity of the agricultural land and enable intensive rice cultivation. This process can be categorized as an improvement of cultivation by engineering works. The formation of such reservoir networks and management of the many sluices attached to the reservoirs and channels is also a very important factor for improving the irrigation. This can be categorized as an improvement of cultivation by social man-



1 – 13 Rectangular "Sara-Ike" (flat reservoir)
a – I Irregular reservoir
○ Local name differs from reservoir name
▬ Reservoir did not exist in the middle age (based on records)
▨ Reservoir presumably did not exist in the middle age

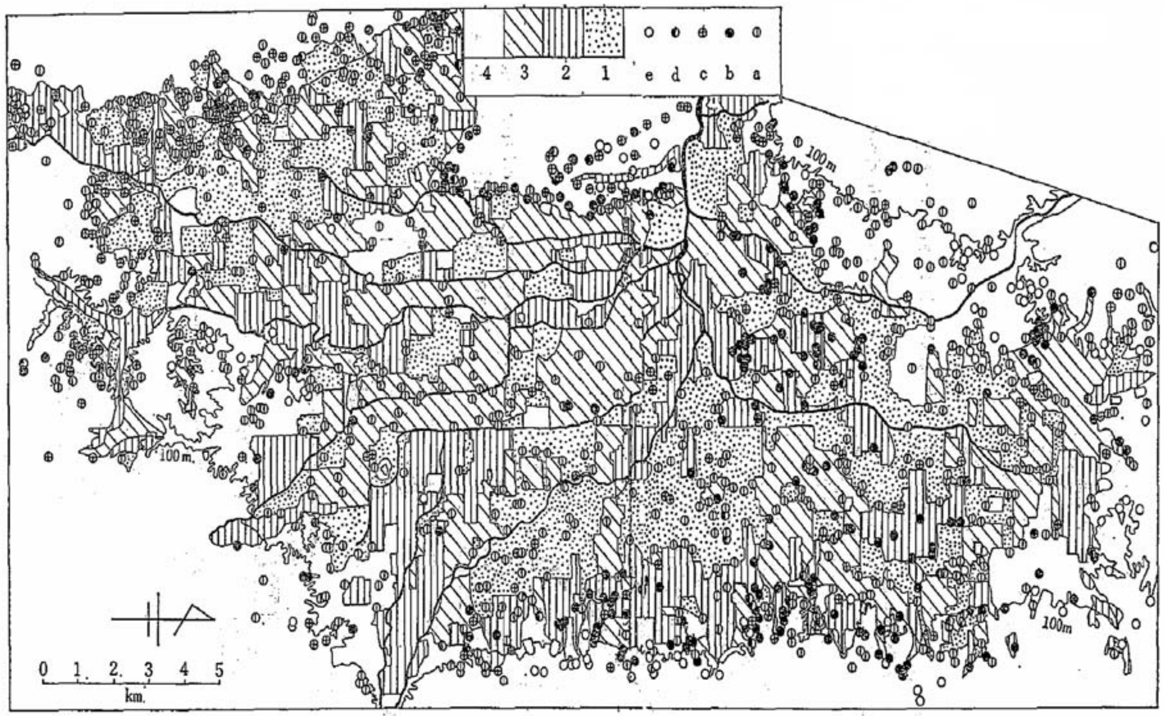
Figure 4.4 Two types of reservoirs (*tane-ike* and *sara-ike*) in Nara Basin

agement. There is also another improvement method for achieving intensive cultivation of profitable crops: the use of fertilizers, agricultural chemicals, etc. This can be considered as an agricultural method of improvement.

Traditional irrigation systems and problems of modernization

Traditionally in Japan, each paddy did not always have its own intake from the channel. Many paddies were supplied with irrigation water from a neighbouring paddy (figure 4.8). This system might have been inconvenient regarding the choice and timing of the crop for each paddy, but it was a very effective use of irrigation water that contained some fertilizer from an adjacent paddy and was of a suitable temperature from the planting already done in the adjacent paddy. A major inconvenience of such a traditional system, however, was that it almost precluded the use of agricultural machines.

From the second half of the 20th century, land consolidation began with the construction of paddies with an area of approximately 10 ares,



a : Local name differs from reservoir name
b : Local name corresponds to reservoir name
c : Difficult to classify as "a" or "b"
d : Local name is "Shin-Ike" (a new reservoir)
e : Unknown (unconfirmed)

1 : Area irrigated by "a" reservoirs (and a pump) only
2 : Area irrigated by "b" reservoirs, river and rain
3 : Area irrigated by both "1" and "2" or "c" or "d" reservoir
4 : Unknown or urban area

Figure 4.5 Presumed origin of reservoirs and irrigation patterns in Nara Basin (*types "a" and "c" presumably were constructed in or after the 12th century*)

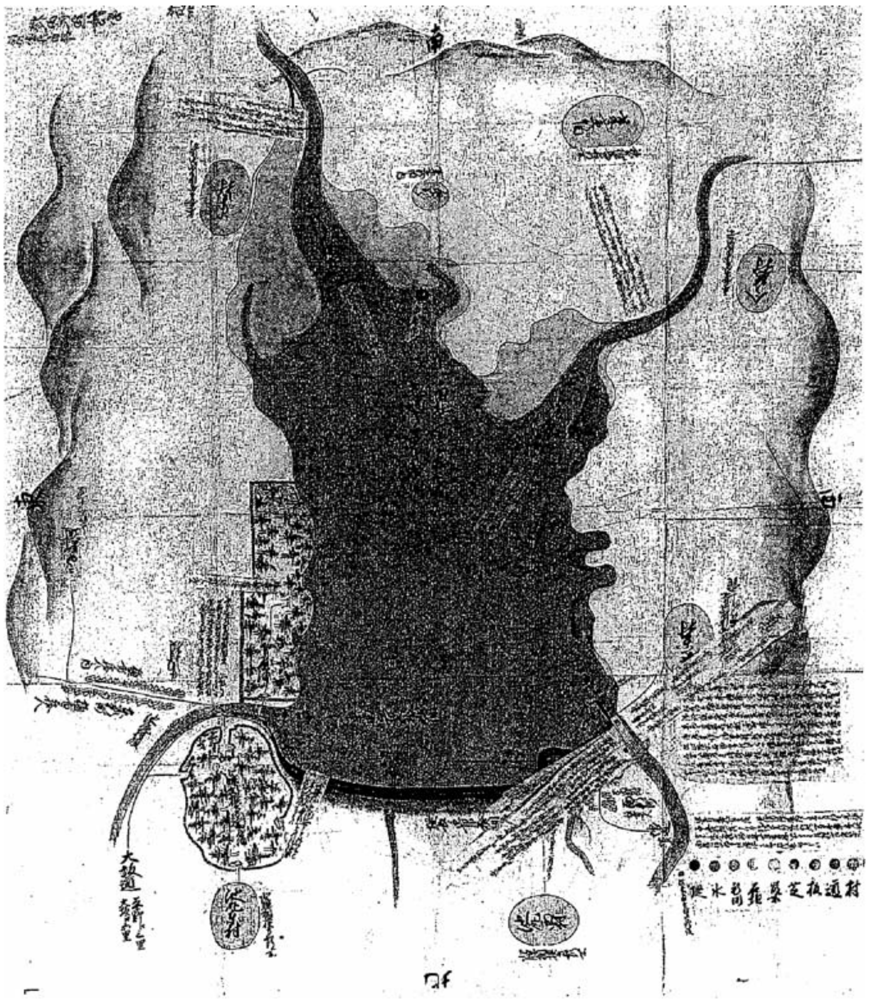


Figure 4.6 Sayama-Ike depicted on a 17th-century pictorial map

each possessing an independent intake for irrigation water (figure 4.9). This type of paddy typically is accompanied by a ditch used for both water supply and drainage, and was still effective for re-using fertilizers again and again.

For the mechanization of agriculture, however, a larger paddy area with wider access to each paddy is required. Since the 1970s, a second type of land consolidation has been carried out throughout Japan, consisting of paddies each with an area of approximately 30 ares, indepen-

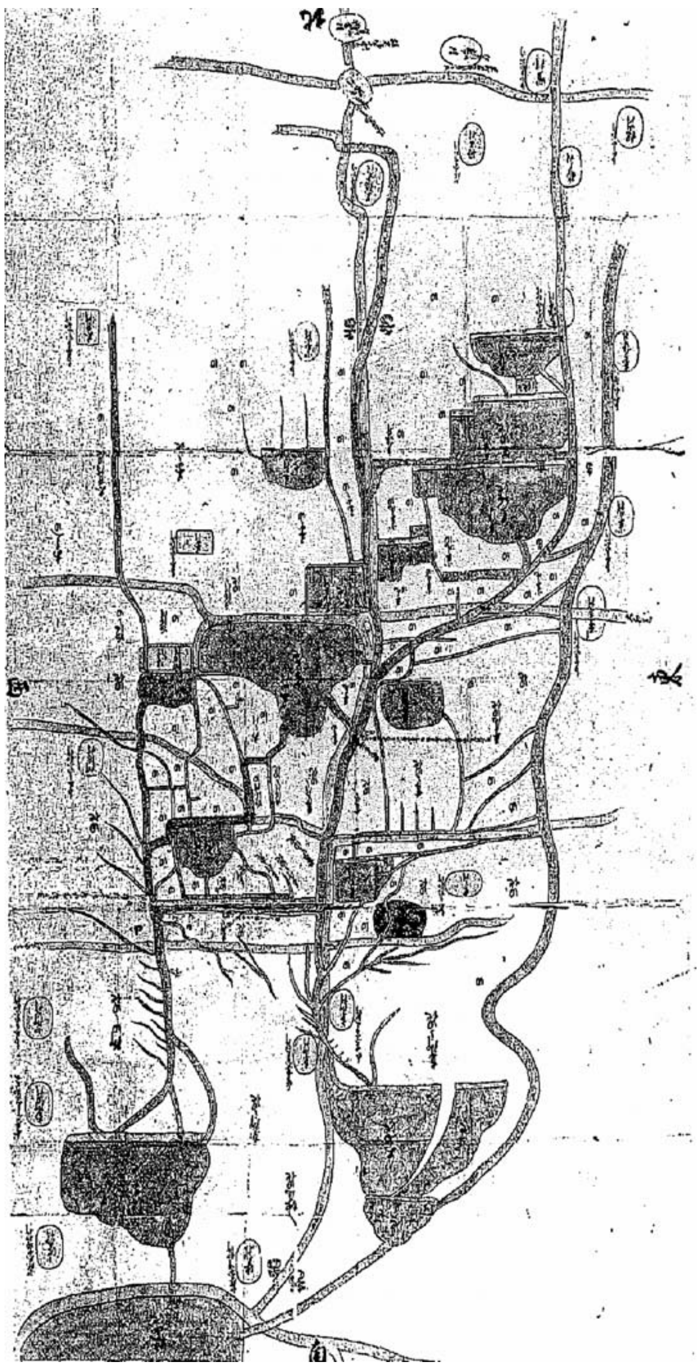


Figure 4.7 A reservoir network and irrigation water system from Sayama-Ike depicted on a pictorial map (1669)

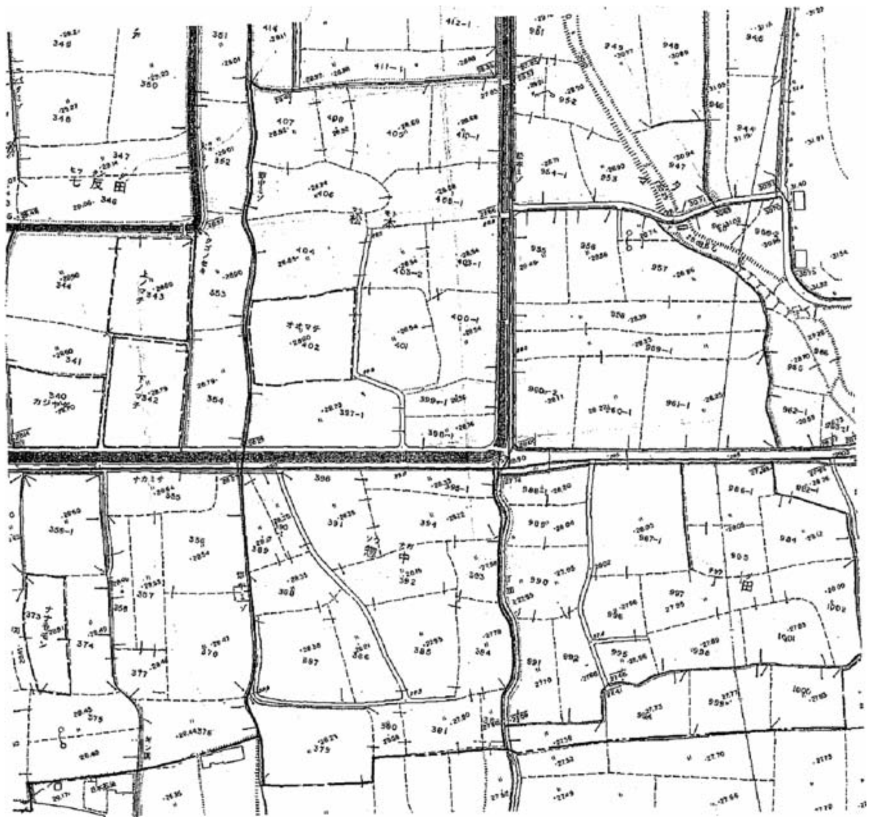


Figure 4.8 A traditional irrigation system without an intake for each paddy

dent access to each paddy, and networks of separate ditches for drainage and water supply. This system is much more convenient for the modernization of agriculture.

Figure 4.10 shows a traditional rural landscape near Lake Biwa in Shiga Prefecture. The paddies had a rather regular and rectangular shape, each with an area of approximately 10 ares. The many narrow ditches and rivers were used for both supplying irrigation water and drainage. The many grasses that covered the banks used the rest of the organic fertilizers. The water thus became very clear before it flowed into Lake Biwa, and the clean water of Lake Biwa was maintained for a long time (making the lake a very good source of water for both Kyoto and Osaka).

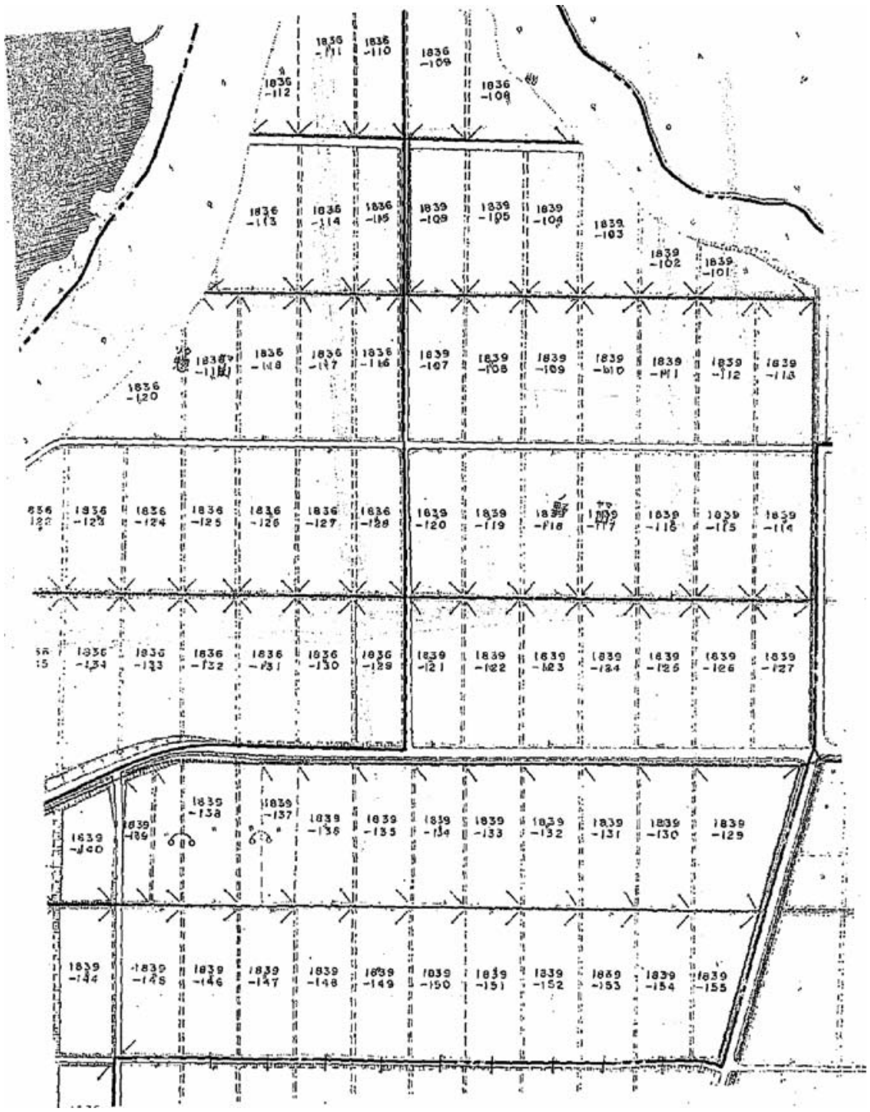


Figure 4.9 A modern irrigation system with an intake for each paddy; ditches are used for both water supply and drainage

Figure 4.10 A traditional rural landscape with a traditional irrigation system

Figure 4.11 shows a rural landscape after the second type of land consolidation; the rectangular paddies and wide river represent a big difference from the traditional landscape. This modern agricultural method used many machines (tractors and cars), and the lack of grasses on the banks (which were now concrete) caused the river to become polluted by the unused fertilizers. The clean water of Lake Biwa was thus polluted.

Figure 4.11 A recent rural landscape after land consolidation, with separate ditches for drainage and water supply (common since the 1970s)

The traditional irrigation system in Japan was characterized by:

- water storage systems, such as reservoir networks of *tani-ike* and *sara-ike*, which enlarged the potential for water usage versus the fast-flowing channel system, and

- repetitive usage of irrigation water that brought economized usage of fertilizer and kept the water clean.

Modernization by land consolidation, with the separation of channels for drainage and irrigation, broke the traditional system and brought about water pollution.

5

Fair distribution and allocation of water among farmers in ancient times

A.R. Salamat

Zayandehrood is a famous river in Isfahan. The term Zayandehrood refers to a river that gives birth to (increases) water. The Zayandehrood River functions as a drain for the upstream area, and water infiltrates into the river from the adjacent lands. If the water volume is measured in different areas of the Zayandehrood, it can be observed that the quantity of water increases in a downstream direction. This is important during summer, when conditions of water scarcity occur. During summer, the upstream region of the river faces water deficiency while the downstream area has a considerable amount of water. In fact, the quantity of water in the downstream area is sufficient to have another stream diverge from the river. Another name for this river is Zendehrood, which has two different interpretations – the first meaning "always alive" and the second referring to the "empowering condition" of the river.

Historical background of Zayandehrood River

To determine how Zayandehrood River has been manifested, it is important to study the geographical, natural and geological situation.

- In the first era, the geological situation of Isfahan is not clear. Fossils found in some parts of the river signify the ending of the first era, but in other parts there are no specific signs of first era remnants.
- In the second era, the sea covered Isfahan plain. Topographical condi-

tions such as Sofeh mountain or other parts that reside at a lower level indicate that the sea bed was flat and that it deteriorated towards the end of the era.

- In the third era, Isfahan plain completely dried up. The central region of Isfahan province consists of an impermeable layer with schist material; the river reach passes through this layer.

Natural and geographical conditions of Iran

By studying the climatic situations of Iran, it can be understood that country is considered to be a semi-arid region (according to the rainfall and air temperature). The average annual amount of rainfall is 250 mm, which is one-third of the world mean annual rainfall. Reasons for the dry and arid situations are geographical latitude, distance from the sea and various topographies.

The major direction of winds in Iran is from west to the east and from north to south. The wind conveys water vapour from the Mediterranean Sea and Atlantic Ocean in the west and the Caspian Sea in the north. However, the Zagros mountain chains in the west and Alborz in the north prevent this vapour from reaching the central plateau. The collision of clouds with these topographies results in rainfall, with precipitation flowing as floods into the Caspian Sea and west boundaries of the country. Today, the construction of various dams in the western and northern parts of the country have decreased water loss, enabling a considerable amount of precipitation to infiltrate into the ground and form groundwater tables.

After the sea that covered all of the Isfahan region (in the second era, above) dried up, Zayandehrood waters flowed towards Isfahan plain (because of the land slope). Due to the impermeable land around the river's reaches, water naturally passed through the schist layer towards Isfahan Plain.

At the beginning, the river was wild, and branches were established wherever the land slope and natural parameters allowed. A careful study of the branches and topographies of the Isfahan region shows that today's *madies* (canals) were established from those initial branches. (At least the initial secondary branches and the existing *madies* are all in the same direction.)

Isfahan was a flourishing city; water was abundant in this plain, so people lived beside or near the river or its branches. The population of the city increased over the decades, with the Zayandehrood River considered to be the "life artery" of the region.

Irrigation history of the Zayandehrood basin

The history of water operation and distribution in the Zayandehrood River begins in ancient times. Ancient documents prove that the Zayandehrood River was one of the most important groundwater tables in Iran. Distribution of water among its catchment areas was carried out by logical and appropriate methods. No integrated document is available about how water was distributed among users in ancient times, however, except for the Sheikhbahaei scroll, which is described below.

Contents of the Sheikhbahaei scroll

Sheikhbahaei was a famous Iranian scientist who lived some 400 years ago. He carried out valuable research in the field of water, irrigation and flood control systems in Iran. One of his famous works describes the fair distribution and allocation of water among farmers in the past. This scroll has been amended over time; different gardens were established, and water distribution rules had to be changed. These various changes are considered in this scroll.

Conflicts are described in the beginning part of the scroll. It states that some "trustful" people were selected to determine field shares for allocating water, and these shares were officially recorded. Trustworthy people were also selected to prevent cheating and to amend parts of the scroll.

According to the divisions mentioned in the Sheikhbahaei scroll, Zayandehrood's water was divided into 33 main shares (see table 5.1). According to the scroll, the demand area of the river extended from Ayedkhash block to Dizi field.

The temporal division of the Sheikhbahaei scroll is described in table 5.2. Sub-divisions in the region (277 shares) are also considered, as shown

Table 5.1 Zayandehrood water divisions allocated to different regions

Regions	Shares	Sub–Regions	Share
1 – Lenjan & Alenjan	10 Shares	Alenjan	4
		Lenjan	6
2 – Marbin & Jey	10 Shares	Marbin	4
		Jey & Borzood	6
3 – Baraan & Roodashtin	10 Shares	Baraan	4
		Roodashtin	6
4 – Kararaj	3 Shares		
Total	33 Shares		

Table 5.2 Temporal divisions of the Sheikhbahaei scroll

		May				July/June				Aug/Jul				
Azad river		9–4	13–10	18–14	21–19	27–22 June	June 28–12 July	18–13 July	25–19 July	27–23 July	July 27–Aug 2	11–3 Aug	17–12 Aug	22–18 Aug
Alenjanat	Lenjan & Alenjan			Shares 10	All the river				All the river			All the river		All the river
Marbin				Shares 4			All the river	All the river			All the river		All the river	
Jey & Borzood				Shares 6										
Kararaj				Shares 3										
Baraan				Shares 4										
Roodashtin		All the river		Shares 6										

		Sep/Aug						Oct				Nov/Oct		
Azad river		26–23 Aug	Aug 27–Sep 1	Sep 10–2	16–11 Sep	19–17 Sep	Sep 20		10–1	20–11	22, 21	30–23 Oct	Oct 31–Nov 6	21–7 Nov
Alenjanat	Lenjan & Alenjan	All the river		All the river		All the river				Sowing in Lenjanat All the water				

Table 5.2 (cont.)

Marbin Jey and Borzood		All the river		All the river			Sowing in Jey, Marbin & Borzood All the water		Sowing in Jey, Marbin & Borzood All the water		
Kararaj										All the river, sowing	
Baraan											
Roodashatin											All the river, sowing

Table 5.3 Sub-divisions of Zayandehrood water

Regions	Share	Sub-Regions	Share
1 – Alenjan and Lenjan	161	Alenjan	47.5
		Lenjan	113.5
Zayandehrood			
2 – Marbin & Jey	66	Marbin	29
		Jey	37
3 – Baraan & Roodashtin	36	Baraan	14
		Roodashtin	22
4 – Kararaj	14		
Total	277		

in table 5.3. These 277 shares were further divided into smaller parts among *madies* (canals), villages and fields. In all, Zayandehrood water divisions resulted in 3,098 shares (see table 5.4).

When precipitation was low and water was scarce, the Sheikhbahaei scroll was used to allocate water. Utilization of the Zayandehrood River in conditions of water scarcity (particularly from 5 June through 20 Nov.) were subject to a regular process discipline and based on the above-mentioned shares. In other months of the year (from 21 Nov. through 4 June), when water was more abundant, utilization from the river was free, and every block and *mady* could use water without restriction.

Studying the Sheikhbahaei scroll

Water has played an important role in the central plain of Iran from ancient times. Water division has been carried out according to the quantity

Table 5.4 Water allocated to *madies*, villages and fields

Regions	Shares	Sub-Regions	Shares
1 – Lenjan & Alenjan	672	Alenjan	315
		Lenjan	357
2 – Marbin & Jey	956	Marbin	282
		Jey	674
3 – Baraan & Roodashtin	1083	Baraan	840
		Roodashtin	243
4 – Kararaj	387		
Total	3098		

of available water, with allocation and distribution in summer (when water is scarce) supervised by ''trustful'' people.

By studying Isfahan from the viewpoint of politics and economics, it can be seen that whenever Isfahan was the capital of Iran, the population increased and the Zayandehrood River, which has a high quantity of water compared with qanats, wells and springs, could not supply all the requirements of cultivated lands. Therefore, the river water had to be utilized on regulated basis. When Isfahan was not the capital of Iran, however, the population decreased, and in the fields belonging to landlords, it was not necessary to regulate utilization of the water. Landlords conveyed water to wherever they needed it, and they dug canals whenever required.

Some of these canals and streams still exist, but they were not specified in the scroll. If we wish to determine the quality and quantity of Zayandehrood river water from historical references, the only document available is the Sheikhbahaei scroll.

When the capital of Iran was transferred from Qazvin to Isfahan, the population increased and Zayandehrood water gained greater importance. At that time, complete studies were carried out on the Sheikhbahaei scroll, and it was put to practical use. The scroll remains a unique document for allocating the water of the Zayandehrood River.

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6

Agency/farmer participation in the management of public sector irrigation schemes: Lessons from Nigeria's Kano River Irrigation Project

M. Sani Bala, I.K. Musa and S.D. Abdulkadir

Nigeria presents an interesting mix of irrigation management approaches, ranging from farmer-developed and -managed, small-scale, traditional irrigation systems to large-scale (but smallholder), public sector-developed and -managed irrigation systems, and a host of other management mixes in between. The economic implications of the nation's dependence on food imports and the threat of drought led to the two-prong policies of the coordinated development of water resources to support food production and the attainment of self-sufficiency in food. Consequently, River Basin Development Authorities were established, and between 1970 and 1985 the government, through these authorities, made substantial investment in irrigation infrastructure development.

Under the programme, several dams and major headwork structures were constructed (although the irrigation distribution network for many of these remains to be completed). As of 2002, the total under large-scale formal irrigation was only 100,300 hectares (ha), representing utilization of less than 25 per cent of the potential irrigation facilities. (See table 6.1.) The unsatisfactory performance of the agency-managed scheme is reflected in the shortfall between the achievement and the target set in the National Development Plan (Adams, 1991).

In 1987, the Federal Government of Nigeria adopted a policy of partial commercialization of the River Basin Development Authorities (RBDAs). This was aimed at transforming the management of public-sector managed irrigation schemes towards joint management of the systems, with both the agency staff and farmers sharing responsibilities for

Table 6.1 Area developed by the River Basin Development Authorities for irrigation development

No.	RBDA	Area Developed (ha)
1	Anambra-Imo	3,926
2	Benin-Owena	815
3	Chad	26,480
4	Cross River	1,354
5	Hadejia-Jama'are	18,475
6	Lower Benue	1,315
7	Lower Niger	1,320
8	Niger Delta	663
9	Ogun-Oshun	272
10	Sokoto-Rima	26,845
11	Upper Benue	13,410
12	Upper Niger	5,425
	TOTAL	100,300

management and resource mobilization. Consequently, under the arrangement, increased responsibilities for operation and maintenance of irrigation systems was to be transferred from the agency to the users. This was primarily intended to remove the treasury subsidy on irrigation services rendered by the RBDAs. The recurrent cost of operation and maintenance of the systems was to be mobilized within the systems themselves, with the government only providing funds for the construction of irrigation infrastructure.

This policy necessitated radical changes in the institutional and legal arrangements for the management of hitherto agency-managed public-sector irrigation systems, such as the Kano River Irrigation Project (KRIP). In particular, the role of water users' organizations was prominent in the management of operation and maintenance and resource mobilization for recurrent cost.

Accordingly, the RBDAs' mandates were drastically revised, and restricted primarily to undertaking a comprehensive development of both surface water and groundwater resources for multi-purpose use (with particular emphasis on the provision of irrigation infrastructure and control of floods and erosion) and for water management within their areas of jurisdiction. They are required, however – unlike before – to hand over all lands to be cultivated by irrigation schemes to farmers.

In 1991, the Federal Government of Nigeria, through its Ministry of Water Resources, invited the then International Irrigation Management Institute (IIMI) – now the International Water Management Institute

(IWMI) – to a Collaborative Action-Research Programme with the Hadeija-Jama'are River Basin Development Authority (HJRBDA). The aim of the programme was to support the turnover of a certain level of system management to the users in three pilot sites of the KRIP. The programme was made up of four major components: institutions, mode of management, operation and maintenance procedures, and resource mobilization. But while the programme recorded some encouraging results, it was short lived, as it was abruptly terminated due to funding limitations. Subsequently, HJRBDA continued, but without further support and without the same vigour.

This paper seeks to examine the efforts of transforming from an agency-management approach to a joint-management approach in the management of the Kano River Irrigation Project of the Hadejia-Jama'are River Basin Development Authority.

The Kano River Irrigation Project

The Hadejia-Jama'are River Basin Development Authority is responsible for the development and management of the Kano River Irrigation Project, which is being developed in two phases and several stages. Located about 50 km southwest of Kano City, it is currently the largest irrigation project of the HJRBDA. Under the phase I, stage I, about 15,000 ha (of the total planned 22,000 ha under phase I) has been completed, leaving a balance of 7,000 hectares undeveloped. The failure to develop the phase I area fully was due, in part, to community resistance to the introduction of irrigated agriculture; at the time the project area was being developed, the KRIP was operated completely by gravity irrigation facilities that had been developed some three decades earlier. The system, as it exists today, comprises 2 dams (Tiga and Ruwan Kanya), 19 km of main canal, 47 km of lateral canals, 320 km of distributary canals, 1,120 km of field channels, 8 functional night storage reservoirs, 1,486 km of drainage and 16,000 units of hydraulic structures (Ben Musa, 1990). There are also a sizable number of other hydraulic structures, such as culverts, bridges, flumes, etc. Crops grown include wheat, rice, maize, sugar cane, tomatoes, onions, watermelons, carrots, etc.

The current major problems and constrains of this project include broken-down, damaged, or deteriorated conveyance structures, to the extent that a sizeable portion cannot be used without major rehabilitation. Mobilizing farmer participation in the area of project management is another important problem of great concern to the HJRBDA.

Issues in irrigation management in Nigeria

Issues concerning performance of the systems

Issues concerning performance of the systems include (but are not limited to) under-utilization of irrigation facilities, poor monitoring of system performance, and the absence of suitable indicators and methodology for the system managers to assess their own performance or that of their systems. It is also necessary to better understand the impact of irrigation on equity, profitability of agriculture, poverty alleviation, and possible land redistribution to address gender imbalances so that irrigation development does not cause social dislocation.

In 1987, the Federal Government of Nigeria was generally dissatisfied with the low utilization of potential capacity by farmers on many public sector irrigation systems. Although the reasons for this are complex, they centred on farmers' attitude and motivation, as well as the institutional arrangement that had led to insufficient attention to operation and maintenance. Even more disturbing was the absence of any data about the performance of the irrigation systems to guide decision-making. Parameters like cropping intensity, crop output, water input, etc. that are necessary for improved management decisions and actions were lacking.

Issues of management of water

By the mid-1980s, it was becoming clear that many of the Sahel states would soon face a water crisis unless more integrated and comprehensive management of water resources could be put in place. The three Sahel-zone River Basin Development Authorities (Sokoto-Rima, Hadejia-Jama'are and Chad) are extremely deficient in surface water; the available surface water resources (478 cubic metres per person per year) are, by international standards, below the water-scarcity level (for example, even Egypt has about twice as much), and the average annual rainfall has decreased to about 65 per cent of that recorded 30 years ago in the region. It was, therefore, essential to ensure that policies be adopted to maximize the benefit obtained from the use of this very scarce resource.

Agriculture – the largest user of water extracted from the rivers – was expected to become more efficient, and to prevent losses through seepage and percolation from canals and by better on-farm water management. To facilitate this, improved irrigation system management, through better control of water delivery, stricter control and enforcement of irrigation schedules, and adequate maintenance are of prime importance.

Issues on management of irrigated agriculture

There are currently far too many institutions involved in the development and management of irrigated agriculture in Nigeria, with little or no coordination and, often, pursuing conflicting and contradictory objectives. The policy reform of 1987 only deepened this crisis, with RBDA's restricted to the delivery of irrigation water only, while another institution was to provide extension and yet another for land preparation. Furthermore, there were separate institutions charged with providing farm inputs, credit, etc. Even more significant was the lack of participation by poor farmers in the management process; the situation was made even the more difficult by the poor definition of the legal framework for farmer participation, and the absence of clear water rights.

Issues on the management of public irrigation systems

Even though the partial commercialization policy of the RBDAs required that operational and maintenance costs be borne by the users rather than the treasury, it was bedevilled by a low cost-recovery level. It was, therefore, urgently required that a suitable means be devised which, whilst enhancing cost recovery, would not aggravate further the levels of system utilization.

It was also recognized that there was a need to institutionalize the irrigation agronomy and management training programme for the RBDAs staffers. While there are several institutes that provide formal training on irrigation technology, as part of agricultural or civil engineering courses, none provides training on organization and management of irrigation.

Issues of irrigation community organization

The formation of effective organizations of farmers that would become equal partners with the irrigation agency is generally perceived as desirable. To do that effectively requires that we identify the factors that will motivate the farmers to support such organizations, and bind them together. It was, therefore, believed that deliberate efforts are required to strengthen local organizations for participation in irrigation management, and to establish the legal framework required for the self-management of irrigation systems by farmers' associations.

Participatory Irrigation Management in KRIP

Participatory Irrigation Management (PIM) in the Kano River Irrigation Project Phase I started with the International Water Management Institute (IWMI), a collaborative action/research programme. The research programme was centred on three pilot sites, representing about 4 per cent of the command area and involving about 4.5 per cent of the total farm families. These sites coincided with the head section of the main supply canal at Bangaza (with 145 farmers covering 271 ha), the middle section at Agolas (with 325 farmers and 139 ha of farmland), and the tail end at Karfi (with 423 farmers and 126 ha).

Among the issues affecting public-sector irrigation systems management identified above, the following four were selected as the focus of the collaborative action/research programme.

Institutional strengthening and support – relating to such issues as legal provisions for the sharing of responsibilities (involving water management of the system) between the farmers and their organizations, on the one hand, and the irrigation agency on the other. Procedures for the formation of water users' organizations were to be given adequate attention as an integral part of the programme. The formation of Water User' Associations (WUAs) was central to all the aspects of the research programme, so farmers cultivating in the three pilot areas were identified on the basis of farmland ownership, and then organized into groups of WUAs around each hydrological boundary. The objective was the sharing of the operation and maintenance duties of the system in a particular water course. The choice of grouping the farmers in accordance to the hydrological boundaries, as opposed to their residential locations (in the villages), was based on the concern that village affinity could entice the WUAs away from the primary responsibility of water management and into pursuit of other community development programmes, under strong village influence, that could be unrelated to the irrigation system.

Changes in mode of management – involving the introduction of necessary alteration in the existing management structure of the agency. This transition required re-orientation programmes for both the farmers and the agency staff, in the form of discussions and/or dialogue on ways and means of implementing the proposed agency/farmer joint management. Part of the objectives of the policy was to optimize the performance of the water distribution facilities on the fields, thereby increasing farm productivity and profitability. The policy was aimed at sharing responsibility for the operation and maintenance of the system between the agency and the farmers.

Operation and maintenance procedures – involving analysis of the actual work to be done and the expenditure to be incurred. These procedures, including the responsibilities to be shared between the agency and the WUAs, were spelled out. In line with this focus, it was decided that the farmers would be in charge of the field channels servicing their respective fields, while the entire group would take charge of the maintenance of the distributary (including drainage) channels servicing the area comprising that group.

Internal resource mobilization – as a prerequisite for the improved and sustainable operation and maintenance of the system. This component included a review of existing resources and articulation of alternative resources and improved procedures for the collection of higher percentages of water rates (these being the principal revenue source for the KRIP). Further resources in the form of labour contributions and other essential resources such as the logistics (among the farmers) necessary to keep the system maintained and operating in an acceptable condition were identified.

Among the reforms brought about by this initiative were appropriate and regular assessment of the cropped area, better motivation of the farmers to pay their water charges, improved procedures for the collection of such charges, and more effective and efficient monitoring of the water charge collection involving the WUAs themselves. This gave rise to a higher percentage of collection of the water charges, from about 30 per cent to well over 90 per cent within a short period. Other sources of revenue, such as fishery, were also identified. It was projected that, if effectively managed, fishery could bring in as much as 2.5 million Naira, or approximately US$30,000/annum (as of 1996).

As soon as the WUAs were formed, maintenance of distributary channels through communal efforts commenced with active participation of the farmers. Farmers at Agolas IV were the first to take the lead in 1991/92, when they organized themselves to desilt the canals and cut tall *Bahamas* grass; they successfully cleaned 2.3 km of the distributary channel serving their farm plots.

Regular meetings began on weekly basis right on the farm plots. Participants were encouraged to draw up and agree on the agenda of the meeting, and to take and document properly the minutes of such meetings. The results of these activities not only saved the agency about US$65/km in maintenance cost, but also improved the performance of the water distribution and drainage facilities around the areas.

The same process was adopted for the remaining pilot areas, Karfi and Bangaza. Farmers' groups encouragingly continue to emulate their counterparts from Agolas, and have sustained their efforts over a significant period of time.

Close examination of the manner in which this pilot scheme actually proceeded shows that, by bringing about positive changes in the relation-

Table 6.2 Changes in profitability of irrigated agriculture. (Source: Musa, I.K., 1996)

Year	Production Cost N/ha (a)	Total Proceeds from Farm Produce N/ha (b)	Return to Farmers N/ha (b-a) = (c)
88/89	4,442.50	9,500.00	5,057.50
89/90	4,907.65	11,295.00	6,388.00
90/91	7,000.42	16,980.00	9,979.58
91/92	7,845.11	18,719.95	10,874.84
92/93	7,895.13	19,989.00	12,093.87

ship between the farmers and the agency to share the responsibility for operation, maintenance, revenue mobilization and general management of the system, the system could be improved by maintaining its physical value, enhancing the hydraulic performance of the systems, and improving methods of revenue collection accruable to the system. These indices will collectively save farmers time in irrigating their fields through better adherence to an irrigation schedule and thus increase crop coverage.

This was confirmed by some of the farmers we visited recently. Yahaya Kazaure (1993) remarked that "tail-end farmers no longer need to come out at night for irrigation" because the hydraulic system has been improved, and water can now reach the tail end in good time for irrigation (unlike the previous practice of tail enders waiting for the head enders to finish irrigating their farms, which may well have been very late in the night).

Table 6.2 shows recorded changes in profitability of irrigated agriculture in the KRIP.

The Management Board of the HJRBDA, encouraged by these positive changes occasioned by the creation and subsequent activities of the WUAs, in confidence later authorized the WUAs to collect water charges on its behalf, and to retain 15 per cent of the total amount collected if the WUA was able to collect 90 per cent or more of the water fees. This was meant to aid the WUAs in generating their own revenue to finance other activities that would be beneficial to both the agency and the WUAs. One of the noticeable improvements in this regard was the tremendous increase in total receivable revenue from the farmers themselves, without having to go through lengthy litigation that characterized the previous method employed by the agency.

This also created a sense of trust, and it was a source of pride among the farmers to be carrying out functions that were hitherto conducted exclusively by agency staff. Visits were exchanged among individual farmers as well as among the various WUA groups, learning from each other, resolving their common disputes and assisting one another, both individually and collectively, in such important areas of crop cultivation as procurement of inputs, organized marketing, tractor hiring, etc. – an exclusive function of the agency previously discharged at high operational cost to the agency.

In the area of conflict resolution, for example, WUA members in conjunction with Miyatti Allah (a national umbrella body overseeing the activities of herdsmen) endeavour to educate visiting herdsmen to the project vicinity as to amicable ways and means of providing drinking water to their animals, with minimum damage to the water distribution facilities. The two groups (WUA and Miyatti Allah) are also responsible, to a large extent, for resolving any conflict that might arise between the farming community and the cattle rearers around the project – a function that used to be carried out by the police and law courts, sometimes involving arrests or imprisonment.

With reference to operation and maintenance of the project, farmers even in recent times seem to be ready to shoulder some responsibility. They confided during a recent interview (for instance) that should the federal government provide them with an excavating machine (equipment they need urgently), they are ready to take charge of fuelling and minor maintenance and also to pay for the services of the excavator (even at the commercial rate) to ensure that the machine is kept in good working condition at all times. These were some of the results of this collaborative programme.

Satisfied with these positive developments, and for the purpose of sustainability, the management of the agency established a unit within its structure and within that of the KRIP to look after and facilitate the activities of the WUAs, prepare the necessary legal documents for the establishment of WUAs, and prepare and keep "Concept Documents" for the establishment of similar association in other projects belonging to HJRBDA (and for possible adoption by projects belonging to other RBDAs elsewhere in the country). This unit is also responsible for record keeping with respect to these Associations, for future reference.

Current status of the WUAs

Recent evaluation of the status of WUAs in the KRIP reveal that many performed creditably in the early stages of their establishment, but had deteriorated a decade later. They were found to be reluctant in discharging those communal efforts that they hitherto were credited with for their collective good. Several reasons were advanced for these developments, by both the agency and the farmers, some of which are highlighted below:

The farmers' side of the story

The farmers attributed the reduced performance of their WUAs to the lack of regular interaction with staff of the agency. This, they believe, led to the breakdown of communication and, as a result, allocated responsibilities were left undone. The farmers emphasized the need to create a constant channel of regular interaction between the agency staff and themselves. Notable reasons for this communication gap might not be unconnected to transfer of agency staff (within their various irrigation schemes) without training the newly posted staff on matters relating to WUAs and their activities.

Irregular attendance and absence from meetings of WUAs was a major problem revealed by the farmers themselves. As a result, many WUA members remained uninformed about scheduled activities regarding operation of the facilities they use. This brought another regime of uncoordinated approach to water distribution in their fields. Irrigation schedules were ignored, with farmers irrigating whenever they desired, without regard for one another. Similarly, because meetings were no longer held regularly with significant attendance, individual farmers were not aware of established schedules for maintaining the facilities. This left the facilities poorly maintained, leading to wasteful performance of hydraulics structures in relation to water distribution and/or drainage.

Irregular meetings of the WUAs also resulted in poor revenue collection. Farmers also complained that their Associations have no funds to execute some activities because the agency has failed to give them the agreed 15 per cent of revenue collected (which is to be retained in their accounts when the collection attains a 90 per cent level).

Finally on the farmers' list are lack of necessary machinery for land preparation (e.g., tractors), inadequate facility maintenance (e.g., excavators) and irrigation facilities (such as siphon tubes) from the agency, and their inability to afford the services of such machinery or to purchase the facilities at commercial rates. These factors have hampered farming activities in the recent past, which in turn has led to a poor farming regime and unsatisfactory marketing (thus, according to the farmers, making it difficult to pay their fees or dues promptly or regularly). It is a vicious cycle that is being recreated; the farmers wished they could also have access to credit facilities for improved performance.

The agency's side of the story

Agency officials also acknowledged that the WUAs have not been performing up to expectation in the recent past. They, however, attributed this to different reasons. In particular, they were of the opinion that the principal reason was inadequate funding from the federal treasury to execute operation and maintenance activities; they argued that the cost for these has risen sharply, but fees have remained the same since 1985. Consequently, even if they were to recover the fees fully, it still would not cover even half the cost required for effective operation and maintenance. Furthermore, the revenue generated through the erstwhile active WUAs has consistently been poor in recent times. These factors, combined, have limited the ability of the agency to discharge its own part of the pact in relation to the activities of the WUAs.

The abrupt termination of the collaborative research programme started by the then IIMI left a vacuum that could not be filled, as staff training was inconclusive. At the time the programme was terminated, not a single agreement had been firmly reached and signed between the WUAs and agency in regard to operation or maintenance of the scheme, including the transfer of identified and specified responsibilities as was negotiated. In other words, the collaborative programme was abandoned before maturity.

The inability of the WUAs to organize regular meetings with good attendance was also mentioned by the agency staff as one of the problems that thwarted the activities of the WUAs. Agency staffers were also of the view that unless the WUAs are motivated to ensure regular attendance of their members at meetings, their activities would not be sustained.

Conclusions

It would be safe to conclude that the inconclusive collaborative action/research programme by HJRBDA and the then IIMI did raise the desired awareness regarding agency/farmer management of the system, which gave birth to the WUAs in the KRIP. This brought about a positive change in the attitude of the agency staff towards the agency/farmer joint-management concept. This positive change did not stop at HJRBDA and its staff, but also spread to almost all the river basins in the country. Today, almost all the river basins in Nigeria are experimenting with establishment of Water Users Associations, without their staff harbouring fears of losing their jobs, as demonstrated in Kano River Irrigation Project Phase I.

This can be considered as one of the greatest achievements of the programme. It is also important to note that farmers' groups made significant achievements, especially in their early years of establishment, indicating a brighter future for both the farmers and the agency, if sustained.

The performance of the WUAs in recent years has deteriorated, however, and to address this a Farmer Services Centre (FSC) is being established to serve as motivation for the farmers and to sustain the efforts required to improve the system performance for the collective good of all parties. The FSC will comprise trained agency staff who will strengthen the capacity of the active members of the WUAs and provide other services that will reawaken the enthusiasm of the farmers for the activities of WUAs. The Centre will be responsible, among other issues, for:

- re-activating the old WUAs, including rendering support to their members;
- identifying jointly the institutional support and capacity building required to provide sustainable and effective WUAs;
- establishing new WUAs in those areas not covered by the collaborative research program; and
- taking the necessary steps to guarantee the sustainability of such new and/or reactivated WUAs.

The FSC would strengthen the capacity of the WUAs to provide those services identified as having the potential to bring their members together. Such issues include the provision of inputs and credit facilities, and of significant, reliable and favourable marketing arrangements. As soon as farmers are organized to take charge of these responsibilities themselves with minimum support from the agency, the much-needed overall efficiency of the scheme could be turned around, including its technical efficiency.

One of the most significant lapses of the collaborative action/research programme was the absence of a physical rehabilitation component. Accordingly, the major recommendations to the agency by the farmers, regarding the effective institutionalization of WUAs, included the following:

- Water distribution facilities need to be rehabilitated to provide, at regular intervals, water control gates that will enable the WUA to deny water supply to defaulting farmers who fail to meet their obligation to the system.
- In the area of revenue generation, the WUA should, as a temporary measure, establish and accept the contribution of farm produce from farmers in place of dues and other levies agreed upon, which the Association can sell with the proceeds being paid to the account of the Association. This, the farmers argue, will make it easier for the majority to comply than contributing cash directly.

It will be pertinent, therefore, to advise that in order to institutionalize and empower the FSC, HJRBDA should endeavour to ensure that the required resources for the operation of the FSC are provided. Some form of financial autonomy that would allow the project to retain the resources mobilized from the system would build back the confidence of the farmers regarding the genuineness of the use of their service fees.

To achieve sustainable operation and maintenance of public irrigation infrastructures, a uniform institutional framework for the organization of WUAs is being developed from generic lessons drawn from various experiments with participatory irrigation management. The PIM Manual being prepared by the Federal Ministry of Water Resources is nearing completion. This manual should take due consideration of experiences from trial efforts and consultation among all stakeholders, to ensure that a suitable arrangement is suggested for the successful implementation of Participatory Irrigation Management in all public irrigation schemes in the country.

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7

History of flood damage and control in Japan after World War II

Yutaka Takahashi

The history of water management in Japan after World War II is an extraordinary story. In accordance with socio-economical change – from poverty to a world economic giant, and subsequent fall into economic depression – water-related fields also have changed dramatically.

Immediately after World War II, Japan suffered from severe flood damage almost every year from 1945 to 1959. In the high economic growth era, from 1960 to 1973, Japan experienced water shortages in big cities (as water demand increased rapidly) and new industrial zones. After the "oil shock" in 1973, Japan entered a period of stable economic growth; during that time, issues of environmental protection and human amenities became important. And after 1990, river technology and administration have shifted direction toward a new period emphasizing harmony between the environment and flood control.

Flood control projects before World War II

It was in 1896 that Japan, which had embarked on a journey toward establishment of a modern state with the Meiji restoration (in 1868), started river management projects – especially flood control projects – on a full scale. With advances in civil engineering technology, flood control projects were successfully carried out, and water resource development was actively pursued after 1960, with great progress and prevalence in each field. This paper introduces the phenomena unique to Japan that have resulted from the rapid urbanization and unparalleled economic growth, for the possible benefit of other countries (especially those developing countries that have great potential for further economic development).

The River Act was officially announced on April 8, 1896. (See table 7.1 for major events in the century of river modernization efforts.) With the promulgation of the River Act, the Meiji Government implemented flood control strategies of concentrating even great floods into river channels. The flood control projects during the thirty-year period between 1900 and 1930 rank among the largest of Japan's civil engineering projects. What is more important, however, is that such a big flood control project as executed on the Tone River was implemented for all key rivers in Japan during the same timeframe.

The effects of these mega projects were remarkable. The frequency of inundation in alluvial lowlands (where inundations due to floods had occurred often over a wide area) was lowered dramatically – the security level for these areas increased, rice production increased under stable conditions, and cities became safer. These improvements provided invisible support for Japan's development in the first half of the 20th century. Thus, the large investment in flood control since the middle of the Meiji era seems to have produced adequate results.

Difficulties in the great flood disaster period after World War II

World War II, and the confusion following Japan's defeat, not only prevented continued implementation of the Tone River Enhancement Plan, but also made continuation of maintenance work impossible. Unfortunately, while flood control measures remained unimplemented for every river in Japan (including the Tone River), a series of big typhoons and late-rainy season heavy rains hit the ruined nation from the late 1940s to the late 1950s. Serious flood disasters occurred almost every year during this period, claiming more than 1,000 lives per year. Control of flood disasters was considered to be the key to Japan's post-war reconstruction.

The 15-year period between 1945 (the year the war ended), when Typhoon Makurazaki seriously damaged the western part of Japan in September, and 1959, when Typhoon Ise Bay struck in September, was the worst period in the history of flood disasters in Japan. The reasons for such disasters, as mentioned above, were a series of unprecedented, large-scale typhoons and late-rainy season torrential rains, and the stagnation of flood control projects during and after the war.

But changes in the runoff mechanism in key river basins and channels are considered responsible as well. Table 7.2, which shows the large flood

Table 7.1 Major events in 100 years of river modernization

1896	Former River Act promulgated. Modern flood control started on the Yodo River and the Chikugo River.
1900	Modern flood control started on the Tone River and other key rivers.
1910	Great flood disasters on the Tone River and other rivers. First-phase flood control plans.
1930	Improvements completed for the Tone River and the Yodo River.
1931	The Shinano River/Okozu Diversion Channel completed.
1934	The Typhoon Muroto (great flood disasters in Kansai and Shikoku areas).
1935	Great water disaster on the Tone River.
1938	Baiu-front-caused heavy rains (great water disasters in Rokko and Kobe areas).
1940	Comprehensive river water management projects started.
1945	The Typhoon Makurazaki (great flood disasters in western part of Japan). World War II ended.
1947	Typhoon Kathleen (great floods on the Tone River and the Kitakami River).
1949	River improvements plans for major rivers drawn up by the Flood Control Investigation Council.
1950	Typhoon Jane (storm surge in Osaka Bay).
1951	New comprehensive river development projects started.
1952	Two acts concerning hydroelectric power development promulgated.
1953	Baiu-front-caused heavy rains (great flood disasters in the North-Kyushu area and the Kii peninsula).
1954	The Typhoon Toya-maru (An Aomori-Hakodate ferryboat sank. Wind and flood damage in Hokkaido).
1958	The Typhoon Kano River (great flood disasters on the Izu peninsula, and in Tokyo and Yokohama).
1959	The Typhoon Ise Bay (nationwide great flood disasters including the Ise Bay area)
1960	Emergency measures act for flood control and debris control in mountain areas put into effect.
1961	Two Acts concerning water resources put into effect. The Typhoon Second Muroto.
1964	New River Act promulgated. Water shortage in Tokyo.
1972	Baiu-front-caused heavy rains devastated the whole country. Water disaster-related suits started increasing.
1974	Embankment of the Tama River broken.
1975	Embankment of the Ishikari River broken.
1976	Typhoon No. 17. Embankment of the Nagara River broken.
1977	Implementation of comprehensive flood control measures started in urbanized areas.
1987	Development into measures against huge flood exceeding design discharge.
1991	Natural diversity river works started.
1995	Emphasis shifted toward river environments.
1996	Basic direction of river-related policies toward the 21st century presented.
1997	Revision of River Act to include fluvial environment conservation etc.

Table 7.2 Changes in large flood design flood discharge in the Tone River (Yattajima measuring station)

Large flood discharge	Year flood occurred	Design flood discharge	Year design Discharge established
3750	1896	3750	1900
7000	1910	5570	1910
10000	1935	10000	1939
17000	1947	17000	1949
		22000	1980

discharge and design flood discharge in major floods in the Tone River over the past 100 years, reveals how peak flow increased after every great flood, and how flood control plans expanded in steps accordingly. Such increases in the size of floods and the scope of plans were not limited to the Tone River. On almost all the key rivers, the trends were somewhat similar to that for the Tone River. Each river experienced the highest flood flow in great floods after 1945 (see table 7.3).

The changes in runoff mechanism at the time of flooding were brought about by drastic changes in land use caused by active development of river basins, and by flood control projects that focused on building continuous high embankments. It is true that heavy rainfall in the river basin was successfully concentrated into channels for discharge into the sea, but the same amount of heavy rain in the river basin as in the past caused larger flood flows midstream and downstream.

Technical activities taken toward rivers are not easy, as rivers are an integral part of nature. Human technical activities targeted at rivers and river basins, which are regarded as an integrated organism, are different from constructing individual structures or facilities; even if the immediate objectives are met, side effects (often unanticipated) will inevitably occur. For example, the Okozu Diversion Channel, which was constructed in the 1910s through mid-1920s to divert the flood flow from the Shinano River, ended the great floods that had often hit the Niigata Plains, thus greatly contributing to rice production and better life for the people in this area. But on the other hand, the diversion work was a remote cause of erosion of Niigata's beach, making it necessary to invest a large amount of money in coastal conservation. (This, however, leads nobody to believe that construction of the Okozu Diversion Channel was a failure.)

During the post-war 15-year period of successive great floods, new flood control plans were drawn up for each of the ten big rivers. This included the building of multi-purpose dams as a new addition to the existing river improvement measures. One of the purposes was flood control.

Table 7.3 Largest flood discharge experienced and design flood discharge at the time

Measured at		Large flood discharge experienced	Experienced on	Design flood discharge at the time	Year design discharge established
Ishikari River	Grand Ishikari Bridge	12,060	Aug. 6, 1981	9300	1965
Kitakami River	Kozenji	7,900	Sept. 16, 1947	5600	1941
Tone River	Yattajima	17,000	Sept. 16, 1947	10000	1939
Kano River	Ohito	4,069	Sept. 16, 1958	1700	1953
Nagara River	Chusetsu	6,713	Aug. 13, 1960	4500	1949
Yodo River	Hirakata	7,800	Sept. 25, 1953	6950	1937
Gono River	Ozekiyama	6,740	Jul. 12, 1972	5800	1966
Chikugo River	Senoshita	10,700	Aug. 13, 1960	5500 (7000)	1949

New experience in the age of high economic growth

From mid-1950s through mid-1960s, numerous electric power generation dams and multi-purpose dams were built, supported by advances in dam-related design and theories as well as in construction techniques. The types ranged widely, from gravity dams to arch dams and to rockfill dams. The age of high economic growth was, at the same time, the age of a boom in dam construction. The high economic growth age, after riding out difficulties in the age of successive great floods, brought other challenges to rivers – namely, water shortages and new types of flood disasters in urban areas.

Japan's high economic growth, which amazed the world, was realized through rapid changes in industrial structures, movement of capable workers from rural areas to big cities, development and business applications of new technologies in various fields, efficient development of waterfront industrial areas, etc. These changes were naturally accompanied by sudden increases in demand for water, which was symbolized by the water shortage in Tokyo during the summer of 1964.

Big cities and industrial districts with swelling population had an urgent need to secure water resources. The Water Resources Development Promotion Act and the Water Resources Development Public Corporation Act were put into effect in 1961 to meet the need of the times. But specific water resource development projects, generally taking a large amount of time, were not implemented in time to obviate Tokyo's water shortage in 1964.

Progress in water resource development since the mid-1960s, however, has helped to avoid a nationwide water shortage, although water was sometimes in short supply in such places as Fukuoka (in Kyushu) and Takamatsu (in Shikoku Island). During the half-century after the end of World War II, some 1,500 multi-purpose and power generation dams were built for flood control, water resource development and water-power development, and have almost solved the problem of water shortages. That is, river development centring on dams was the key to water resource development.

In recent years, however, additional difficult problems have been involved in dam construction, owing to the availability of few locations suited for construction, increases in construction costs (resulting from increased compensation and environmental protection expenses), and the obligation to maintain harmony with the environment. For future measures on water resources, the characteristics of each area will call for diverse solutions, such as creation of a society oriented toward recycling through use of sewage water, shared water use including review of water rights, utilization of rainfall, or desalination of seawater on remote islands. Thus, Japan's quantitative water management is entering a new phase.

The period of high economic growth saw new types of flood disasters unique to cities as well as water shortages. Urbanization completely changes the hydrologic cycle of an area. Use of farm land for housing, paving of roads and building of sewage systems result in less rainfall filtration; surface runoff of heavy rains rushes to sewerage, and rivers in cities can no longer accommodate the water, causing break-up of embankments.

The first example of such a flood disaster unique to cities was the submersion of newly developed housing areas in Tokyo's uptown at the time of Typhoon Kano River in 1958. Each subsequent downpour in uptown Tokyo brought about inundation of wider areas, as if it were following the wave of housing development. New types of flooding in cities, as first witnessed in Tokyo's uptown, prevailed in one city after another nationwide as the population rapidly grew. In short, energetic urbanization as a driving force for high economic growth led to drastic changes in land use in river basins and in the hydrologic cycle, and to frequent flooding in cities.

The cause-and-effect relation between urbanization and urban flood disasters is similar to that between the development of key river basins and subsequent floods through changes in the hydrological cycle since the 1880s, although to a different extent. Changes in the water cycle, similar to those that had taken place on major rivers (including the Tone River) for decades, occurred again during the high economic growth period in river basins of smaller rivers for almost a decade. Development of river basins and promotion of flood control projects remarkably changed the water cycle and water flow under normal conditions, particularly in Japanese rivers, to varying degrees and for short lengths of time. Urbanization is a global phenomenon; in the Asian monsoon area, where Japan is located, as paddy fields capable of storing water are changed into housing sites, the flood flow is increased in rivers running through cities.

River basin development and energetic flood control projects – backbones of rapid modernization since the Meiji era – and drastic urbanization in the post-World War II era greatly changed the hydrological regime, serving as a key factor in the advent of frequent floods. Because new types of urban floods were the result of sudden changes in land use in river basins, traditional river improvement measures became insufficient.

The River Council presented its "Comprehensive Flood Control Measures" in 1977. The term "comprehensive" was used because the measures were aimed not only at flood control of channels, but also at controlling heavy rains in entire basins. Specifically, the goal was to keep as much surface runoff as possible in the river basins by temporarily storing heavy rains in, or making the water infiltrate into, parks, school grounds, or sports fields, so as to reduce the amount of water rushing into sewerage or channels. Comprehensive flood control, though oriented only towards city rivers, was the first step in changes in the River Authority's flood control policies.

Basically, the flood control concept should be comprehensive regardless of time or place. Floods cannot be controlled only by means of artificially fixed channels. In the fields of learning and administration, specialization has increased efficiency, making it possible to attain the highest level. However, in river administration as a part of national land administration – which, by nature, should cover all related aspects – administrative actions for flood control for entire river basins are demanded in response to rapid changes in national land use resulting from extraordinarily hectic urbanization. Suggestions for comprehensive flood control measures may be regarded by some as first aid, but they reflected the path that flood control measures should take.

Promotion of measures against a huge flood exceeding the design discharge in 1987 was another advancement in flood control. Under Japan's flood control policies, probable flood levels have been specified according to the importance of the river, and the designed flood discharge for particularly important rivers is set at the 200-year probable flood level. Today, the flood safety target is considerably high as compared with the highest probable flood level of 100 years set in the past. It also means, however, that administrative authorities cannot assume responsibility for floods exceeding that level. Since immediately following the nationwide flood damage caused by the Baiu-front in 1972, an increasing number of victims have been filing suits against river administrators. In such flood-disaster-related lawsuits, whether or not the floodwater exceeded the designed flood discharge serves as a key deciding factor.

The River Council presented measures for controlling such a huge flood in the submitted report, in an attempt to specify some actions even against such damage for which no specific actions had been taken. This was because it is such floods which exceed design floods that cause grave flood damage. It is assumed that the Council made its recommendation based on recognition of the need to take actions even against such damage.

One of the specific measures is what is termed "super-embankments," which have been being built on many rivers. With this type of bank, the levee crown is widened and the width of the embankments made several times as large as a regular embankment. "Super-embankments" not only increase safety from flooding but also help to proceed with urban renewal on the widened levee crown, such as along city rivers like the Sumida

River in Tokyo. Even where the river does not run through the central part of the city, diverse development projects are going on centring around "super-embankments," which suggests that river projects should basically be implemented from a comprehensive viewpoint. Historic projects such as building of the Shingen embankments (by Takeda Shingen) on the Kamanashi River and of Taiko embankments (by Toyotomi Hideyoshi) on the Yodo River in the 16th century are highly appreciated as being of a comprehensive nature. Under a democratic system in which dictatorial policies are not permitted, administrative actions for rivers through integration of administrative policies are strongly demanded.

Toward river improvement in the 2lst century focused on the river environment

Since the late 1980s, partly through reconsideration of a general loss of interest in rivers, there has been growing interest in river environments and renewed recognition of rivers as something that should make people comfortable. Loss of rivers' importance for navigation, resulting from wide use of railway systems since the Meiji era, and elimination of fears about rivers realized through promotion of flood control measures has caused people to pay less attention to and lose interest in rivers. Rapid development of road transportation in the post-war period, deterioration of river water quality and the building of high, straight embankments also caused people to lose interest in rivers.

Along the Sumida River in Tokyo, as along other riversides, high embankments were constructed to fend off storm surges equivalent to that caused by Typhoon Ise Bay. Those structures invited unfavourable general response.

Today, however, "super-embankments" have been completed for some 20 per cent of the river length, and terrace revetments have been built to make riverside walking possible. New tall buildings on the bank stand facing the river. River control projects not only aimed at coping with floods and droughts, but emphasizing the relation between the river and the public, have been gradually making progress since the 1980s. Water quality in the Sumida River and many other urban rivers has improved since the high economic growth days. People are thus rediscovering an interest in rivers.

Since the late 1970s, much attention has been paid to the aesthetic aspect of rivers, and riversides, embankments and revetments have been prepared so that people can have easy access to them. The trend gradually prevailed to rivers all over the country in the 1980s. What is really important to the relationship between humans and rivers is, however, conservation of the river in such a way that the river can perform its natural functions as a part of nature, and not giving it a facelift by revetments, etc. This, in turn, depends on preservation of an ecosystem on the river.

In the vanguard in such a movement is the ecological revetment, completed through stone masonry, on the Ichinosaka River in the city of Yamaguchi in 1972. Mugworts and willows were planted in the flood channel, and fireflies returned (the bank protection works are also known as the fireflies revetment works). This case was followed by various similar cases nationwide, which took the ecosystem into consideration.

In 1991, the Construction Ministry decided to start the creation of natural diversity river improvement works all over the country, paying due attention to favourable conditions for the growth of living creatures, and providing for the conservation and creation of beautiful natural views. Then, in 1995, the River Council submitted a report on ''what future river environments should be like.'' This report presented three basic items for conservation and creation of river environments: securing diverse natural habitats, securing a healthy hydrological cycle, and reconstructing river-community relations. The Council made another report in 1996, the 100th anniversary of the promulgation of the River Act, on the basic direction of river-related policies toward 2lst-century society. In this report, the Council looked back on the past century of modern flood control measures, listed current challenges in river development, and reflected on the social role rivers in the 2lst century.

Based on these reports, the River Act was revised in 1997 to include fluvial environment conservation, and to reflect public opinion.

II

Political economy, control and markets of water

8

The participatory approach of managing water in Japan

Nobumasa Hatcho and Yutaka Matsuno

There are some 270 million hectares (ha) of irrigated land in the world, and nearly two-thirds of freshwater resources is used for irrigation. Global water demand is expected to reach 5,060 km^3 in 2020, an increase of about 1,300 km^3 from the 1995 level. The agricultural sector will need 3,138 km^3, or 62 per cent of total global water supply, to meet expected food demand in 2020, thus requiring development of an additional 400 km^3 of new water resources from the level in 1995. Under these circumstances, more and more efficient use of water is required in the irrigation sector.

To improve irrigation efficiency, past development placed high priority on engineering and structural aspects. It has become clear, however, that without appropriate operation and management systems in place, no irrigation system can achieve best performance. Participation of the local resource users is required to achieve the good performance and long-term sustainability of the system.

In Japan, community-based water management of a participatory nature has evolved into the modern legal entity of the Land Improvement District (LID), which undertakes water management, construction and rehabilitation work. This chapter discusses the history of water resource development and management in Japan, and identifies lessons that can be learned from the Japanese experiences of promoting participatory management.

Background

Until the early 1900s, the majority of irrigation systems in the world had been developed by users and managed in a participatory manner. Irrigation area increased from 40 million ha in 1900 to 100 million ha in 1960, and to more than 267 million ha in 1997. Most of these newly developed areas were constructed through government initiatives, using funding from a national or donor/colonial government.

Similarly, management of irrigation systems has moved from the hands of local users to government agencies. This has not been accompanied by an increase in operation and maintenance (O&M) financing, however. As a result, over the past two decades, O&M funds per hectare, in real terms, have declined, hampering the performance of government-developed and -operated irrigation systems.

While not all problems can be attributed to a lack of participation, this is recognized as one of the most important issues in improving irrigation performance. What are the problems of irrigation, and how are they related to the lack of participation?

The problems associated with irrigation management are many: among them, inadequate water availability at the lowest outlets, poor condition/maintenance, lack of measuring devices and control structures, inadequate allocation of funding for O&M, inequitable water distribution, lack of incentives for water saving, and poor drainage. Many of these problems could be improved by enhancing participation in all aspects of irrigation development and management.

In past development activities, the needs of development were assessed from the government side (a top-down approach) and did not always reflected the actual needs of the people who would manage resources after the development activities were completed. In addition, emphasis typically was placed on the development/construction aspects, with no due consideration given to the operation and management or the required organizational set-up of managing the system. As a result, the performance of the constructed system was poor, and the system deteriorated progressively due to poor maintenance and management.

Japan, over its long history of paddy field irrigation, adopted a participatory or communal approach to managing water resources. Most of the irrigation system construction was initiated by farmers, and participatory management followed automatically. Rather than seeking individual profit or benefit, the maximization of communal benefits was prioritized, which necessitated a long-term perspective of managing resources. People understood by their experiences and from historical lessons that they could only survive in harmony with nature or within the limits of environmental capacity. Through such processes, the rules of resource use and

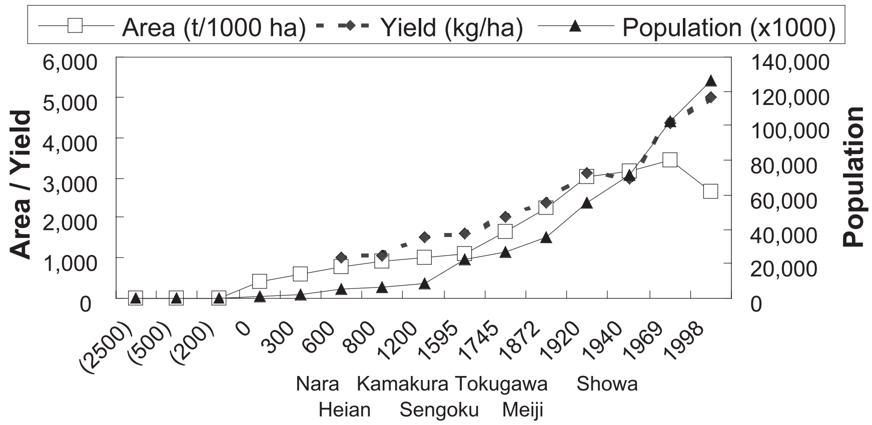


Figure 8.1 Historical development of paddy fields and population
Source: Nagata (1994), Tomiyama (1993), Yamazaki (1996)

associations for utilization evolved – becoming, respectively, the modern-day Land Improvement Law and Land Improvement District (LID).

Japanese experiences in irrigation development and management

Central control and management of land and water resources

Irrigated rice agriculture started more than 2,300 years ago in Japan by importing technology from China and Korea. The paddy field area reached about 800 thousand ha in 600, with a yield of about 1 ton/ha (see figure 8.1). The development and management of the paddy field were by the hand of the central government.

Chessboard-like city planning and land development (the Jo-Ri-system, as shown in figure 8.2) were implemented, and government allocated land to farmers with a certain tax burden. Paddy fields under the Jo-Ri system were developed without taking account of local undulation of land, however, so some fields had poor drainage while others were left abandoned because of difficulty in water supply or flood-prone conditions.

On-farm development was not very good, and no incentive was provided for appropriate management or efficient cultivation. The product tax (rice or local product) itself was about 7 per cent of the production volume; while this was not a heavy burden, the required labour contributions were sometimes very demanding. Some farmers failed to comply

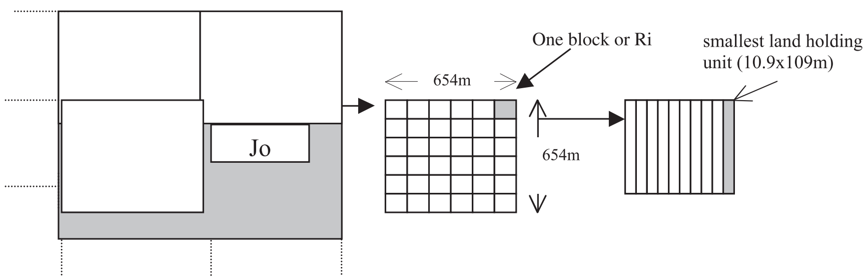


Figure 8.2 Jo-Ri system and land holding

and abandoned their allocated land, becoming landless. According to the registration record of a village in 726, out of 400 registered farmers and labourers, 89 people had abandoned the land and become homeless and wanderers.

Particularly during the construction of a new capital, the number of farmers who abandoned their land grew. The abandonment of the government-allocated land caused a degradation of property, which also diminished the government's tax revenue. The principles of the "national (or public) land/national people/national water" policy thus became difficult to maintain.

Integration into the feudal system

After the collapse of central control and management by the government, these functions moved to local areas. The scale of development became reduced and scattered, and the paddy field area increased by only 200 thousand ha between the 10th and 15th centuries. However, abandoned and uncultivated lands, reaching 20 to 40 per cent of the total paddy field area, were rehabilitated, and water management and on-farm technology development enabled production (and the population) to increase. Cooperation in farming and water management, meanwhile, induced the establishment of a rural society based on the village community.

It is estimated that about 1.1 million ha of land had been developed by the end of the 1500s. At the time of land tax reform by the Meiji government in 1871, there were more than 2.6 million ha of paddy fields. The enormous expansion achieved during Tokugawa period (1603–1867) was brought about by continued efforts to strengthen the economic base of the feudal lords, or "Daimyo." It was during this three-century period that massive development was carried out in the downstream reaches of large rivers. Development was realized through the advancement of civil engineering technology related to mining and castle construction during the period of civil wars. With the advancement of large-scale irrigation systems, water users' organizations became necessary to manage the facilities and water.

The scale of land and water development, once localized, started to expand as the territory of the Daimyo increased by centralizing individual estates through military invasion and wars. The Daimyo directly controlled the peasants and agricultural land, since these were the source of their power. This system emphasized the expansion of agricultural land and the increase of its productivity. To purchase weapons and goods, cash crop production and mine development as well as market transactions were promoted.

Irrigation development by diverting water from major rivers expanded the land under cultivation. Small, isolated irrigated systems dependent on tanks were integrated into the river irrigation system. This allowed the feudal lords to control the peasants by directly controlling the flow of water. Irrigation infrastructures and management, as well as customary rules of water use, were established during this period and formed a prototype of the present irrigation system in Japan. Only feudal lords who controlled the technology and the wealth, and who could mobilize the peasants, could carry out large-scale engineering works.

Characteristics of resources management in Japan

Organizations of resource users

Japan has a long history of applying a participatory approach in irrigation development and management. Local initiatives in development and management of resources played important roles. Throughout the history of irrigation development, community-based management organizations were merged into larger organization, and rules for settling water disputes (particularly during periods of water shortage) were established.

As the development and water use advanced, disputes over land and water use became unavoidable both within and among villages. However, the accumulation of experience with similar disputes gradually brought about the consent and agreement to consolidate rules for land- and water-sharing to avoid repetition of conflicts. Thus, the basic pattern of water management for irrigation was gradually formulated at the village level.

In about the 14th century, the power of locally dispatched government officials became so strong that they actually administered and owned the province or the manor in which they were assigned or stationed. These officials grouped local warriors and small landowners as their subordinates, and became federal lords at the provincial level. These provincial lords soon started to compete, and fought with each other for control of better land.

Under such circumstances, self-reliant cooperative attitudes were gradually formulated in rural villages, and autonomous village institutions called ‘‘So’’ were established. Under this system, communal management of water resources and forest/grassland (‘‘Iriai’’) gradually evolved. The Iriai system allowed villagers from different villages to utilize the same piece of land for collection of fuel wood and of grass for animal feed.

Progress in the communal use of water and forests led to the development of the communal paddy cultivation system peculiar to Japan, such as transplanting and harvesting with mutual help by community members. This system of farming in collaboration eventually led to the formulation of the basic pattern of rural communities in Japan. In addition to farming in cooperation, farmers built their irrigation and drainage facilities together, and operated, repaired and managed them in an autonomous way. Without mutual help and cooperation, water delivery could not be secured and the paddy farming system could not be maintained. The prototype of the paddy farming system unique to Japan took shape in this period with land development and administration by landlords, water management at the terminal level by autonomous villages, and self-supply of compost for farming.

Though there was fighting among landlords, the water management system at communal level was not much affected by these conflicts, and agricultural production continued to flourish. Village self-governance 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 management system thus formed at the terminal and village level was continuously strengthened and institutionalized in rural communities.

Based on the autonomous rules of villages, the economic power of farmers expanded with the development of on-farm technologies. Some of these were water management and drainage, fertilizer application, expansion of the dual cropping system, and the reduction of damage by drought or cold weather. Farmers were stratified into groups, the upper class of which later became local warriors or landowners.

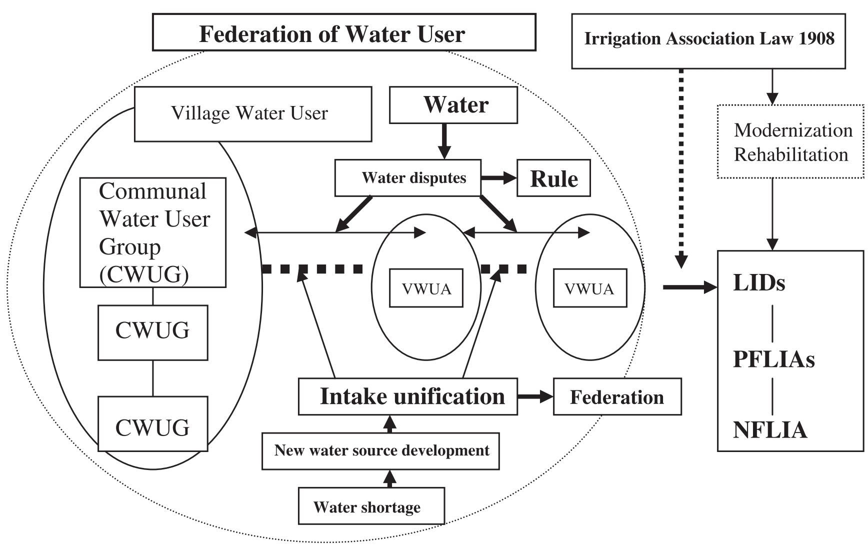
The same principles of self-help and management in villages expanded to larger developments that gradually were implemented in alluvial plains and other places. This was the foundation of autonomous rules. Basically, the same system of management is still adopted even in modern Japan.

Integration of organizations into the feudal system

During the Edo period, the feudal lords used rice as a form of land tax, with the tax imposed on a village rather than an individual basis. Thus, the entire village was required to work together to manage the system properly and increase rice production. The villagers also worked together to build reservoirs and canal systems, and cooperated to maintain the system in an effective working condition. The village was a territorial community, and within the community a village-based water user group was formed. This was the lowest level of political structure in those days.

Above the village level, a Water Management Association (WMA) of village water user groups was organized to carry out operation and maintenance of water use facilities, water distribution/allocation and water use coordination (see figure 8.3). Farmers from concerned villages were mobilized to carry out the operation and maintenance of major facilities, such as headworks, main canals, division structures, etc. Minor facilities at the tertiary and on-farm levels were operated and maintained independently by the village-level water user groups.

The village-level water user groups carried out three major tasks: operation and maintenance of terminal water use facilities, ditch cleaning in



** N(P)FLIA: National (Prefectural) Federation of Land Improvement Association*
** LID: Land Improvement District*

Figure 8.3 Evolution of water user associations and LIDs in Japan the spring, and weeding/grass-cutting in the summer. Provision of labour for these tasks was mandatory for villagers. Even today, residents in rural communities are asked to contribute their labour for several days a year for the management of local resources and common properties in the community.

Although the entire country became rapidly Westernized as a result of modernization after the Meiji Restoration in 1868, it is worthwhile to note that traditional culture and rules of rural communities have been (either intentionally or unconsciously) preserved in Japan. The basic framework of Japanese society started to take shape on the self-help and self-governing management water system developed in the feudal age.

Water disputes

Water disputes had been continuous and annual events in Japan, where water was the source of life for producing paddy rice. Although Japan has relatively abundant rainfall, seasonal and annual fluctuation cause water shortages, leading to repeated water disputes that sometimes even ended in violence. The political system of the feudal lords was not quite capable of resolving these conflicts, since the situation was often complex and difficult to understand.

To overcome these difficulties, the customary rules of water allocation were established based on the principle of "priority on older paddies." Newly developed paddies had to suffer serious damage during drought years. However, since upper stream areas could take water easily, the principle of "priority to upper stream users" was also applied. These two principles do not necessarily match, however, and so water disputes resulted.

Eventually, the Water Management Association at the highest level took the task of resolving water disputes, and customary rules were approved as a customary water right in the River Law enacted in 1896. In the 1900s, water disputes persisted, with more than 72 thousand water disputes recorded in the 25 years between 1917 and 1942. Disputes continued until about the 1960s, when large-scale water resources development started and sufficient water supply was secured.

Government involvement in resource management in modern period

In the modern period, the rules of water management system were similar to those of the former communal irrigation system, though modified according to the needs of new environments. The Ordinance on Water

Management Associations was enacted in 1890 to provide legislative recognition of water user organizations. With this reform, private ownership of land was recognized, and individual landowners were required to pay tax. Irrigation Associations were established to carry out operation and maintenance of water use facilities, with the membership of individual landowners (differing from the former water user groups based on the village unit). However, at the village level, the traditional system persisted under WMAs, which were not included in newly formed Irrigation Associations.

In 1909, the Ministry of Agriculture and Commerce enacted a Land Consolidation Act, which authorized the formation of Land Consolidation Associations to implement land improvement projects, including irrigation and drainage works. Thus, the construction was carried out with subsidies from the Ministry of Agriculture and Commerce, while Irrigation Associations under the jurisdiction of the Ministry of Internal Affairs carried out the operation and maintenance. This dual system of construction and management continued until the post-war establishment of Land Improvement Districts.

After World War II, land reform (carried out during the period 1946–1950) released tenant farmland of 1.93 million ha to 4.75 million farm households. A private property system was established, and tenant lands decreased to about 10 per cent of the total farmland. With the change of land ownership, the Land Improvement Law (LIL) was enacted in 1949 to abolish the previous land improvement system based on land-owning classes. Under this law, Land Improvement Districts were created with the membership of cultivator-farmers (in contrast to the old Irrigation Associations or Land Consolidation Associations composed of only landowners).

The Land Improvement District is a legal entity, and is in charge of performing the O&M of land improvement facilities. An LID is different from the village-based water user groups, because it has the legal rights to carry out its required tasks.

The major characteristics of the LIL are that:

- A legal status was assigned to government-operated irrigation and drainage works.
- An LID is to be set up with farmer-cultivators as the members. With the application of 15 or more farmers who want to implement a land improvement project, the Governor can approve establishment of an LID.
- For the implementation of a land improvement project, an application is required with the agreement of two-thirds or more of potential beneficiary farmers. When the project is approved, even dissenting farmers are obliged to participate in the project. The collection of service and general expense fees can be mandatory, like a tax.

- A government subsidy is provided to the project according to the public nature (size, importance), and the beneficiary farmers must repay the remaining cost of construction.

A Land Improvement District has two major functions: promotion of land improvement projects, and operation and maintenance of constructed facilities. The number of LIDs increased rapidly, from 6,302 (3,139 newly established, and the others reorganized from old associations) in 1958 to 11,664 in 1970, but then decreased to 8,224 in 1989, and to 7,297 in 1998 (due mainly to the mergers of small LIDs). With these integrated functions of construction and O&M, the participation of farmers has improved greatly. Under the present system of the LIL, farmers can participate in design, formulation, construction, and O&M in an integrated manner, because they are the focal points.

Lessons from the Japanese experience

Japan has a long history of participatory and community-based management of resources. Such a 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 can be attributed to the long-term evolution of organizations through which internal rules and coordination mechanisms were established. It has always been local initiatives that promoted such processes, and the government role was only supportive in nature. In addition to the organizational development, though, there are several important characteristics of Japanese irrigated agriculture that enabled sustainable management of local resources.

Cycle-oriented resource use and basin perspectives

During the Edo period, farmers skilfully managed local resources by joining the natural resources of paddy fields, dry fields, commons (grassland, forest), rivers, and the surrounding mountains. Forests were very important as a source of fertilizer, fuel and building materials. It was a complex system of production, consumption, and recycling, combining available resources, and was based on the materials cycle.

The paddy field cultivation in the delta areas of large rivers created different farming practices from those in hilly areas, where community forest and grassland provided materials for home-made manure. In low-lying areas, farmers had to rely on fertilizers such as oil cake, powdered fish, and herring. It is interesting to note that farmers paid to collect hu-

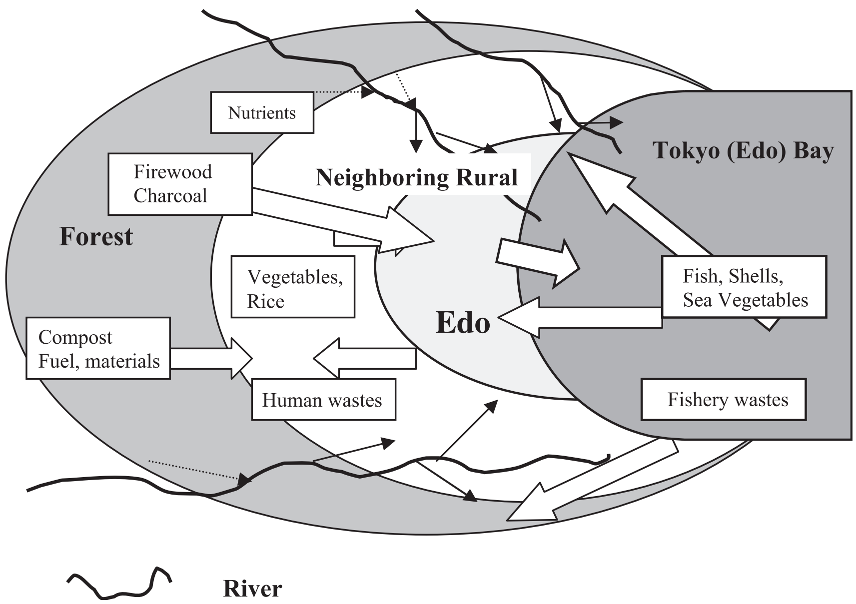


Figure 8.4 Material cycle in Edo city
Source: Tsuchida (2002), p. 112

man waste from houses in the capital Edo (present Tokyo), which they used as fertilizer.

A highly cycle-oriented system was already in use during the Edo period (see figure 8.4). Such a system was necessary to maintain the production level under limited resource availability. As such, those who abused resources or violated community rules faced severe punishment, even ostracism from the village or death.

To enable a cycle-oriented system, understanding of the material flow from a basin perspective becomes very important. Farmers, through their experience, understood the importance of forests and grasslands for enhancing the nutrient level of paddy fields, increasing the availability of water from rivers, and controlling floods. Thus, community rules for preserving these resources were strictly enforced.

Local technology

Small repairs and maintenance of water and flood control facilities were undertaken by community groups; however, because of their size and technical complexity, small-scale development works were gradually carried out by wealthy and powerful farmers and local resident warriors. In addition, from the middle years of the Tokugawa period, wealthy farmers and merchants formed groups to invest for new land development. Their investments were recovered during a tax-concession window of 10 to 20 years, and additional benefits were obtained in the form of rents and tax-exempted lands. Some land-owning farmers or merchants learned and mastered flood control and irrigation technology. A professional engineering group was even formed to take on civil engineering works.

In the beginning, planning, design and implementation was the job of engineering bureaucrats of the central government, or the Daimyo. But in the latter period, resident warriors and upper class farmers implemented irrigation and flood control as well as reclamation work. By involving farmers in the construction and rehabilitation work, the capacity of farmers to manage the system improved, and the applied technology became more locally adapted. The irrigation and flood management system and farmer participation in the development of local resources management during the Tokugawa period was passed down to modern times, and is at the heart of present management.

In the modern period, after the Meiji Restoration, the introduction of engineering technology from the West was encouraged through hired foreign engineers. Consolidation of paddy fields for intensified production and development of irrigation facilities were carried out by government initiative. Although modern engineering technology was imported from the West, the application of the technology was adapted to the local social and institutional environments in Japan.

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

The government's role

The government's role in irrigation and drainage projects has always been limited to assisting in the construction of irrigation systems as well as legislative support. The role of management and operation has always been handled by farmers and their organizations. The Land Improvement Law specifically stipulates that all land improvement projects will be initiated by farmers and managed through land improvement districts.

Major stakeholders in irrigation development, LIDs, government officials/technocrats, and policy makers are united under the Land Im-

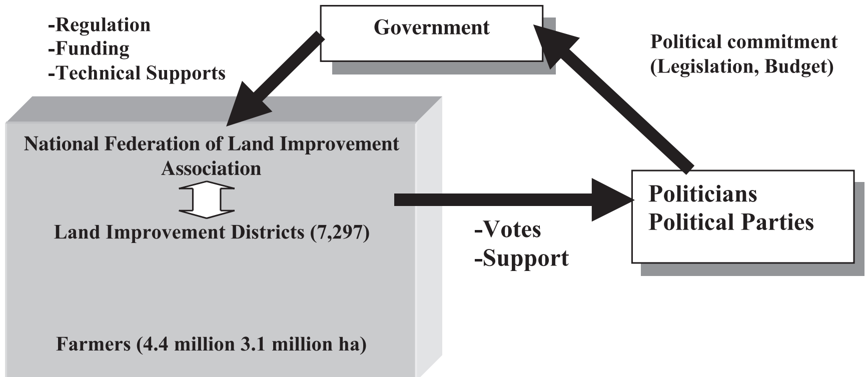


Figure 8.5 Major stakeholders in irrigation development in Japan

provement Law for the common objectives of enhancing agricultural production and improving farmers' living standards. These stakeholders reinforce the function of each other to assist in the development and management of irrigation system in Japan. LIDs were formed into a national federation, and irrigation engineers were grouped into a national association as well, which put pressure on policy makers to support their activities and provide political commitment (as shown in figure 8.5). This may be called a golden triangle of irrigation development and management, which has been strengthened by mutual support and benefits.

Incentives and enforcement of rules

Farmers need sufficient incentive to work together and manage local resources in a sustainable manner. 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 and labour burdens in the Nara period that brought about the collapse of the system of central control of land and water. An incentive is not only the availability or price of water, but the overall economic environment and farmers' living conditions surrounding irrigated agriculture that needs to be improved.

Many of the environmental problems related to land and water resources are caused by inappropriate uses of these resources, by users who cannot see any prospects of improving their livelihoods or who can only survive through unsustainable uses.

Conclusion

This chapter has described the background of a participatory approach of managing resources and its characteristics from a historical perspective. Japan has created an efficient resource management system based on the participatory approach over the long history of irrigation development. Paddy field irrigation necessitates cooperation and mutual help among resource users. The peculiar characteristics of this paddy irrigation farming prompted a participatory approach to management, which maintains an internal mechanism for redistributing water at a time of drought in a rational manner.

In addition, it has been the constant efforts and initiatives of the local people, together with support from the government or local leaders, that enabled the establishment of the present irrigation network and related management institutions (namely LIDs). Legislators and government officers assisted the initiatives of local farmers, and established a framework of laws and institutions. The present system of rural development and LIDs, with support from politicians and government, is a good example of participatory management, particularly in situations with smallholder- and subsistence-type irrigated agriculture.

However, cooperation or participation cannot be automatically attained. To ensure sustainable management, it seems important to view the management of irrigation schemes from the wider perspective of irrigated agriculture. As such, the performance assessment of irrigation schemes should cover a wider scope, rather than focusing too much on irrigation efficiency or water use efficiency. A similar argument can be applied to the pricing of water. Pricing could decrease the water loss in some cases, but it could also damage the incentive of farmers to cooperate or participate in management under paddy farming.

In addition to the management of resources by farmers, the secret of sustainable paddy farming over several thousand years comes from the material cycle mechanism inherent in paddy irrigation. Instead of applying an excessive amount of external inputs, it is important to enhance the capacity of the material cycle of paddy farming. Over the history of development in Japan, the basic approach has always been harmony with nature and cycle-oriented uses of resources, represented by forest conservation against drought or reuse of sewage water and human waste for irrigation and fertilization. The sustainability of paddy farming should be re-established by taking account of this historical approach to managing resources.

Enhancing the capacities of farmers and inducing institutional change and technological innovation are very important but time-consuming processes, and would require social and cultural changes. For technological innovation and extension, it is important to share the available technology and know-how with resource users and to work together with them. With such efforts, we might be able to accelerate the process of these required changes and address the challenges we face today.

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9

History and paradigm shift of Japan's ODA policy in the water sector

Masahiro Murakami

One of the most important resources for life is water. Its scarcity (too little water) and security have been key factors in poverty reduction and conflict prevention or peace-making, while its superabundance (too much water) is a fear of people living in a watershed. Water problems occur in different guises throughout the world, owing to climatic diversity and differences in scale in developing countries or developed countries. Flood disasters, a first-priority national policy for protecting the life and property of people in a watershed, occur mostly in temperate and monsoon regions. Droughts and water shortages, which are a crucial problem threatening the lives of people in the developing countries, occur mostly in dry regions and semi-arid countries.

The importance of water to all life on the planet is more obvious than ever before. Growing populations in the developing counties, regional conflicts, and unrelenting poverty are all intimately related to water – or its absence. Among the many water-related problems, water scarcity and security in the developing world are the most crucial issue to be resolved; some 1.2 billion people lack access to safe drinking water and 3.0 billion lack adequate safe sanitation. Furthermore, 2 million children per day suffer from water-related disease (with some 5,000 infants per day dying from cholera, diphtheria, and other waterborne diseases).

This chapter identifies the role of Japanese Official Development Assistance (ODA) by reviewing international development projects undertaken since the 1920s. It covers three different phases in the history of Japan's international development, to distinguish the foreign policy at different stages. Phase I (the pre-war stage of international development, and during military occupation in east Asia), 1920 to 1945, reviews the work of Yoichi Hatta, the Japanese civil engineer who devoted himself to helping the water infrastructure development of Taiwan. Phase II (the post-war stage of international development, with war reparations), 1945 to 1954, reviews the work of Dr. Yutaka Kubota, the Japanese engineer who devoted himself to developing water infrastructures in Asia. Phase III (the international cooperation stage), from 1955 to the present, reviews some paradigm shifts of Japan's foreign policy and ODA charter in 1992 and 1993 by taking into account the increasing concern of international society about water poverty and human security in developing countries. The chapter then tries to identify some alternative strategies to resolve water and poverty problems and either avoid conflict or secure peace-building in the developing world.

Phase I – International development, 1920–1945

Yoichi Hatta, a pioneer of international development in the pre-war era, was classed as one of Japan's best civil engineers. He arrived in Taiwan in 1909 to serve at the civil engineering bureau, controlled by the Taiwan governor-general's office. There, he was ordered in 1919 to design an irrigation network so as to conceive the objectives of water resource development and flood control within the Chia-nan Plains (a region previously troubled by droughts, floods and salt accumulation in the soils).

After fact-finding missions to the US and Canada, he began to construct a 1,273 metre-long earthen dam and the Wushantou Reservoir (with a storage capacity of 150 million m^3). Heavy machinery, including 50-ton cranes and a German steam locomotive, were used to complete what was then the largest civil engineering works in Asia. After nine-and-a-half years, including designing and raising of finances, the dam with a network of 16,000 km of irrigation channels and 150,000 hectares of irrigated land was completed in May 1930.

"That water supply system, built 70 years ago, is still functioning," Chen Cheng-mei, chief of the finance division of the Chianan Irrigation Association, told the *Taipei Times* in May 2000. Today, Taiwan offers practical and technical assistance pertaining to water resources management to African countries, and Taiwanese governmental delegates participated in the UN World Summit on Sustainable Development. Both water resources management and civil engineering technologies have matured in Taiwan throughout its history, but the foundation of Taiwan's technologies pertaining to water conservancy engineering was established during Japanese occupation between 1895 and 1945, and by the work of Yoichi Hatta.

Phase II – International development, 1945–1954

Japan planned for post-war development during its military occupation of Asian countries in the 1940s. Yutaka Kubota, born in 1890 in Japan, initiated a water infrastructure development project in what is now the People's Democratic Republic of Korea (PDRK) in 1930, when he served as a managing director of Nihon Chisso Hiryo (presently the Chisso Corporation) and concurrently as president of the Korea Hydroelectric Power Company.

The Sup'ung-nodongjagu hydroelectric dam project, which was the largest concrete gravity dam in Asia at the time, was a prime example of non-official economic development under Japan's military administration in Korea. The project was conceived by a Japanese private company to generate 700 MW of electricity by constructing a concrete gravity dam with a structural height of 106 metres. The dam, which was completed in 1941, is on the border between China and the PDRK on the Yalujiang River. After the war, hydro-electricity from the Sup'ung-nodongjagu dam was a major energy source for the PDRK.

The post-war relationship between Japan and Asian counties officially began in June 1951, when the Japanese Government signed a treaty in San Francisco that adopted war reparations for the Asian countries. The reparations started in 1954, in accordance with Article 14 of the treaty. Japan signed reparation treaties with Burma, South Vietnam, the Philippines and Indonesia, which laid out reparations in the form of products and services (despite strong demands for monetary reparations). This may be called "economic cooperation" reparations, as the products and services from Japan were directed to infrastructure, plants and facilities mainly for economic activities. Loans were also provided, with the reparations as collateral. Cambodia, the Republic of Korea, Laos, Malaysia, Micronesia, Singapore, and Thailand received grant aid, which were treated as "quasi reparations."

Burma was the first country in Southeast-Asia to accept Japanese reparations in 1954. A part of the war reparations was used for construction of the Balachuang hydroelectric dam on the Salween River. The Balachuang Dam project was a prime example of economic assistance that primarily benefited the donor country. The project was conceived by Kubota Yutaka (who had resume his professional work after World War II and established a private consulting firm, Nippon Koei Co. Ltd., in 1946), who persuaded Prime Minister Yoshida Shigeru to include it in the enterprises to be funded by war reparations. The hydroelectric plant was intended to provide electricity for Rangoon and Mandalay and, at its peak, provided about 40 per cent of Burma's electricity.

Phase III – International cooperation (ODA), 1954–

Japan's Official Development Assistance (ODA) began in 1954, when Japan joined the Colombo Plan (an organization set up in 1950 to assist Asian countries in their socio-economic development). Japan had become a member of the World Bank in 1952, and received loans for 31 projects, including the Fourth Kurobe Dam, which helped lay the foundations for its unprecedented economic growth in the 1950s and 1960s.

While receiving aid in the 1950s from the World Bank for the reconstruction of its own economy, Japan soon began the process of delivering aid to developing countries. Since that time, Japan's ODA commitment has increased and expanded yearly. Previously a borrower from the World Bank, Japan has become one of the world's largest ODA donors as well as one of the largest contributors to the World Bank and International Development Association. With the increasing expansion of ODA in the 1980s to 1990s, there has also been a gradual move to include countries outside of Asia, with countries in Eastern and Central Europe being the most recent additions.

In 1992, Japan was the top donor in the world in terms of net ODA disbursement, and was the major donor in 25 countries. From 1990 to 2000, while the ODA provided by all member countries of the Development Assistance Committee (DAC) of the Organization for Economic Co-operation and Development (OECD) fell slightly, Japan's ODA increased by almost 50 per cent, amounting US$13.5 billion in 2000 (see figure 9.1).

The three main categories of ODA are: Bilateral Grants (grant aid and technical cooperation), Bilateral Loans (loan assistance, generally known as "yen loans"), and Contributions and Subscriptions to multilateral donor organization. The major portion of bilateral grants is undertaken by the Japan International Cooperation Agency (JICA), while the Japan Bank for International Cooperation (JBIC) is in charge of bilateral loans.

Asia is the region with which Japan shares the closest historic, economic and cultural relations; and, because of the depth of these relations, Asia is considered as the highest priority region under Japanese ODA policy. During FY 2000, Japan allocated more than half of its bilateral assistance (US$5.23 billion, or about 54.8 per cent of the total bilateral assistance) to Asia.

Japan's ODA policy places particular emphasis on the Association of

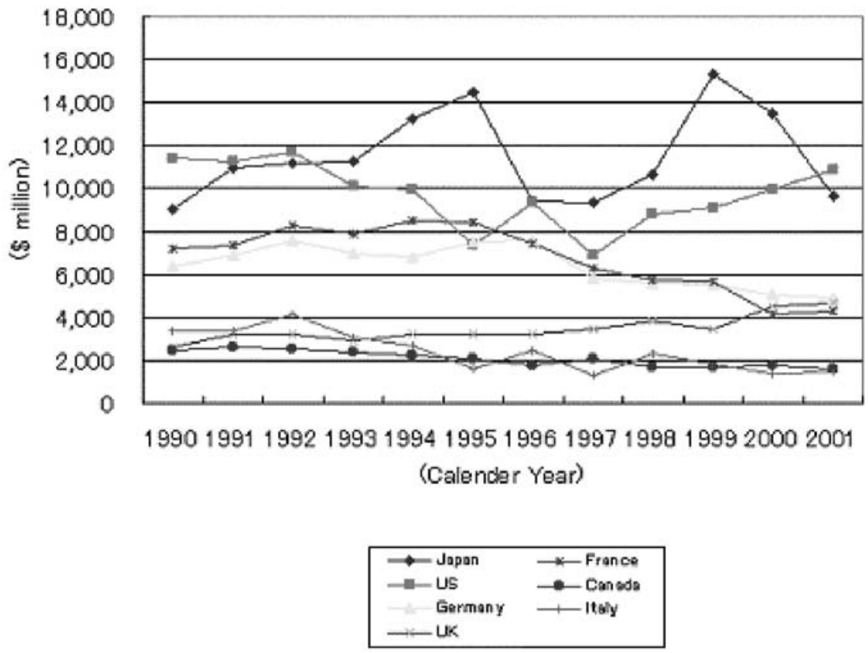

Figure 9.1 Trends of major DAC countries' ODA
Source: DAC on-line database
Note: Net disbursement basis

South-East Asian Nations (ASEAN) region, which received 59.2 per cent of Japan's ODA to Asia during FY2000. Rectifying the economic disparities between original and new ASEAN members is particularly important for further consolidating the integration of ASEAN and for advancing regional stability.

A paradigm shift of Japanese ODA policy in the 1990s

Japan's provision of economic cooperation is based on the concepts of "humanitarian and moral considerations" and "the recognition of interdependence among nations." The Japanese government provides ODA after taking into account the following four principles cited in the ODA Charter, published in 1992:

- Environmental conservation and development should be pursued in tandem;
- Any use of ODA for military purposes or for aggravation of international conflicts should be avoided;

- Full attention should be paid to trends in the recipient countries' military expenditures, their development and production of weapons of mass destruction and missiles, their export and import of arms, and so on, in order to maintain and strengthen international peace and stability; and
- Full attention should be paid to efforts towards democratization and the introduction of a market-oriented economy, the situation regarding the securing of basic human rights and the level of freedom in the recipient country.

It is imperative that Japan enforces the above principles in a timely and appropriate manner while monitoring conditions of relevance in each recipient country. However, it must be borne in mind that each country has its own set of economic/social conditions and foreign relations to deal with. Noting these realities as well as various principles of the UN Charter (especially those relating to sovereign equality and non-intervention in domestic matters), the ODA Charter states that assistance should be implemented while taking into account, comprehensively, each recipient country's request, its socio-economic conditions, and Japan's bilateral relations with the recipient country.

All of the ODA Charter's principles (particularly the third and fourth) are concerned with issues that have a crucial bearing on recipient countries' security and internal affairs. Effectively dealing with problems in these areas is impossible unless the recipient country acknowledges and shows initiative in dealing with them on its own (whether or not it is urged to do so by Japan or other members of the international community). It is not for Japanese policy to automatically suspend or revise aid, but rather to express concern and urge remedial actions. This is the reason that the third principle in the ODA Charter emphasizes adequate attention to "trends."

Typical examples of diplomatic disincentive are found in the cases of Burma (Myanmar), Pakistan and India, in relation to the serious questions of human rights and nuclear development. In Burma, Japanese Overseas Development Assistance accounted for 78 per cent of the country's bilateral ODA in 1988. After the massacres of pro-democracy demonstrators in August and September 1988, and the military coup by Saw Maung, the Japanese government suspended all economic assistance to Burma. Nevertheless, on 17 February 1989, the Japanese government reversed its position, recognizing Saw Maung's regime and announcing the resumption of on-going ODA projects in Burma.

In April 1991, the Japanese government announced a new policy on ODA. In the future, the statement said, assistance would depend on a country's record in the four areas. If these principles were taken seriously, Burma, with its declared military budget of more than 40 per cent of its total national expenditure and its refusal to allow the country's elected leaders to take power, would have been ineligible for Japanese ODA. However, Japan has been less than strict in applying these conditions to any of the countries to which it gives economic assistance. Exceptional aid was allocated to rehabilitation work for the Balachuang hydroelectric project in Burma in 1995 (which received the first Japanese reparations in 1954, but has fallen into disuse since 1990 owing to a lack of maintenance).

Reviewing the ODA Charter

The ODA Charter was approved by the cabinet in 1992, but the world has changed dramatically since then (including regional conflicts and terrorism). The Government of Japan, therefore, revised the ODA Charter, with the aim of enhancing the strategic value, flexibility, transparency and efficiency of ODA, in August 2003.

The Government of Japan recently undertook a major review of the ODA Charter, taking into account changes in the domestic and international situations over the ten years since its formulation in 1992. These changes include:

- The advancement of globalization has made the issue of development of developing countries more important in the international arena. In particular, since the terrorist attacks in the United States on 11 September 2001, there has been greater international awareness of the possibility of poverty breeding hotbeds of terrorism, so the role of ODA is being reconsidered.
- The international debate on development assistance has been evolving, with the appearance of the new concepts on sustainable development, poverty reduction and human security, and new areas such as peace-building.
- On the other hand, under the severe economic and fiscal conditions, Japan needs to make further efforts to ensure that its implementation of ODA is strategic, transparent and efficient.
- Additionally, as participation in ODA has diversified, and includes non-governmental organizations (NGOs), volunteers, local government bodies and others, and public interest in ODA increases, broader public participation in the implementation of ODA is required.

The Government of Japan established the Charter for its Official Development Assistance in order to garner broader support for Japan's ODA through better understanding, both at home and abroad, and to implement it more effectively and efficiently.

It has been argued that the importance of economic growth is recognized as a requirement for poverty reduction, but not as a sufficient condition. In addition, large-scale infrastructure such as large dams has often had negative impacts on the environment and local society. DAC peer review is critical in terms of "the software and financial aspects, including cost recovery, availability of recurrent and maintenance financing, propoor user charges, as well as adherence to social and environmental standards such as appropriateness of resettlements, environmental impact, and capacity building." There is also a need to learn lessons about debt sustainability of recipient countries, as large-scale infrastructure projects usually require large loans, as well as about negative impacts on the living environment, income distribution and Asian crisis in a wider setting.

The "consolidation of peace" was politically added to expand the conventional area of Japan's ODA for "peace-building," including the cases of Afghanistan, Mindanao (the Philippines), Aceh (Indonesia), Sri Lanka and Iraq. A "peace-building" or "conflict prevention" approach implies possible engagement in the peace process before the concerned parties in conflict reach a peace agreement, so the provision of ODA to the security area, including for humanitarian relief, could blur the distinction between civil and military affairs. When a unit of Japan's Self-Defense Forces (SDF) was sent to Iraq for humanitarian and other assistance, public opinion in Japan was divided. This linkage between ODA and SDF activities was the first time in Japan's ODA history.

The new agenda for peace in the UN system and lessons of the human situation in Myanmar could lead a new concept of "human security," which was adopted as a Basic Principle in the new ODA Charter in 1992. ("To ensure that human dignity is maintained at all stages, from the conflict stage to the reconstruction and development stages, Japan will extend assistance for the protection and empowerment of individuals.")

Current status of Japan's ODA in the water sector

Since the World Water Forums in 2000 (at The Hague) and 2003 (at Kyoto), there has been increasing concern about solving regional conflict, environment and water issues. Serious water problems, such as a shortage of safe water supply, pollution, floods, etc., are occurring in various parts of the world owing to rapid increases in population in the developing world. In September 2000, 189 countries participated in the UN Millennium Summit, which adopted the Millennium Development Goals (MDGs) to ensure environmental sustainability. The need to "halve, by 2015, the proportion of people without sustainable access to safe drinking water" is one of the most important targets in the MDGs. At the World

Summit on Sustainable Development (WSSD) held in Johannesburg, South Africa, Japan announced the ''Clean Water for People'' initiative as well as a Japan-US partnership to support the provision of safe water and sanitation to the world's poor.

Water problems are extremely diverse, and occur in different places and at different times. Some regions, such as the Middle East and Africa, are suffering from scarce rainfall and chronic shortage of safe water supply without lifeline infrastructures, while other regions, such as the monsoon regions of Asia, suffer from periods of too much water. (Though many people also suffer from a lack of safe water in water-rich monsoon Asia, owing to the poverty and inadequate civil minimum water supply infrastructure.) International society has started to understand the significant implication of global water problems, which requires a comprehensive approach that includes not only addressing technical problems concerning drinking water supply, sanitation, pollution, water conservation, and efficient water, disaster protection, and water resource management, but also socio-cultural problems such as water poverty and conflict prevention/solution. Japan's foreign policy gives priority to supporting water projects in developing countries, in accordance with the guideline of the ODA Charter in 1992 and OECD/DAC.

Approximately US$5.7 billion was made available in the period FY1999 to FY2001 through Japan's ODA in the water sector, for example. Significant effort also was made to provide access to safe drinking water and sanitary sewerage systems for more than 40 million people in the five-year period FY1996 to 2000. And the amount of Japanese ODA extended towards ''Water Supply and Sanitation,'' for which concrete goals were set in the MDGs and at the WSSD, averaged over US$1 billion in a recent three-year period, and was approximately one-third of the worldwide ODA (about US$3 billion per annum) extended to the water sector, making Japan the largest donor country in the global water sector.

In order to properly address the increasing demands for access to safe water and sanitation in Africa and Asia, Japan will provide comprehensive assistance from well-drilling to planning, building, and proper maintenance and management of water and sewer systems that will be appropriate to the particular needs of the region (regardless of whether it is urban or rural). Some examples of such assistance and representative countries include:

- Strengthening water supply systems and operation/maintenance through groundwater development in Africa (Senegal, Tanzania, Mali, Mauritania, and Zambia),
- Strengthening the development and operation/maintenance of water supply systems and sewerage systems in Asia (Sri Lanka, Indonesia,

Cambodia, Myanmar, Laos, Viet Nam, the Philippines, Nepal, Pakistan, Thailand, and China),
- Stable water supply and water governance in the Middle and Near East (Egypt, Morocco, and Tunisia),
- Water supply and/or sewerage treatment projects in cities in the Latin American region (Guatemala, Brazil, Peru, and Mexico),
- Water supply and/or sewerage treatment projects in the Pacific Islands region (Fiji), and
- Strengthening control of water-related diseases, including arsenic poisoning and the guinea-worm disease, in Asia and Africa (Bangladesh and Niger).

Not so long ago, water supply coverage in Japan was low, just as it is now in developing countries, and outbreaks of infectious diseases due to contaminated water sources were not infrequent. In the aftermath of World War II, only about one-third of the Japanese population had access to safe water supply in 1950, including a very high rate of unaccounted for water (UFW) owing to pipeline water leakage, and outbreaks of infectious diseases reached epidemic proportions. With the enactment of the Water Supply Law in 1955, a mechanism for the systematic development of water works in Japan was put in place. The number of patients suffering from infectious diseases from water rapidly declined as water supply coverage expanded to develop water saving/conservation technologies that included the reduction of UFW by pipeline water leakage. Based on these historical lessons, Japan could drive to promote equal access to safe water supply by all through building legislative and developmental frameworks.

The problems of Africa and the Middle East

Although Asia is the region with which Japan shares the closest historic, economic, and cultural relations, Africa has the highest percentage of people living in absolute poverty, and faces many other grave issues as well (including conflicts, infectious diseases and cumulative foreign debt). As a consequence, conditions of poverty are still widespread; for example, 40 per cent of the entire African population must survive on a per capita income of less than one dollar a day. Alleviating poverty in Africa and integrating the region into the global economy count as major aid challenges for the international community.

Japan has actively tried to help, and provided US$969 million in ODA to African countries during 2000 (which accounted for 10.1 per cent of total Japanese bilateral aid for that year). Japan has hosted three meetings of the Tokyo International Conference on African Development

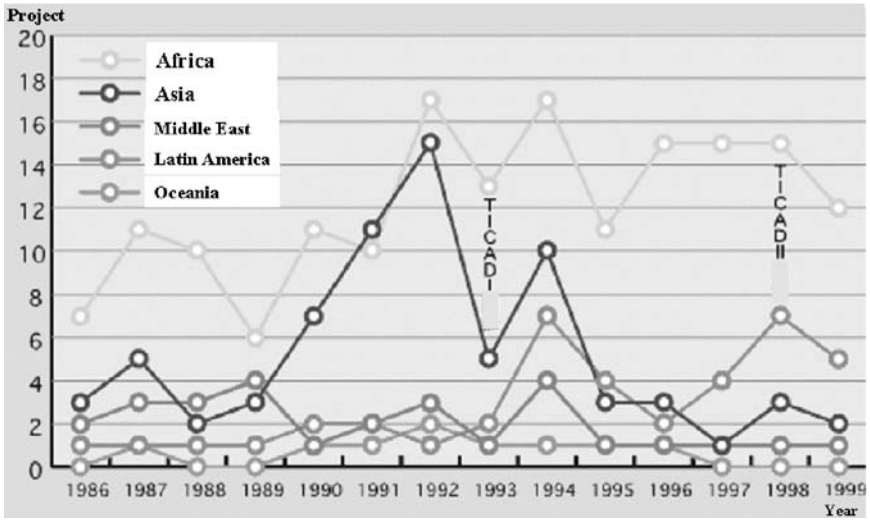

Figure 9.2 Japanese grant aid projects to supply safe drinking water

(TICAD, in 1993, 1998, and 2003), which advocates the importance of self-help efforts by the African countries themselves, and of partnership from the international community in supporting those efforts. At TICAD II, in 1998, Japan pledged to provide some ¥90 billion in grant aid to African countries for education, health and medical services, and water resources sectors over the next five years (and had provided over ¥53 billion in such aid by December 2001). That assistance has afforded educational opportunities to more than 300,000 African pupils and provided safe water to nearly 2.7 million Africans. An intensive development programme has been carried out in Africa to develop groundwater for safe water supply in local communities since the 1980s, amounting ¥90 billion of Japanese grant aid in total (see figure 9.2)

To achieve the goals of development, poverty alleviation, and improved standards of living, the plan was principled on a shared awareness of the value of helping African countries harness the hidden potential of their citizens (ownership), and having members of the international community participate as equal partners in that enterprise (partnerships). The Tokyo Agenda for Action advocates three approaches to African development: capacity building, gender issues, and the environment. On top of this, it articulates specific strategies for action in three broad fields: social development, economic development and good governance.

Japan has since announced various new assistance programmes for Africa, including ¥90 billion in grant assistance over five years for education, health care, and water supply sector infrastructure. It is anticipated that this aid will lead to the construction of school facilities for the education of an additional 2 million children throughout Africa, and help at least 15 million citizens improve their living conditions. Given that the UN's MDGs include such targets as halving, by the year 2015, the proportion of people without sustainable access to safe drinking water, it can be seen that global concern about issues surrounding water is rising. Japan is undertaking consideration of, among others, establishing an international partnership for the purpose of improving governance over environmental issues, particularly water quality and comprehensive water management planning in developing countries.

The population in the Middle East and North Africa has doubled over the past 30 years, to 280 million. If the current average annual population growth rate among Muslim countries continues, the population will double again within 30 years, to exceed 500 million. The Middle East and Africa hold 5 per cent of the world population, but less than one-fifth of the people in the region have convenient access to safe water or renewable water (from rainfall).

The Muslim world is mostly located in the water-scare arid to semi-arid zones (see figure 9.3), the population of which is 1.2 billion (Murakami, 1995). The annual water resource potential per capita in these zones

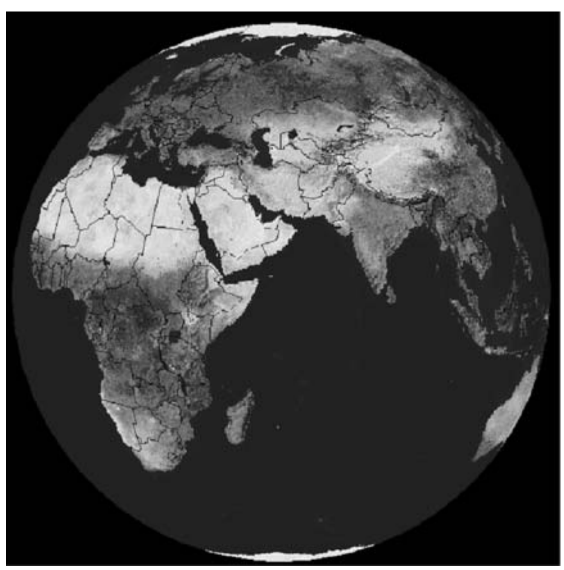

Figure 9.3 The world's arid region
Source: Satellite image map; Encarta 2000

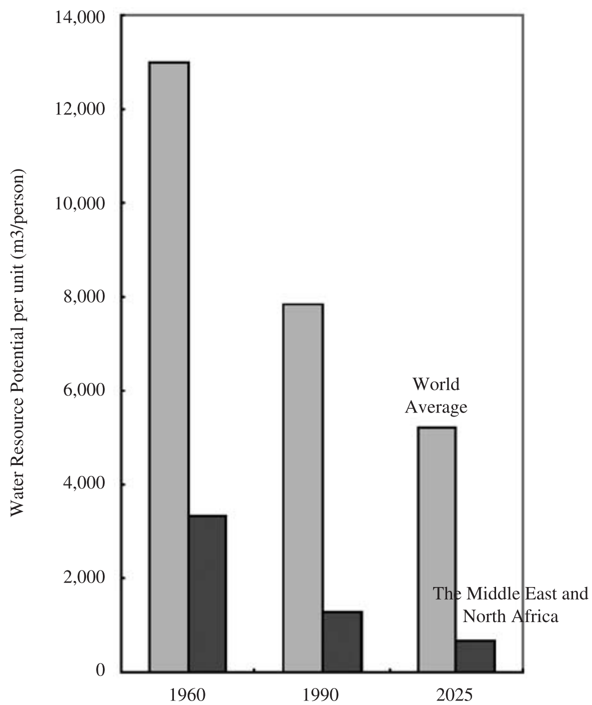

Figure 9.4 Decreasing annual per capita renewable freshwater
Source: (World Bank, 1994a,b)

decreased by 60 per cent, from 3,300 m^3 in 1960 to 1,250 m^3 in 1995, because the population increased but rainfall did not. Moreover, rainfall is expected to drop to 650 m^3 in 2025 (see figure 9.4).

In Jordan, for example, water resource potential per capita decreased from 308 m^3 in 1990 to 190 m^3 in 2000. The severe drought of the past few years has affected people's lives, and the government has had to employ a crisis-management system. The water resource potential per capita is expected to go down to 95–114 m^3 by 2025 if population growth maintains its pace (Murakami, 1995).

About 60 per cent of the population in the Middle East and North Africa is concentrated in cities, where the average population growth has been 4 per cent every year. Currently, 45 million people cannot access safe water, and 80 million live in unhygienic conditions.

The population in Sub-Saharan Africa, meanwhile, is about 600 million, and population growth there is the highest in the world. Particularly in the semi-arid Sahel, basic water human rights are threatened, and most

Table 9.1 Ten countries with lowest water resource potential in 1990s

Country	Population (million)	Renewable fresh water potential (m^3/year/person)
Djibouti	0.69	14
Jordan*	6.33	207
Yemen*	18.12	287
Singapore	3.59	346
Tunisia*	9.84	443
Cape Verde	0.44	455
Kenya	30.34	495
Burundi	6.97	516
Algeria*	31.60	544
Oman*	2.72	709

Source: Created from "The World's Water" (Peter Gleik, 2000, Murakami, 2000 and World Bank, 2002)
Note: * Countries in the Middle East and North Africa

of the population is susceptible to water-borne infections such as Guinea worms, malaria, typhoid and dysentery. According to the United Nations interim estimate of the population growth rate, 62 countries supply less than the minimum of 50 litres of water per day per person (for drinking, cooking, hygiene, etc.), and the number of people without sufficient water has reached 2.15 billion.

Among these, 33 countries average under 20 litres per day. Among them, 70 per cent (23 countries) are in Africa, including 22 countries in Sub-Saharan Africa (see tables 9.1 and 9.2 and figure 9.5). An estimated 1,000 m^3 of water per year (1,500–1,700 m^3 where affected by the water stress) is required per person to support agricultural and industrial production, as well as supply drinking water. Though per capita water supply in Sub-Saharan Africa is the lowest in the world, water resource potential per capita is not necessarily low in these 22 countries (Murakami, 2000); only 4 countries are below 1,000 m^3.

This means that poverty lies at the heart of the water resource problem in Sub-Saharan Africa; it is not a lack water, but an inability to invest in small-scale development for ensuring access to safe water. Many people, thus, have no other choice but to drink unsanitary water. This suggests there is a real need for development assistance to utilize the water resources of Sub-Saharan Africa. However, the reality is that it is very difficult for international aid to compensate for the pressure of population growth and the deteriorating, chronic scarcity of water supply in some regions of Africa; half-hearted efforts will not create a fundamental solution.

Table 9.2 Renewable freshwater potential and countries with less than 20 litres daily of safe water supply in 1990s

Country	Population (million)	Renewable fresh water potential (m^3/year/person)	Daily safe water supply (litres/ day/person)
Gambia*	1.24	17,724	3
Haiti*	7.82	1,407	3
Djibouti	0.69	14	4
Somalia*	11.53	738	6
Mali	12.56	4,936	6
Cambodia*	11.21	44,424	6
Mozambique*	19.56	2,965	7
Uganda*	22.46	2,938	8
Tanzania	33.69	2,256	8
Ethiopia*	69.99	1,572	9
Albania	3.49	6,017	9
Bhutan	2.03	46,839	10
Chad*	7.27	5,227	11
Central African*	3.64	38,736	11
COD*	50.34	15,498	11
Nepal	24.35	6,982	12
Rwanda*	7.67	822	13
Lesotho	2.29	1,747	13
Burundi*	6.97	516	13
Angola*	12.80	12,344	14

Source: Created from ''The World's Water'' (Peter Gleik, 2000 and World Bank, 2002)
Note: * Conflict-related country (being beset with refugee problem)

In other words, Sub-Saharan Africa faces a difficult future unless the international community pays more attention to water problems and provides financial assistance. Certainly, the ''Green Revolution,'' started in the 1960s and continuing to increase food production, contributed to increasing the average Gross Domestic Product to approximately $600 in Sub-Saharan Africa by improving agricultural production and securing food, developing cities and roads, and greening the desert. However, although often upstaged by the drive for economic development, water problems are a serious issue. Though securing safe water and sanitation is an age-old problem, it is also a key strategy for poverty eradication in Africa. The international community and the Japanese government should address the ''Blue (Water) Revolution'' immediately.

Another key influence on water security is regional conflicts. UN Secretary-General Kofi Annan stated in the UN Annual Report of September 1999 that regional conflicts in Africa, in particular, and the international community's powerlessness to deal with them, are serious

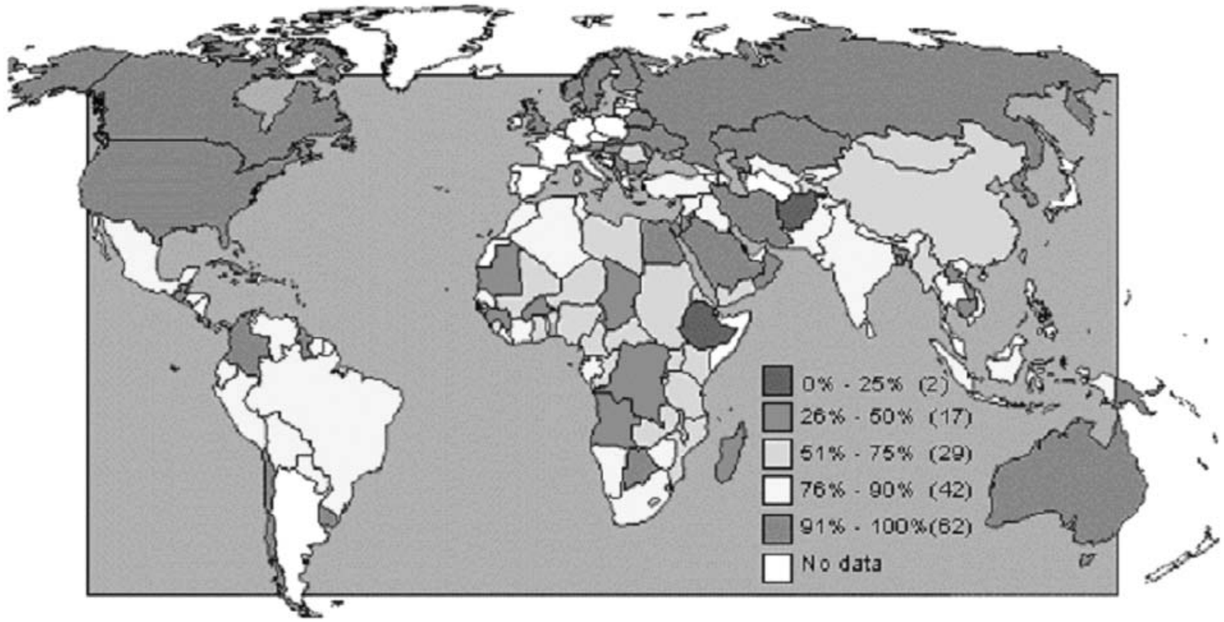

Figure 9.5 Safe water supply coverage of the world
Source: UNICEF, 2000; http://www.childinfo.org/eddb/water/printmap.htm

problems (Annan, 1999). It is evident that there are many water scarce countries in the arid to semiarid region that lack alternatives to develop renewable fresh water in their territories.

Renewable fresh water is a limited resource. The changing global climate has brought with it decreasing rainfall in semi-arid regions, where rainfall patterns are already irregular and varied. Therefore, the security of water resources is an issue that has serious implications for ensuring basic human rights in the (least) developed countries, and is today becoming key to preventing and solving regional conflicts.

Alternative ODA policy strategies to resolve water-poverty problems

The Worldwatch Institute reported in July 1999 that people in developing countries are in danger of starvation and water conflict, due to food production declines as a result of rapidly advancing water scarcity. It points out that the shift from the "Green Revolution," which increased world food production, to the "Blue Revolution," which will make water use more effective, is an urgent task.

It is conceivable that the global environment will be degraded irretrievably, and that conflicts over the security of water resources will develop when a global food crisis emerges and the price of food escalates significantly. In December 2000, in the "State of the World," the Worldwatch Institute pointed out that water resources and the role of the international community are extremely important in eradicating starvation and reducing poverty (Brown, 2001). Water poverty exists in many countries in the developing world, particularly in parts of Sub-Sahel Africa and Asia.

International leaders are beginning to realize that recent serious droughts have led to starvation and an increase in the numbers of refugees. In addition, the irregular and frequent flood damage caused by global climate change and abnormal weather combined with structural water scarcity may provoke additional regional conflicts.

Poverty reduction, conflict prevention and the reconstruction assistance scheme in Afghanistan are dependent on international assistance for water resources and water supply. Humans must re-affirm that water issues are key to solving starvation, poverty and conflict problems in developing countries, and that they can be addressed through international assistance, in which Japan will play a leading role. This does not mean that the efforts of the United Nations and Japan have not been enough, but rather that the water problem is much more difficult and serious than originally envisaged in the 1970s.

The international community must again acknowledge water resource problems as an important and immediate priority, giving more attention to solving the problems and providing increased development assistance to prevent the situation further regressing. With fresh water supplies reaching their limits in some areas, water problems may not be solved simply by controlling the population and desalinating seawater. In this situation, then, what should be done?

The new agenda in countries facing issues of water scarcity and water security requires integrated water resource management (which includes non-conventional water resource development), such as rationalization of agricultural water, water-saving and prevention of water leakage of urban water, re-use of treated sewage and diversion to the agricultural sector, increasing the collection rate of industrial water and recycling, desalination of brackish water and sea water, contamination control and conservation of water resources, etc.

In many developing countries, people not only lack safe drinking water, but they also are in a vicious circle wherein the lack of sanitation and sewerage means that those scarce water resources which do exist are often polluted and dangerous to consume. Even though it is recognized that sewerage systems are indispensable for urban infrastructure, developing countries are not able to develop them because of the large-scale financial investment and high technology required.

Dispersed small and medium-scale sewage treatment systems could be introduced at the local level as one answer to the problem of sewage management. Such treatment systems would provide more realistic and meaningful environmental assistance than trying to develop, in phases, large-scale systems. The systems should be based on the following principles: low cost, simple maintenance, energy (power saving), resource-saving (recycling solid waste for bio-filter), consideration for the ecosystem (no chemical use, but natural purification), preventive conservation of the local environment (and restoration), and incentives for fostering administrative technicians and enlightening the general public. The model and method for water purification should be suitable to national environmental conditions, the level of local technology and policy objectives. With a view to sustainable development, the maintenance of facilities should be gradually shifted to a social capital (infrastructure) development and technology transfer programme that focuses on capacity building at a local level rather than a centralized system.

There have been some important amendments in the strategy of ODA policy since Japan's ODA Charter was revised in 1992 and 2003. These may form a part of the basis of integrating water resources management to secure the long-standing water poverty problems in the developing world.

Concluding remarks

This chapter has described three phases in the history of Japan's international development to distinguish the foreign policy at different ages: phase I (pre-war stage; international development during military occupation in east Asia), 1920–1945; phase II (post-war stage; international development with war reparations), 1945–1954; and phase III (international cooperation stage; ODA), since 1955.

Japan stands as the top donor country in the world in terms of net ODA disbursement from 1992 to 2000, since the change in ODA policy in 1992. However, the ODA budget has been decreased by steps since 2001, in accordance with Japan's serious economic recession at the end of the 1990s. However, Japan's foreign policy gives priority to supporting water projects in developing countries, in accordance with the guideline of OECD/DAC and the ODA Charter. The amount of Japanese ODA extended towards "water supply and sanitation," for which concrete goals are set in the MDGs and at the WSSD, averaged over US$1 billion in FY1999–2001, which is approximately one-third of the worldwide ODA (3 billion US$ in those three years) extended to water sector.

This chapter has reviewed the paradigm shift in the history of Japan's foreign policy of international development to identify the crucial role and position of the water sector in ODA. The ODA Charter of 1992 and 2003 demonstrates a new agenda, including environment conservation, democratization, governance, human right, poverty reduction, global perspectives, sustainable growth, peace-building and human security. Water is still a key element in the basic concept of international cooperation for "basic human needs," "poverty reduction," "disaster management," "human security" and "peace-building."

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10

Lessons learned in the history of Dutch water management

Dick De Bruin and Bart Schultz

This chapter will describe some of the crucial moments, decisions and activities in the history of water management and land reclamation in The Netherlands. With the present day know-how, political situation and standard of living, most probably the developments would have been different. However, one has to judge these developments in the light of the conditions at the time they took place. (Figure 10.1, a map of The Netherlands, shows the location of the geographical names mentioned in this paper.)

The history of water management in The Netherlands shows how the original natural landscape was transformed into a man-made landscape, and has led to a never-ending struggle with water. Human intervention is continuously needed to be able to survive with effective solutions.

Essentials of water problems in various eras

Those were the days (1000–1600)

The first inhabitants of the lowlands settled on the natural levees and creek ridges along the rivers and deltaic salt marshes, on the sandy ground and the strips of clay behind the dunes, long before the Christian era. Later on, in the 10th century, their descendants moved into the adjacent, huge peat areas further from the rivers and the coastline. They

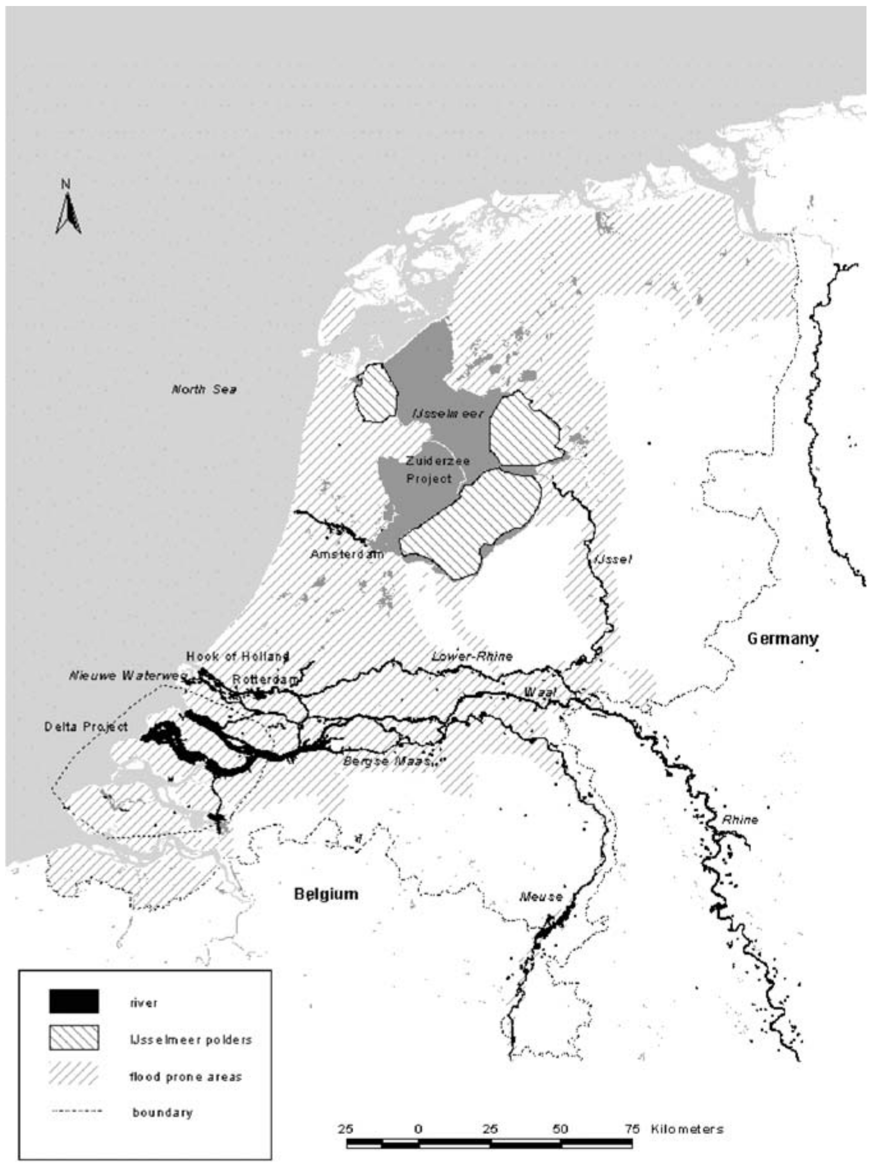

Figure 10.1 Map of The Netherlands, referring to names as mentioned in this chapter

lowered the groundwater levels in these wastelands (nowadays, these lands would be characterized as ''wetlands'' as defined in the Ramsar Convention), which were then situated a few metres above mean sea level. This was done by digging ditches that were able to discharge excess water by gravity to the lower adjacent waters. This first cultivation process was more or less completed in the 14th century. This has left an ineradicable mark on the landscape, in particular in the western part of The Netherlands (Van de Ven et al., 1996).

In the 14th century, local communities that had settled and developed in the first danger zone for floods started connecting their local dikes. This was the beginning of collective dike construction that would last for centuries. This second radical intervention in the natural water-saturated alluvial lands, which later on were developed to become the national economic centre of Dutch society, generated a complicated hydraulic and hydrological chain reaction that is still going on and will never stop.

Fighting water-logging (1600–1900)

The cultivation of the water-saturated peat lands caused a considerable drop of the surface level due to subsidence and oxidation in the course of the centuries. In addition, the more deeply situated subsoil layers, due to natural causes, continued subsiding as well. These processes resulted in a drop of the surface level, amounting to 2 to 3 metres up till now. (One may wonder how this threatening process will further develop in the far future.) It urged the need, sooner here and later there, to reclaim the old cultivated grounds and transform them into ''polders,'' initially by means of small primitive sluices that could be opened at low outside water levels. In the course of the 15th century, windmills were to bring help. In the 19th century, these windmills were, in turn, replaced by steam-driven pumping engines, and in the 20th century by electric and diesel engines (Schultz, 1982).

Solving major problems with river floods (1850–2000)

After the closure of the main dikes along the river branches, flood control remained a problem. The now-confined ''wild'' floodplains and unstable braiding channels offered insufficient discharge capacity during major (but frequent) floods. Many dike bursts occurred and, in addition to regular social disruption, many disasters occurred. This became a matter for continuous political attention and prioritization, even at national level.

As long as floodplains and channels could not be cleared sufficiently, excess water during river floods was discharged through the river to the sea, as well as via spillways (local lowered crests of the flood control dikes) and connecting by-pass corridors over land behind the river dikes. Only after the completion of large-scale regulation and normalization works – made possible after the invention of steam-driven equipment – were these by-pass corridors gradually abandoned. In addition, the floodplain became further cleared from hydraulic obstacles during floods.

This led, in the 20th century, to a river system with a rather unnatural floodplain character, while water pollution (initiated by industrialization and urbanization after World War II) more or less destroyed aquatic life. Intervention measures were needed, to restore the landscape and aquatic life, and to develop a balance between prosperity (economy) and welfare (ecology) and achieve sustainable and environmental friendly (but effective) floodplains. This process is still going on, and will require continuous attention in the future.

Water management (1950–2000)

For the drainage of cultivated land, numerous pumping stations are needed – in particular, in those areas that are situated below mean sea level. Discharge of surplus water (seepage and rainfall) by gravity is, in many cases, not possible anymore. The main system of normalized creeks, canals, lakes, retention basins (*boezems*) and ditches has developed through the ages, but it still needs fundamental improvement and extension. This is mainly necessitated by continuing urbanization and industrialization, and also by the mechanization and further optimization of agriculture in Dutch society, and the diversification of rural land use.

With all these developments, of course, water quality problems became manifest. Real and sustainable solutions required fundamental changes in the institutional set up of the system of water management in the entire country. Water pricing, which for centuries has been a cornerstone of water management in The Netherlands, is further developing. Gradually, ''water'' has become a prior limiting factor in spatial planning on a national scale. At the regional and local levels, the fundamentals of these policies must be followed. Consequently, the issue of effective water management now has the active attention of all public sector levels in the country, and is regularly given attention by media and school training programmes. This is crucial for public awareness and the acceptance of investments in water-related infrastructure facilities. It helps with the decisions on and implementation of further improvements and adaptations of the water management systems (pumping stations). This process will have to continue in the future.

Solving major flood problems due to sea surges (20th century)

In the second half of the 20th century, safety along the landside of the seacoast was improved by a drastic shortening of the coastline through construction of the Zuiderzee and the Delta Project. The provisional tailpiece of these large-scale projects was the construction of a movable storm surge barrier in the open river between Rotterdam and the sea, the Nieuwe Waterweg (completed in 1997). But large-scale intervention with construction and works for the closure of estuaries and tidal lagoons, the essence of these projects, has introduced long-term and gradual changes in morphology and related natural coastal developments. In addition, it has generated an impact on coastal flats and gullies and their natural habitat.

Presently, restoration measures are going on, and no doubt will continue in the future on a large scale. These restoration measures are not restricted only to additional technical interventions, but also include changing water management and spatial planning in polder areas in the line of defence along the sea. All relevant measures must lead to a flexible situation such that adaptations to water management and flood control are relatively easy to implement.

The future

The population of The Netherlands has now stabilized; only a modest increase is foreseen in the future. The population in 2000 was around 16 million. For the next 50 years, some scenarios have been developed: it is expected that by 2050 the population will further increase between 17 (minimum scenario) and 20 million (maximum scenario). To survive in this industrialized society in the long term, proper spatial planning and effective water management are crucial (the more so because it is expected that a sea level rise and climate change will hamper the existing system of flood control). The balance in the vulnerable Dutch delta is also being disturbed because the developing society leads to activities such as:

- natural gas extraction (causing soil subsidence with consequences for water management);
- deepening of approach channels to ports (causing further salinity intrusion); and
- extension of horticulture under glass (having a further impact on water management).

Improvements and further fundamental changes will be needed continuously to face the impact of these activities.

Highlights in the history of Dutch water management

For centuries, The Netherlands has known a sound social and political structure, so that many long-lasting projects could be successfully executed and implemented. People's awareness of the need for human intervention has not been a real problem – in particular, if supported by a non-governmental organization (NGO) – from the 1970s onwards. Also, the media every now and then give attention to developments in the water sector, which strengthens public support for fundamental changes and improvements in the modern system of water management. This, again, is a stimulus for teachers (including professors at universities) to take up water management subjects for case studies in education programmes and as part of a curriculum. This generates automatic public awareness on a large (and important) scale in the mind of the younger generations in Dutch society. With this in mind, the Department of Public Information within the Ministry of Transport, Public Works and Water Management (in fact, all communication counters in the country where infrastructure works are developing) has a crucial task: not only for the supply of direct information, but also for education programmes.

Apart from these structural factors, there were chance factors leading to new measures for water management. New interventions were often decided upon after natural disasters had occurred, (such as storm surges and river floods, but also after droughts). Those disasters were sometimes predicted, but sometimes totally unexpected, even recently. A few examples:

- In the 16th century, a number of new water boards were established for developing better local and regional water management, because earlier the Zuiderzee (in those days an estuary) had threatened large parts of the adjacent land.
- In the 18th century, the implementation of difficult-but-successful works on stabilization of the discharge distribution over the two main branches at the apex of the Rhine delta on Dutch territory provided the basis for the later regulation and normalization works of the river branches.
- The execution of the reclamation of the Haarlemmermeer (18,000 hectares, southwest of Amsterdam) in the 19th century and the Zuiderzee Works and the Delta Project, both in the 20th century, was also a reaction to previous severe damaging floods.
- The digging of the Nieuwe Merwede and the Bergse Maas (southeast of Rotterdam) in the 19th century can also be considered as a reaction to the many river floods. These artificial by-passes at the downstream end of major rivers have eased flood control considerably.

- The past decade has shown a similar reaction: in 1993 and 1995, the whole country panicked when high water levels occurred in the rivers (frequency: once in 150 years). For years, plans had been made to reinforce the river dikes to withstand surges from the sea, but both government and public opinion were little aware that large river discharges still formed an actual threat to the safety of the country as well. Large polder areas were in serious danger of being flooded, and about 250,000 people had to be evacuated (together with about 1,000,000 cattle) until the high river levels dropped to safer levels. Therefore, after 1995 the river dikes were reinforced at high speed. (Technically, this was not really a "problem," but the legal and administrative aspects required for adequate and successful implementation were illustrative.)
- Excess water due to heavy rainfall in 1998 surprised many people. It was thought that the (discharge) capacity of the waterways and pumping stations were up to all weather conditions. The situation showed that water-logging and even inundation due to heavy rainfall is still a reality, even in the well-drained, economically most important zones.

The last two examples above led, soon afterwards, to the establishment of a State Committee: the so-called Committee for Water Management in the 21st Century. Both events clearly showed how vulnerable The Netherlands still is where water is concerned (which seemingly came as a surprise to the Dutch Government as well). The members of the Committee not only represented professional (umbrella) organizations, such as water boards and flood control agencies, but also respected independent institutions, such as universities and NGOs. This later gave, after an inventory and related studies, the conclusions of the Committee the character of public recognition and good direct media coverage. This, of course, proved to be effective during the subsequent political debate.

In August 2000, the Committee published its proposals to decrease the vulnerability of society to floods and an excess of water. The Committee considered both non-structural and structural measures, including research to be done, to make The Netherlands less vulnerable to high waters at sea and in the rivers and during excessive rainfall. This is the more so important because of expected sea level rise and climate change in the 21st century.

Also characteristic for the history of the Dutch delta area is that situations occurred (sometimes predictable, sometimes completely unexpected) that constituted a real threat to the country's survival, and therefore were a cause for great concern. Sometimes, the technical solution to the problem was known; other times, people did not see a way out, but a technical innovation was then introduced to "save the day" (as *deus ex machina*). Two examples are:

- the unexpected appearance in 1730 of the pile worm, which destroyed the wooden piles and sheet piling that had protected the sea dikes thus far against wave attacks. This threat was considered a very serious one, and everywhere prayer meetings were held to avert this danger. A solution was found in the use of stone facings composed of natural stones and rock from abroad, which had been made feasible thanks to the development of mass transport by ship. Since then, natural stones for revetments are used from quarries everywhere (since the country has a water-saturated soft soil, there are no quarries on its own territory), thereby taking the extra transport cost for granted (''safety'' has first priority in this respect);
- the critical situation that had evolved in the first half of the 19th century with regard to the rise in high water levels of the main rivers, necessitating a constant heightening of dikes, and the insufficient depth of approaches from the sea in harbour basins that necessitated the development of new, stable approach channels from the sea. Both phenomena threatened the physical and economic existence of the country. The introduction in the period 1850–1870 of the steam-driven bucket dredger solved both of these problems. The bucket dredger and other earth moving machines were innovations that heralded a new technical era.

Interventions in water management were not always only a reaction to deal with the consequences of previous interventions. Water management and land reclamation were already being applied to cope with the growing population or to improve the living conditions of the population. Technical innovations (such as the bucket dredger) made new measures for water management possible. Several typical developments and innovations can be mentioned:

- The Dutch had achieved independence from Spanish rulers during a war that lasted 80 years (1568–1648). Later, invaders again and again came over land from the east and the south. An effective way of defending the Dutch territory was the use of land corridors in rural areas that could be temporarily submerged by systems of sluices, spillways along the rivers and lakes, diversion of levees, drains, lakes and reservoirs, etc. These were, first of all, designed and developed by the military. The experience formed a solid basis later on when developing efficient drainage and irrigation systems in the country. Learning and developing ''by trial and error,'' especially based on military experiences through the ages, have determined the skill of the Dutch on water management.
- Efficient flood control has always been essential for the existence and safety of Dutch society. Transport – in particular, shipping – has always been essential for the economic development of Dutch society. Reli-

able flood control is served by stable and single deep main channels, while feasible shipping is also served by stable, deep channels. So, the interests of flood control and shipping are similar. This is exactly the reason that both flood control and shipping are still in one (managing authority) hand.

- The ''discovery'' in 1921 of sufficient deposits of boulder clay nearby, when a start had already been made on constructing the enclosure dam in the Zuiderzee, was a positive surprise. It guaranteed the supply of sufficient adequate material for the further completion of the major enclosure dike (Afsluitdijk, in 1932) and, in addition, for the construction of reliable surrounding dikes for confining the new polders later on.
- A similar unexpected innovation has eased the construction of the Delta Project since the late 1950s. Then, the development of geo-textiles offered a replacement for the traditional technique of applying a thick, willow fascine mattress as an adequate sand filter. In particular, because the existing production fields of willow material in the country could not supply the required quantities if the traditional designs of bank and bottom protection had to be executed, the invention of the geo-textiles ''saved'' the Delta Project. In this respect, it is curious that the political decision to start with the work for this project were taken before the geo-textiles had been invented.
- Originally, the designs of the complex and multi-functional projects of the Zuiderzee Works and the Delta Project had not taken into account the subsequent recreational potential of the areas. The original political decisions to execute the works were based only on economic considerations (rate of return) of, mainly, safety and agriculture. Later on, after completion of the works, recreation became a booming industry. Consequently, the economic figures of the pros and the cons of both projects changed drastically.
- Some decades later, the same thing happened with the aspect of ''nature development'' as a means to achieve more balance between prosperity (economy) and welfare (ecology). Nowadays, the widely accepted concept of ''building with nature'' is based on this approach.
- Other examples, crucial for today's water management issues but not further elaborated here, are the closure of dams with sand supply in tidal waters, beach-nourishment developments, and the integration of long-term spatial planning and economically feasible water infrastructure. The latter, in particular, is related to sea level rise and climate change, but so far it insufficiently takes into account the rapid increase in the value of public and private property behind the flood protection structures/dikes.

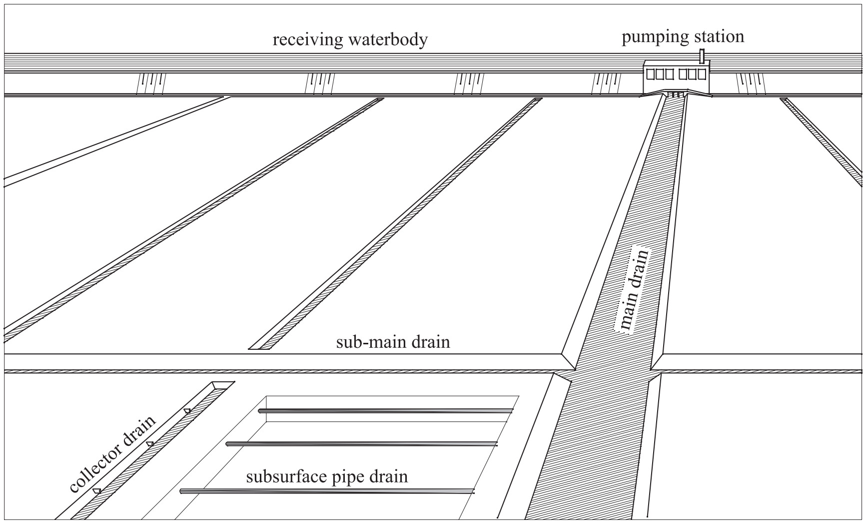

Figure 10.2 A schematic presentation of a drainage system in a Dutch polder

"Dredge, drain, and reclaim": Polders in The Netherlands

The Netherlands' polders have facilities for flood protection (dikes) and drainage. The drainage system, which serves for removing surplus rainwater and seepage water, consists of a field drainage system to control the groundwater table, a main drainage system or hydraulic transport system to flush the water from the field drains to the outlet, and an outlet structure to discharge the water from the area (see figure 10.2). Two categories of drains can be distinguished in the main drainage systems: collector drains and main drains. Collector drains receive the drainage water from field drains and transport it to the main drains. Several flow control structures, like weirs and culverts, may be installed in the main drains. The outlet of the drainage system in the polders may be a drainage sluice or a pumping station. In many cases, local and even regional functioning systems were developed through the ages, mainly by trial and error. In particular, the "errors" always have been important lessons learned. The outcome of some important lessons from practice is presented hereafter.

Discharge of surplus water

The water level at the outlet constitutes the drainage base for the area concerned. This level, relative to the land level, governs the amount of hydraulic head available for the drainage flow, as it determines the extent to which the water levels may be lowered below the land surface. It also determines whether the area can be drained by gravity or requires pumping. Severe wind can occur in the flat Dutch polders, coming from various directions; in some cases, this can hamper effective drainage. Examples are known where old drainage systems, including pumping stations, needed adaptation to achieve better water discharge control in a polder.

In relation to the discharge possibilities, the drainage of the polders can be classified into:

- *tidal drainage* – This applies to the flat areas near the sea. Drainage can take place during low water (ebb tide). Especially during spring and autumn, northwesterly winds can cause relatively high sea water levels, thereby hampering the effective drainage periods;
- *drainage on the main rivers* – In case there is drainage by gravity, this might be restricted during relatively long periods (especially during the spring) due to the occurrence of high river water levels. Such rises in level can last for several days or weeks. Often, in such a period, heavy rainfall occurs; then, additional pumping capacity is needed;
- *drainage on lakes* – This might be hampered during periods when water levels have risen due to wind forces (long fetch, drainage system located on lee shore); and
- *drainage on another polder, or a canal system* – In this case, it is necessary to check the combination of both water management systems.

Most of the polders in The Netherlands were originally reclaimed for agricultural purposes. Only since the recent decades have more and more other forms of land use been developing, such as industry, urban areas, recreation, nature conservation and infrastructure. In many cases, this leads (in terms of water management) to other discharge figures, changing groundwater levels and even subsidence. This implies that the original designs have to be reviewed and adjusted, and that these adaptations will have to continue in the future. This is a typical lesson learned from practice.

As far as the field drainage system is concerned, three principle systems may be distinguished:

- subsurface drain pipes, which are generally applied in clay soils;
- open field drains, which are generally applied in peat soils; and
- collector drains, which are locally applied in sandy clay soils.

Soil ripening and desalinization

Immediately after the emergence of newly reclaimed polders (especially in the case of drained lakes), soils were un-aerated, had a very loose structure and were almost impermeable. In the old reclamation schemes, this has caused a lot of problems for the first farmers. In the IJsselmeerpolders, drainage measures in combination with an adapted crop rotation scheme were taken in the initial stage to promote soil ripening. With open field drains in combination with reeds (and, later, cereals and rapeseed), a first lowering of the groundwater table could be established. In this way, crack formation in the upper clay soils was promoted, which resulted in an enormous increase in permeability. After a few years, when the groundwater table was lowered sufficiently, the open field drains were replaced by subsurface pipe drains, resulting in a further lowering of the groundwater table (Schultz and Verhoeven, 1987).

Originally, most soils in the lower part of The Netherlands contain(ed) brackish groundwater. The subsoil is rather saline, especially in lands gained from the sea and in a number of the drained lakes. With the prevailing climatologic conditions, and by applying an appropriate water management system, desalinization of the topsoil could be achieved within a few years. Two processes contribute to this:

- the permeability of the un-ripened deeper soils is normally very low, whereas the permeability of the ripened top layer is rather high. During winter, there is a rainfall surplus, so salts were quickly washed out from the top layer; and
- the major part of the seepage flows directly to the main drainage system. Because of this, the brackish water generally does not affect the root zone.

Subsidence and sea level rise

After reclamation through impoldering, the soils ripened. This essentially involved an irreversible loss of water and, as a result, the sediments shrunk and settled, leading to a subsidence of the surface. Through the ages, The Netherlands has faced the problem of subsidence in combination with sea level rise. Gravity drainage through sluices became increasingly difficult, even impossible, and remedial measures had to be taken. Due to the subsidence that has taken place, for most of the old polders pumping is nowadays required. In some cases, the water now passes four pumping stations before it is discharged to the sea.

The geological profile in the lower part of The Netherlands can be briefly summarized as a Holocene top layer consisting of clay and/or peat, and a thick (of marine origin, so containing much salt) Pleistocene layer mainly consisting of sand. The thickness of the Holocene top layer can be up to 20 metres. Due to their location below mean sea level, seepage occurs in the deeper polders. Normally, this seepage amounts to less than 1 mm/day.

In the western part of the country, the groundwater is brackish or even saline as a result of transgressions and regressions in the subsoil. Therefore, the seepage water is often brackish. For this reason, the water in the water management systems has to be flushed regularly, for which substantial quantities of freshwater from the river Rhine and the IJsselmeer are used. (The consequence of this is that as long as the Rhine is polluted upstream, that pollution will reach everywhere in the Dutch polders). As an example: In the western part of The Netherlands, the amount of water used during a summer period (partly for supply and partly for flushing) amounts to 650 million m^3, equivalent to a water layer of 290 mm. However, during the summer, this ''foreign'' water is rather poor, thereby posing many water quality problems in the polder.

Water quality

Over a long period, one of the main goals of the water management system in relation to water quality was the prevention of salinization (in particular, as created by saltwater intrusion by sluices, or saline or brackish seepage). From the middle of the 1960s, other water-quality aspects received more emphasis, because of the increased use of water for industry, domestic water supply, recreation and nature reserves, and the simultaneous increase of domestic and industrial wastewater and cooling water. (In fact, ''cooling water'' was the first environmental issue that was discussed internationally in the Rhine basin to develop and achieve international standards and norms at outlets, from the early 1960s.) So the control of both water quantity and quality became required, and such measures such as purification plants, separate sewer systems, and flushing of lakes or canals with water of relatively good quality had to be taken to control and improve the declining water quality (surface water) systems. Since 1992, a large programme has been implemented to clean polluted lake, canal and harbour bottoms.

The restoration of (surface) water quality is very costly. Since the early 1970s, Dutch society has invested about three times more money than for execution of all the works in the Delta Project together, and these expenses will continue. The lesson learned is that the restoration of a severely polluted water system is extremely expensive, much more so than the development and maintenance of a regular flood control system.

Water management policy in The Netherlands (1960–2000)

The way that water policy, widely accepted on national political level, has developed in The Netherlands is an illustrative example of a lesson learned. Some essentials will be summarized.

In 1968, the *First National Policy Document on Water Management* was published. It concentrated mainly on the item: "water managers should cover the enormous water need of the future for agriculture, for flushing of salt, for drinking water and for other purposes." This was a prudent start of what later would become a revised policy for integrated water management. It was foreseen that a regular updating of the water policy on a nationwide scale would follow. At the time preparations started for a first updating, a severe drought occurred (in 1976).

The water situation, with problems of salinization and pollution on the one hand, and an increasing demand for drinking, irrigation, cooling and processing water on the other, made it necessary to pay special attention to the main water infrastructure. Especially, problems with water quantity and quality during the extremely dry summer of 1976 led to increasing research on well-balanced distribution with widely accepted priorities of water on a nationwide scale. An intense study, the Policy Analysis of Water Management in The Netherlands (PAWN), was undertaken. It was a typical example of important lessons learned during a severe drought in a growing season. The primary objectives of this (€15 million) study were:

- to develop a methodology for assessing the multiple consequences of water policies, and
- to develop various water management policies, compare their consequences, and create a capability in The Netherlands for further analyses.

The *Second National Policy Document on Water Management* (1984) was supported by the policy analysis as developed by PAWN. This document was based on the cost-benefit relation of water development and the multiple uses of water. The document elaborated on the need for water, taking into account the uses of surface water and groundwater.

The *Third National Policy Document on Water Management* (1989) was based on "integrated water management"; it related groundwater with surface water, and water quantity with water quality. Water systems were identified, and the document specified that "the water systems have to be managed and developed so that they satisfy their ecological objectives and functions." It was the first time that natural developments in floodplains were supported, and even stimulated, by a nationwide policy document.

The *Fourth National Policy Document on Water Management* (1997) took the different water systems, both fresh and salt, as the basis for decision-making. It therefore went one step further than the Third Policy Document, in that it also elaborated (in attachments) on the quality norms of numerous polluting elements in surface waters. This was earlier developed step-by-step (every five years) in intermittent sets of indicative quality norms, as developed by independent research institutions and accepted by Parliament.

Water management in The Netherlands in the 21st century

Considering all these lessons learned, what will the near future bring?

Originally, water management in The Netherlands was focused on water quantity control – or, to describe it more precisely, on water level control. However, already at early stages, the problem of salt water intrusion from the sea was perceived as a threat, and activities, such as the damming of river mouths, were implemented to reduce this problem. During the second half of the 20th century, attention became more-and-more focused on water quality control, due to pollution from various sources.

The Netherlands must now focus on integrated water management, which is the current "hot issue"; all attention is given to this approach. During the past decades, the whole legal and organizational structure has been reorganized and modernized, anticipating on this approach. One can expect that this will not be the last sentence of the "Dutch water story." Discussions are already going on to develop an approach based on "environmental management," which basically means that the various types of planning and development approaches (like water management, spatial planning and nature conservation) are developed in an integrated way. Of course, where this will end in the future cannot now be foreseen.

Water management in The Netherlands will possibly also have to be adjusted as a result of provisions that are needed because of, for example:

- an accelerated rise in the sea level due to climate change,
- additional and related interventions in the regimes of surface water and groundwater, and
- a large-scale use of underground construction.

Perhaps the biggest setback will be caused by a natural element that has so often been misjudged in Dutch history: namely, severe sea storm surges or extreme river floods. Among the present inhabitants of the low part of The Netherlands, the feeling prevails – just as it did over fifty years ago (before the disaster that occurred in 1953) – that the problem of safety from sea floods has been solved now that the normative storm surge has been determined at 1.15 metres higher than the 1953 storm surge at Hook of Holland (the approach along the western coastline to Rotterdam harbour). The return period of this normative storm surge is 10,000 years. However, it can be concluded from the delta report that a storm surge 2 to 3 metres higher than the 1953 storm surge (and so 1 to

2 metres higher than the storm surge that determines the height and the strength of the present primary defence line against the sea) is physically conceivable.

Another shock was the flood in the main rivers in 1995, which only had a return period of about 150 years. The Dutch have raised the river dikes up to a return period of 1,250 years. Although river floods can be better forecasted than sea floods, thus reducing the risk of loss of human lives, the damage to urban and industrial areas in the river polders would be enormous if one of the main dikes should fail. This is more serious in the western part of the country, where the majority of the population lives and the most intensive economic production is generated. Most of the western part lies under mean sea level – in some densely populated places, even more than 6 metres below sea level. Even after the recent dike reinforcement projects that now almost have been completed, it is not inconceivable that a flood disaster will occur in the river area, the more so because climate change has tended to increase peak flows in the European river basins.

The non-occurrence of critical storm surges and/or river surges also may lead to misjudgements. History teaches that experiences with rare events are not, or are seldom, passed on; after one or two generations, people tend to forget about a disaster or ignore reality in the face of other urgent problems. This is also a lesson learned – unfortunately, not a typical Dutch lesson, but a universal one.

Whether the Dutch people really accept the fact that these disasters may actually happen is questionable. For the near future, problems need to be solved in relation to the expected sea level rise, for which scenarios have been developed. Financially, an accelerated rise in the sea level naturally means a setback, though not so acute as is generally assumed. If a rise of 0.7 metres over a period of 100 years is assumed, which is on the high side of the most recent estimates, the necessary provisions with regard to safety, drainage, urban areas and so on would cost about €16 billion (US$16.5 billion). This amounts to not more than 0.5 per cent of The Netherland's Gross National Product, provided that the expenditure can be spread over a period of one hundred years.

Even with a "maximum scenario" of 5 metres in 300 years, expenditures for hydraulic and other works will be minor if compared to present expenditures in society for such sectors as social services, education and defence. In addition, it should be kept in mind that these estimates are based on the existing technology, whereas it may be assumed that in the future it will be feasible to build more cheaply, thanks to the availability of new technology (such as, perhaps, cheap acceptable nuclear energy) or at least light building materials (and, most probably, synthetic materials) for the facing of dikes and others.

Of course, some experts do realize the prospects, but the problem is how to communicate the message (indeed, in some cases, a doom scenario) to the population. As is often the case, politicians will sooner listen to loud voices from NGOs and the media than to advice coming from a small group of scientists and water decision-making experts. In this respect, the situation in The Netherlands does not deviate from usual situations elsewhere in the world.

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11

Irrigation design in the Netherlands East Indies: The Tjipoenegara system in West Java

Maurits Ertsen

Irrigation technology has been an important factor in the expansion of the sawah (rice field) area in Indonesia, with the population acquiring the technology of wet rice cultivation over centuries. A colonial irrigation technology developed over time, but at the beginning of the 20th century, when colonial irrigation engineers had established the beginnings of a systematic approach to irrigation design, many engineers admired their pioneering colleagues but criticized the way they had to work: lack of maps, money and data such as hydrological information.

From about 1800 until about 1885, the Dutch engineers usually designed the main structures (weirs in rivers and feeder canals) and connected them to existing irrigation systems. From about 1885, complete irrigation schemes were planned. Extensive research preceded the building of these systems, which included networks of distribution canals as well as major structures. This systematic approach was well established in the 1930s, and the period between 1885 and 1930 can be considered as the learning trajectory for the actors involved (Ertsen, 2002a and 2002b).

The period between 1920 and 1930 can be considered as a turning point between the period of gaining design experience and the period of scientific design approaches. This chapter focuses on that period; it is built around a case study of irrigation system design in the Netherlands East Indies, the Tjipoenegara irrigation system (in modern Indonesia, known as the PSAPB Citarum, from the Cipunegara River; see figure 11.1). This system was designed and constructed between 1922 and 1938[i]. Additional cases will be used to illustrate the main case study.

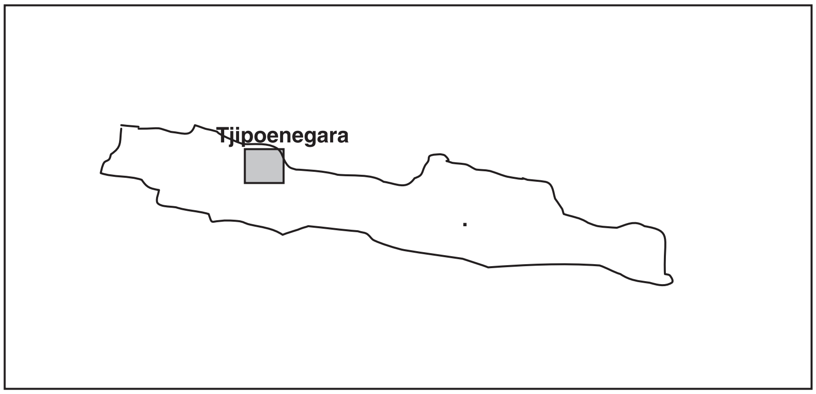

Figure 11.1 Location of the Tjipoenegara area

Irrigation design in the Tjipoenegara area

Irrigation systems were (and are) constructed to achieve certain goals; they are the material translation of production and water management arrangements (Ertsen, 2002c). The irrigation systems in the East Indies had to irrigate both sugar cane and peasant crops, mainly rice. The two crops were present in the same irrigation systems, and water was distributed separately in time through the same canal system. Therefore, water distribution methods were designed to divide (distribute and measure) the water in a just way. At the same time, though, water management should maximize the economic profit of irrigation water per unit of land.

There was no disagreement on these guiding principles, but this was not the case for the actual shape of water management. After a period of discussions (concentrated around the turn of the 19th century), a centralized water management system developed, with engineers in charge (Ertsen, 2002c). Although the position of the engineers was never uncontested, their position in water management was strong, and it was within the group of engineers that the physical shape of water distribution systems and structures was determined.

The Tjipoenegara River has a catchment of about 1,500 square kilometres and a length of approximately 100 kilometres. As with many Javanese rivers, it has mountainous headwater regions and an extended coastal plain. The irrigation system was developed under the responsibility of the Department of Public Works, but the actual design and construction activities were executed and managed by N.V. Ingenieurs Maatschap "Eigen Beheer." This was not common; usually, the department developed systems themselves. Nevertheless, the Tjipoenegara area is highly suitable to represent the process of irrigation system design in the Netherlands East Indies.

In a letter dated 27 December 1922, Maatschap presented to the Director of Public Works a design to construct a water diversion structure in the Tjipoenegara River. On 2 December 1927, the intake construction (named Salamderma) was officially opened. Although the canal system was far from complete, water diverted from the Tjipoenegara could be brought to the existing Javanese water reservoir of Andjatan to irrigate about 5,000 bouws (1 bouw equals 0.7 hectare) during the 1927/1928 West Monsoon.

When starting the research and preliminary design activities, the engineers of Maatschap encountered what they called ''un-reclaimed terrain.'' The irrigated areas, if present, were rain-fed rather than irrigated. Although local water reservoirs (sitoes) were present, filling of these sitoes, and thus irrigation, was irregular. Drainage in the area also left much to be desired. The area was flat, as in most locations on Java's north coast. Occasionally, drainage canals were blocked to be able to bring water to fields nearby. Large terrains changed into swamps in rainy periods, and many swampy areas fell dry only in dry East Monsoon periods. Frequent inundations were a cause of lower harvests, but harvest losses as a consequence of water scarcity were considered much more important.

The lands were considered a colonization area, so the project had to bring new living opportunities for immigrants. The fact that the area was not densely populated probably accounts for the fact that, especially in the first years, the progress of the work remained behind schedule due to a lack of workers.

Governmental and private lands

The largest part of the Tjipoenegara irrigation system was a governmental area located east of the river, with a smaller part west of the Tjipoenegara. Most of this western area had been private property – the Pamenoekan and Tjiassem (P&T) Lands, which was the largest privately owned area in Java (Daukes, 1943). Originally, the lands were two properties, but they were brought together in an intriguing process of ownership changes between 1816 and 1900. In 1910, despite occasional discussions to bring the P&T Lands back under government property, the lands were sold to the Anglo-Dutch Java United Plantations Ltd. for 7 million guilders.

Then, on 26 June 1914, the Government issued a decree that they intended to resume ownership of part of the P&T Lands. In 1914, a committee was installed, which started in 1916 to value the property and propose an arrangement. Finally, the committee proposed to bring some 200,000 bouws of the P&T Lands under government control. When, in 1922, the Government announced plans to construct the Tjipoenegara irrigation system, it was agreed that the P&T Company would participate in the project; it would pay a share towards the expense of the dam, and in exchange could irrigate part of its lands within the new scheme, up to some 15,000 bouws.

For a time, when the system was not yet completed, the company had to pay annually a share of the development costs. The erection of the dam took some years, but the company could not proceed with its part of the work until the dam was completed. With the completion of the dam, however, development of the P&T Lands became imperative. The contract with the government required the company to put the entire area under irrigation within a certain number of years after the dam's completion; otherwise, it would forfeit the right to the water for the incompleted area (Doukes, 1943).

In 1940, the estate counted some 22,000 acres of paddy. Although the P&T Lands played a significant role in the general development history of the Tjipoenegara area, its influence on the design of the modern irrigation system was not as significant. Its irrigated area was separated from the main irrigated area, and the P&T Lands were supposed to develop their own area. Only the company's plans to hire land to grow sugar cane in the governmental lands would prove to be of importance.

Design issues in the Netherlands East Indies

In the main governmental area, Dutch engineers designed a system according to the standards expected in the Netherlands East Indies of those days. With the main design activities taking place in the 1920s and early 1930s, the Tjipoenegara design process could incorporate experiences and lessons from earlier designs. The design reports, written by Maatschap and presented to the Department of Public Works, regularly mention that the design was made "in accordance with" the Krawang works, which are located immediately to the west of the Tjipoenegara area. The Krawang works (with a total irrigable surface of more than 100,000 bouws) were opened officially in 1925, when the main intake and part of the main system were ready. Completion of the works took until 1936.

The Krawang works were not the first large system on Java to be designed "from scratch," with the necessity to handle a large number of issues simultaneously. Some 50 years before, around 1870, it was engineer Van Houten who seems to deserve the credit for being the first

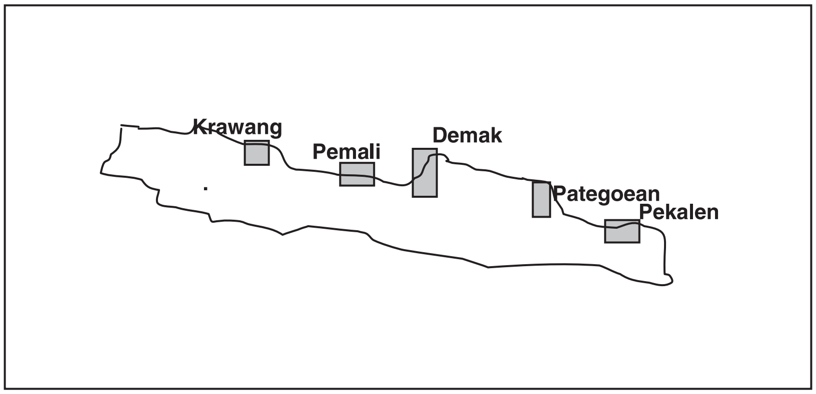

Figure 11.2 Location of Javanese irrigation schemes mentioned in the text

Dutch engineer to design a complete irrigation system based on extensive research (in the Demak area). Nevertheless, it is engineer Lamminga who is credited with being the one to establish the ‘‘integrated’’ approach with his designs of the Pekalen and Pemali irrigation schemes around 1890. (See figure 11.2.)

Lamminga himself gives all the credit to the so-called Irrigation Brigade. This institution was established in 1885, together with a new governmental regulation that restructured the Department of Public Works. The Irrigation Brigade, part of the department, had the task of conducting preparatory studies for the development of modern irrigation of all governmental areas. After some years, the Brigade itself merged with other units of the department, but its work was incorporated in the General Irrigation Plan for Java in 1890.

When the Irrigation Brigade was established, Lamminga was working in the Pekalen area. He had started his activities in the area as an employee of the Regional Public Works Service, but while awaiting the establishment of the Irrigation Brigade he was put under direct command of the Director of Public Works. Designing complete irrigation systems, taking into account several issues simultaneously, using an integrated approach – these terms do not necessarily mean that an irrigation system had to exist completely on paper before it could be constructed. A ‘‘complete irrigation system’’ was divided into smaller units (like intake structures or canals) or issues (water requirements or layout). Earlier, more general designs of the main system were setting the context for later designs of secondary and tertiary areas, and occasionally later designs influenced an earlier design outcome during construction. (See table 11.1.)

An integrated approach did not necessarily mean, either, that the fu-

Table 11.1 Design documents of the Tjomal/Tjatjaban area, Pemali

Year	Date	Description	Remarks
1895	October	1st part presenting an overview of the expected economic and financial effects of the construction of irrigation works in the region mentioned. Annexes (all dated August 1895): Overview of the surfaces of the lands and their agriculture, per dessa, located within the irrigation area Tjomal – Waloeh – Ramboet; according to the data of the cadastral bureau in Tegal; Overview of the land tax, which is currently paid by the dessas located within the irrigation area Tjomal – Waloeh – Ramboet; according to the land tax sheets of 1894 for the Department Pamalang and for end of 1895 for the Department Tegal; Overview of the transcribed land tax, during the years 1885 to 1894, of the assessment of the dessas, located within the irrigation area Tjomal – Waloeh – Ramboet; according to the statements of the Controllers of Pamalang, Tegal and Protjol.	Lamminga is engineer 2d class.
1896	April	2d part presenting the general plan with road trenches and the longitudinal- and cross-sections of the main canals.	
	August	3d part presenting the designs of the prises d'eau at Sokorvatie, Tjipero, Kedjeneh and the changes made in the structure at Soengapan.	

Table 11.1 (cont.)

Year	Date	Description	Remarks
	25 September	5th part presenting the design to prepare the kali Tengah for draining the bandjirs (flash floods) of the Waloeh; and further the designs of the bridges over these rivers in the Postweg and in the road along the main canals and the bridge over the Ramboet in last-mentioned road.	Apparently not chronological.
	8 December	6th part, detailed designs of the irrigation.	Lamminga is now engineer 1st class. Apparently not chronological.
1897	March	4th part, structures in the main canal.	Apparently not chronological.
	May	7th part, drainage canals.	

(author: Lamminga)

ture management of the system was included during the design of the irrigation infrastructure. As Lamminga himself notes: "When at the end of 1893 the Pekalen works were completed, a detailed constructed technical network of canals and structures was available; that this alone, however, was not sufficient, became clear with the rice harvest of 1894, which at many locations was far from magnificent. This was caused by the total lack of order with planting; there have been cases in which in the same tertiary unit harvest took place and close by planting took place" (Lamminga, 1905).[ii] Elsewhere, he refers to the absence of a relation between design and management, when he states that if water management arrangements are necessary, "this is possible; the arrangements of the works are such that with them any desired water distribution can be achieved" (Lamminga, 1910).[iii] Therefore, it remains to be seen if it is correct to suggest that, as in the Pekalen area, Lamminga anticipated future water management arrangements when designing the Pemali system (Ravesteijn, 2002).

What Lamminga (and his predecessors) did anticipate was the possibility to measure and regulate all flows in the system,[iv] and a co-existence of sugar cane and rice in the irrigated area, which influenced the canal capacities. This second issue will be discussed in the remaining part of this chapter. First, the relationship between water availability and the command area will be examined; the potential occurrence of sugar cane appears to be one of the determining factors. Sugar cane pops up again when the method to determine the capacities of the irrigation infrastructure in the Tjipoenegara area is discussed. An issue linking the command area and canal capacities is the layout of the system.

Command area

Originally, in first discussions on the system, a non-movable intake structure was planned close to the confluence of the Tjilamatang and Tjipoenegara rivers. In 1921, however, the Head of the Irrigation Department, Tjimanoek, proposed to select a location more north, being closer to the irrigated area, thus avoiding the expensive crossing with the railway and allowing for easier sediment flushing. Maatschap proposed a movable weir to the Director of Public Works, to avoid potential problems with high water levels during floods.

After some discussion, the Department of Public Works approved a non-movable intake weir about 6 km downstream from the existing railway bridge. For reasons of flushing, the final location of the intake was selected at 5,315 metres downstream from the bridge. The advantage of the new location was that the main canal could be made considerably shorter, but it also meant that the border of the command area had to be moved somewhat to the north. This proved to be no problem, however, since there was plenty of available land, and it was still possible to locate the main distribution structure at the most favourable location close to the desa Boegis.

One of the accompanying reports included with the letter of December 1922 of N.V. Ingenieurs Maatschap "Eigen Beheer" to the Head of Public Works dealt with the potential command area in the Tjipoenegara region. (See figure 11.3.) From measurements of the Tjipoenegara discharges between 1916 and 1921, it was deduced that the mean available West Monsoon discharge would be about 40 m^3/s. As the main irrigation season on Java was the wet West Monsoon, the command area was based on the water requirement for that period. From this amount, 30 per cent (about 12 m^3/s) was to be available for irrigating the P&T Lands.

Based on this preliminary assessment, it was proposed that the total irrigated area would be 56,250 bouws gross with surface irrigation. The irrigated area was to be divided into four secondary units, each supplied with its own canal originating from the main division structure, Boegis. The Boegis structure would also supply a few tertiary canals directly with water. When the location of the intake was finally decided upon, other measuring structures in Boegis than planned were selected, resulting in a lower head loss and, thus, a larger command area. A final plan reset the command area of the respective canals. (See table 11.2.)

The available flow in the West monsoon was 40 m^3/s, of which 4 m^3/s was to be pumped out of the Tjipoenegara, to irrigate Block 26 of the P&T Lands. For one bouw net irrigation, 0.8 l/s was set as needed. With 20% of the surface used for kampongs and other infrastructure, 36 m^3/s allows an irrigated gross area of (36 * 1000) / (0.8 * 0.8) = 56,250 bouws. With a main canal as much to the south as was considered possible, land availability would be about 64,000 bouws gross. If the main canal would be located to the north, allowing a number of natural watercourses to pass the canal to be designed would be easier and cheaper. This diminished the gross available area by 4300 bouws, leaving some 3500 bouws too many. Not irrigating lower parts near the sea saved 1575 bouws in Cheribon, and 1972 bouws in Batavia. This brought the gross area at 56,250 bouws, to be divided as:

Block 28 of the T&P Lands	13,933 bouws
Tjigoegoer	2,360
Pamanoekan	3,182
I. Total for the Pamanoekan canal	19,475 bouws
II. Soekra canal	8,011
III. Andjatan canal	8,367
IV. Kadanghaoer canal	20,937
Total gross area	**56,250 bouws**

Head losses of the measuring devices in the main distribution structure Boegis decreased the irrigable area. Irrigating 684 bouws directly from the main distribution structure, that is to feed the tertiary canals directly from it, compensated for this.

Figure 11.3 Tjipoenegara irrigation command area in the 1922 design document

Table 11.2 Final command area of the Tjipoenegara irrigation system

Secondary command area	Surface (bouws) (1 bouw = 0.7 hectare)
Pamenoekan canal	13,933
Soekra canal	11,547
Andjatan canal	9,086
Kandanghaoer canal	24,414
Directly irrigated from Boegis (main distribution structure)	707
Total	59,687
→ Added to this an area, which was to be irrigated from a diversion on the left bank with a surface of	4,310
→ And an area, which was to be irrigated by pumping water to irrigate an area on the left bank with a surface of	3,560
Together	67,557

Based on the total area of 67,557 bouws, the net irrigable area still had to be determined. A standard approximation in the East Indies was that 20 per cent of the gross area had to be used in the future for the realization of villages, roads, canals, etc. This would result in a net irrigable area of 54,046 bouws in total, which had to be irrigated with the 40 m^3/s West Monsoon discharge of the Tjipoenegara. This resulted in an available discharge of 0.74 l/b/s for the whole net area. It was assumed, however, that after the irrigation system would be completed and used for some years, up to 20 per cent of the area would be used for sugar cane cultivation. Sugar cane did not need irrigation water in the West Monsoon, thus allowing the design engineers to increase the theoretical water availability for the other main crop, rice, to 0.935 l/b/s, which was close to the standard 1 l/b/s used in most Javanese systems.

Layout

Three related aspects concerning the layout had to be solved by the designers:

- the size and, thus, number of tertiary (and other) units;
- the shape of the units; and
- the number and route of the canals supplying the water to the units.

As a rule, a tertiary unit was supposed to have a single intake (or off-take, depending on the perspective one takes) as this facilitated clear water management. A basic idea of Dutch water management was to give the responsibility of water management within the tertiary unit to the farming population itself, with the governmental agency responsible for bringing the water to the unit. Within such a system of shared responsibilities, multiple water intakes for a single unit were considered to disturb clear management (Van Maanen, 1931). Size did matter in this context: distributing water to individual users would imply a too-detailed canal network to be managed by the governmental officials together with high distribution losses, whereas distributing water to too many users would undermine the capacities of the farmers to manage water themselves. A balance was not easily found. The first irrigation systems constructed occasionally included tertiary units up to 500 or 600 bouws.

In the 1880s, sizes of units were decreased considerably. Especially in the Pategoean system (see figure 11.2), tertiary units were designed to be extremely small. In a first area (designed in 1886), tertiary units varied between 20 and 153 bouws. A second area was 86 bouws, divided into 15 tertiary units because of topographical circumstances. An area designed in 1890 was divided into tertiary units of about 25 bouws. The Pategoean irrigation system was managed with the idea that most of the water distribution tasks and responsibilities were to be given to the cultivators. Providing them with a system of smaller units would enhance the manageability of the system, and thus decrease water use. This was not the case, however, as the water demand in such small units fluctuates strongly, resulting in relatively high peak demands. Furthermore, dividing the available water into smaller portions increases the relative water losses.

A balance was found in an optimal size of approximately 200 bouws net, again mainly based on Pemali experiences. In the 1920s, the optimal size was decreased to 150 bouws for agricultural reasons, as the water could then be brought to the field directly from the canal and not through other fields. For economic reasons, sometimes the tertiary units were made larger than 150 bouws, especially in flat areas, but in the Tjipoenegara area the 150 bouws net norm was the guideline in the design process. For example, one area of 6,518 bouws counted 49 tertiary units, giving a mean unit size of 133 bouws; another area counted 20 units with an average size of 150 bouws, with units between 223 and 99 bouws. The final layout of the units depended, most importantly, on the topographical circumstances. Borders of villages (desas) were used, if possible, to divide between tertiary units, but as desa borders usually did not fit with the circumstances of the natural terrain, they were not that important (Van Maanen, 1931). The shape of units was a point of consideration. Relatively long and narrow units had their positive side, as water could be brought directly from the canals to the field.

A negative aspect was the length of the canal itself, which could result in water scarcity for the tail-end sawahs. Thus, the potential of unequal distribution between head and tail due to socio-economic differences between head and tail users was recognized and used as an argument to decrease the length of tertiary units. Another disadvantage of long and narrow units was the potential of higher water loss, as non-used water could flow easily into the drainage canals without possibilities to be used in another field. All in all, tertiary units with square-like shapes were preferred, because water losses and tail problems were less.

The puzzle of finding a suitable layout is recognizable in the Tjipoenegara area, too. In the documents dealing with the layout of units, it is mentioned that the layout was made in accordance with the views of Chief Engineer ir. J.R. Gaade, head of the irrigation works of Krawang Residency at the time. Those views apparently were written in a letter in 1929, directed to the Director of Public Works. The layout was complicated by the erratic course of the streams intersecting the area and the existing conduits, which was occasionally cause for a somewhat irregular layout. Tertiary or secondary drainage canals usually formed the borders of the tertiary units.

Capacity of the canal system

With the layout of the system determined, the dimensions of the canal network could be taken into account. Two issues played an important role. First, the water carrying capacity of each canal has to be specified. Second, when each canal had a known flow capacity, the physical dimensions (width, height, water depth and so on) of the canals could be calculated.

The capacity of the canal system was determined based on the water requirement for the West Monsoon. How much water should be transported to what amount of land surface was the basic question. Statistically, necessary canal discharge capacities are lower for larger surfaces than for smaller areas, expressed in litres per time unit per surface unit (litre/second/bouw, or l/s/b, in the East Indies). Two general reasons for this phenomenon are that in larger areas peak water requirements are spread, and do not occur simultaneously on all the fields. Furthermore, in a smaller area water flows more easily in the drainage canals, resulting in relatively higher surface water losses. The question is, of course, how much ''larger'' and ''smaller'' is.

In the case of colonial Java, two more arguments determined the relative capacity for canals. First, Dutch colonial water management arrangements were based on rotational irrigation, meaning that the available flow was concentrated on smaller areas and not proportionally spread over the entire area. Therefore, the relative canal capacity for smaller areas needed to be increased further. Second, sugar cane, present in most irrigation systems designed by Dutch engineers, did not need irrigation water in the West Monsoon season. This would mean a decrease of the canal capacity for the overall command area.

Statistically, however, it was very well possible that in smaller areas sugar cane was not present, whereas in larger areas it had a high chance of being grown. Thus, canal capacity for larger areas could be decreased, but for smaller areas this was not possible. This issue – the presence of sugar cane – was considered to be valid even in situations where sugar cane had not become important yet. With a well-functioning irrigation system, investors would be encouraged to start sugar factories, which in turn would lead to more sugar cane in the system and thus, finally, to lower water demands (Van Maanen, 1931).

Capacity curves

In the Netherlands East Indies, all these considerations resulted in so-called capacity curves: graphical representations of the relation between the command area and the relative capacity needed. The first capacity curves were rather crude estimations, but they developed into quite sophisticated and detailed tools for irrigation design. A short overview of the development of capacity curves in the Pategoean irrigation system is illustrative of this process.

In 1889, when the first irrigation areas in the Pategoean system were designed, the starting point for determining canal capacities was that generally 1.5 l/b/s was sufficient (a figure based on experience). Occasionally, however (during soil preparation, for example), a larger amount of water was necessary. All this was covered by giving the large secondary canals a capacity of 1.5 l/s/b, the smaller secondary canals a capacity of 3.0 l/s/b and the tertiary canals a capacity of 6.0 l/s/b. Unfortunately, ''larger'' and ''smaller'' were not quantified. The crude estimation in 1890 was that a total area of 1,090 bouws received water at a rate of 1.5 l/s/b, whereas areas of up to 25 bouws received a maximum flow of 3.0 l/s/b. For areas between 25 and 1,090 bouws, the capacity was ''gradually decreased'' to 1.5 l/s/b.

In 1891, the capacities were remodelled again. For larger areas, with the eye on sugar cane cultivation, a capacity of 1.5 l/s/b was considered too high. Therefore, it was assumed that for indefinite terrains, the capacity had to be 1.2 l/s/b, for 1,000 bouws it would become 1.5 l/s/b, and for 25 bouws 3.0 l/s/b. With these figures, a hyperbolic curve was constructed, enabling the determination of the capacity needed for every area: a real capacity curve (figure 11.4). Later in 1891, the curve was adapted. It was assumed that instead of 1,000 bouws, the capacity of 1.5 l/s/b was already achieved in areas of 500 bouws.

In other areas, similar capacity curves have been developed (such as the Bedadoeng curve in Irrigation Department Pekalen-Sampean), but again the Pemali system design of Lamminga set the standard. The Pemali curve is still part of the irrigation course at Delft University of Technology. The Pemali curve served as a reference curve, which had to be adapted to the specific region depending on soil, topography, etcetera (Van Maanem, 1931).

The difference between the area under study and the Pemali reference was accounted for by a coefficient *a*. The Pemali curve is based on a mean water requirement of 1.0 l/s/b for a standard unit of 200 bouws. It was assumed that about 20 per cent of the total irrigable area – that is, of the whole irrigation system – would not be irrigated during the West Monsoon. Furthermore, it was assumed that this 20 per cent reduction would be fully noticeable at a scale of 1,000 bouws. Units of 1,000 bouws, therefore, had to receive 0.8 l/s/b. (The Pemali curve is shown in figure 11.5.)

The Tjipoenegara area was considered to be an empty area – at least, empty enough to assume that the gross irrigable surface had to be de-

Bouws	L/s/b	Bouws	L/s/b
1	About 3.75	140	2.25
7	About 3.5	240	About 2
15	About 3.25	450	About 1.75
25	3	1000	1.5
50	2.75	1600	About 1.4
90	About 2.5	3500	About 1.2

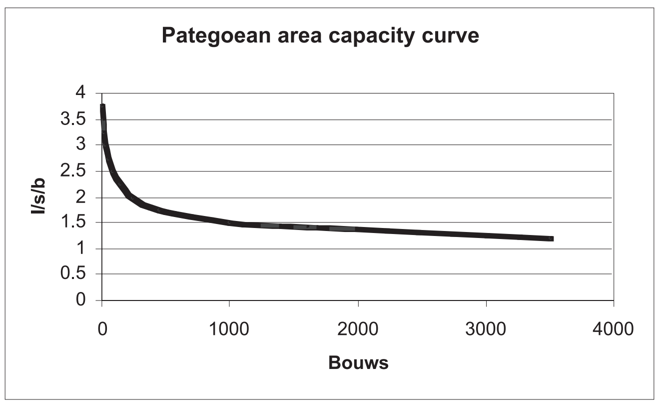

Figure 11.4 Capacity curve of the Pategoean irrigation area

creased by 20 per cent, as canals, roads, villages and other infrastructure had to be realized. Furthermore, 1,000 bouws of net irrigable area should receive 800 l/s, as in the Pemali example; if the irrigation system would function for more years, some 20 per cent would have been used for sugar cane cultivation and sugar factories. Thus, in the longer run, an area of 1,000 bouws would contain 800 bouws needing irrigation, which would receive 1.0 l/s/b. Together, these percentages meant that, in the end, 64 per cent of the gross area would be covered by sawahs, which would receive the well-known 1.0 l/s/b. As a consequence of an extension of the area, water availability per 1,000 bouws decreased from 640 l/s to only 592 l/s, meaning 0.935 l/s/b of sawah.

How were these basic figures translated into a capacity curve?

Step 1: A first assumption was that an area of 5,000 bouws net was the mean, standard area. This 5000 bouw net was translated into $5000 * 1.05 = 5250$ bouws gross, of which 64 per cent was covered with sawahs, giv-

Pemali

Bouws	*L/s/b*	*Bouws*	*L/s/b*
0	3	100	1.25
10	2.5	200	1
25	2	1000	0.8
50	1.6	> 1000	0.8

Tjipoenegara

Bouws	*L/s/b*	*Bouws*	*L/s/b*
0	2.8	100	1.15
10	2.3	200	0.935
25	1.85	1000	0.74
50	1.5	> 1000	0.74

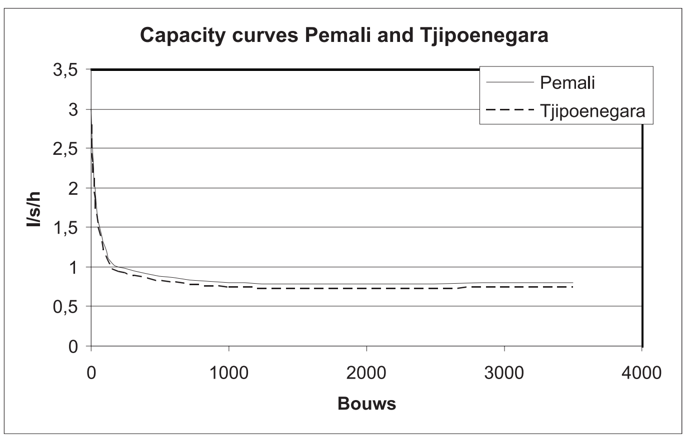

Figure 11.5 Capacity curve in the Pemali and Tjipoenegara irrigation systems

ing 3,350 bouws of sawah. An area of 5,250 bouw gross had to receive water at the rate of $3350/5250 * 0.935 = 0.6$ l/s/b.

Step 2: Units of 200 bouws were counted as if the area needed the standard amount of water per bouw, 0.935 l/s/s. A canal to such a unit would have a capacity of $200 * 0.935 = 187$ l/s. Note that the 200 bouws standard unit is similar to the Pemali reference. In the Tjipoenegara system, however, the standard capacity was 0.935 l/s/b, which means that coefficient *a* was 0.935. Note, as well, that the coefficient *a* has not been determined taking into account soil type or topography. Coefficient *a* is actually less than 1.0 due to increases in the irrigable area during the design process.

Step 3: Units smaller than 200 bouws needed more water, which was accounted for using the Pemali curve, taking into account the value of *a*. The Pemali curve was also used for the area between 200 and 1,000 bouws.

Step 4: From 1,000 bouws, the curve continued as a straight line until the value at 5,000 bouws net was reached (0.6 l/s/b).

Step 5: Leaking losses were set at 10 per cent, decreasing water availability by 10 per cent. Coefficient *a* thus became 0.842, resulting in a water need for 5,000 bouws net of 2,820 l/s.

The final capacity curve – that is, the final one proposed by the designers in January 1926 – had the same shape as the Pemali curve until 1,000 bouws with a coefficient $a = 0.842$; from 1,000 bouws, a straight line was drawn to the 0.564 l/s/b for areas of 5,000 bouws and more. The Head of Irrigation Works of Krawang Residency, however, amended the proposed curve. The resulting new capacity curve, and the one used throughout the design process, was similar to the Pemali curve, with a required capacity for areas of 1,000 bouws net or more of 0.74 l/b/s, and for areas of 200 bouws net a capacity of 0.935 l/b/s. Coefficient *a* was set at 0.925 after all. The final curve, quite similar to the Pemali curve, is shown in figure 11.5.

Concluding remarks

The colonial irrigation systems on Java were built to irrigate both sugar and rice, using the same canal system. In the first systems designed (or re-designed, as many of the first Dutch systems were modifications of existing Javanese systems), sugar cane and rice were already present. In a system such as that in the Tjipoenegara area – an ‘‘empty’’ area – a stable cropping pattern had yet to establish itself. Nevertheless, the presence of sugar cane was taken for granted, and had become something like a ‘‘design mantra’’ or major design rule.

The P&T Company had plans at that time to ask for a sugar concession in the governmental area, for an area of some 7,000 bouws of sugar cane, about 15 per cent of this area. Together with the infrastructure needed for sugar factories and extra roads, the 20 per cent norm used in the command area calculations was in sight. Nevertheless, the assumption for sugar cane to develop according to the standard 20 per cent could be considered a risk, as the Tjipoenegara area was not particularly suited to sugar cane. It is pretty much on the outer western border of the Javanese island suitable for sugar cane (Daukes, 1943), and the P&T Lands never successfully developed either sugar cane cultivation or factories. The economic crisis of the 1930s, with dropping prices for sugar, made sugar cane cultivation even more unattractive. In short, sugar cane cultivation in the Tjipoenegara area never prospered.

One could argue that one of the key design rules in the Netherlands East Indies had found its geographic and economic limits. Reasoning along the same line, in its turn the key design rule has set a limit for the functioning of the irrigation systems nowadays. ''Further increases in the productivity of the land require multiple cropping [*of rice*], and this in turn necessitates an irrigation system which can store water during periods of heavy rainfall and deliver it during the dry months.... The irrigation systems in Java were designed to control the flow of rainfall and rivers in the interests of sugar cultivation, not to store water for rice'' (Alexander and Alexander, 1978).

Although the above statement might be true in general, it seems to miss the crucial point for Java. The Dutch engineers certainly have realized the need for storage, and they have built a number of reservoirs. The crucial point not detected is the capacity of the larger canals – which had been designed for a mixed cropping pattern of sugar cane and rice in the West Monsoon, thus being lower than would have been necessary when monocropping rice in the West Monsoon (the main cropping pattern in modern Indonesia) – would have been considered.

Notes

i. This paper is partly based on design reports for the Tjipoenegara irrigation system available at the National Archives (The Hague, the Netherlands), Collection Haringhuizen-Schoemaker (nr. 2.22.07, inventory numbers 1 to 23).
ii. Author's translation.
iii. Author's translation.
iv. This issue is discussed in detail in Ertsen 2002c.

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12

Municipal or private ownership of water and sewage utilities?

Jarmo J. Hukka and Tapio S. Katko

In most Western countries, private enterprises established the first water works in towns in the mid-1800s, but in most cases the works were transferred to the ownership of municipalities and cities quite rapidly. In Finland, water works have been operated and owned by municipalities since the 1880s. In France, the private operators that emerged in the mid-19th century have gradually captured markets around the world also in energy and transportation services, especially in the form of long-term concessions or management contracts.

At the National Water Supply and Sanitation Days in May 2000, author Hukka appeared in the role of the English statesman, municipal politician, banker and scientist, Sir John Lubbock (Lord Avebury). Author Katko played the role of Bernard Wuolle, who held many prestigious posts in Finland. The main focus of the presentation was municipal business activity and related principles, with the discussion largely based on a lecture given by B. Wuolle, then director of Helsinki Electric Utility, at the first Finnish Municipal Days in Helsinki in September 1912 (Wuolle, 1912).

Sir John Lubbock (1834–1913), made Lord Avebury in 1900, was an English banker, statesman, influential Liberal-Unionist politician, Vice-Chancellor of the University of London, Chairman of the London City Council, and naturalist. He wrote extensively on a variety of scientific, historical and sociological subjects. In his work "*On Municipal and National Trading*" (1906), Lord Avebury strongly criticized the business activities of the central and local governments in England.

Bernard K. Wuolle (1876–1962) was one of the leading engineers of his time in Finland. He acted as managing director of The Finnish National Railway Company (1917–1922), served two years as a Cabinet Minister after Finnish Independence in 1917, and acted as professor of General Mechanical Engineering and Industrial Economics in Helsinki University of Technology until 1946. During his long career in engineering and as a social actor, he, among other achievements, examined the role of engineers in societies and the role of technology as part of culture (Michelsen, 1999).

In 1912, as managing director of the Helsinki City Electricity Works, Wuolle referred to Lord Avebury's critical writings about municipal business activity. This article contains some direct quotations from that 1912 lecture, intended as a basis for making comparisons with today's situation. The article also attempts to highlight issues related to private water supply and sewerage.

Wuolle started his 1912 lecture by saying that "the ever-increasing role played by various technological sectors has been one of the most important phenomena in the development of municipalities over the last few decades. Densely populated communities follow natural economic laws in striving to take advantage of technological developments in all areas in order to be able to satisfy their key needs more fully and at a lower cost than by leaving these matters up to private individuals."

Key arguments by Lord Avebury, and rebuttals

Lord Avebury had, in his work *On Municipal and National Trading* (1906), sharply criticized the business activities of English municipalities and the state. In his lecture, Wuolle referred to five key arguments presented by Lord Avebury, and commented on them. Overall, Wuolle asserted that "there is much truth in what Lord Avebury claims. Yet, his testimony only proves that the mentioned drawbacks exist in some instances. They are not, however, sufficient grounds for drawing general conclusions."

***Argument no. 1*: Municipal administrators are already saddled with enough, if not too many, statutory tasks and liabilities whose satisfactory performance requires all their time and energy.**

Wuolle: "Although the work load of municipal administrators is heavy even without utilities, an excessive work load is an indication of poor organization and thus remediable by the right division of labour. Moreover, English municipal legislation may also be partially responsible for the foolish acts committed. Would it not, therefore, be better to reform legislation instead of encouraging a return to private enterprise even in sectors which are more naturally served by municipal utilities?''

The international debate of the last few years has ignored the fact that, in most Western democracies, water supply and sewerage services are provided by municipally owned (often quite autonomous) utilities. For example, in the European Union, some two-thirds of consumers are served by municipality-owned utilities (EUREAU, 1997).

England and France are exceptions as concerns local administration. In England, the local level has always had relatively less decision-making power than in the Nordic countries, and the power they have has continually decreased over the last decades while the role of the central government has increased (Hietala, 1987; Johansson, 1997). France has over 36,000 municipalities. The number of contracts awarded to private operators there has increased continuously, which according to Clark and Mondello (1999) is due, in part, to the fact that under French law mayors are personally liable for any damages resulting from water supply and sewerage. Law also stipulates that a mayor cannot take insurance to cover such damages. When a municipality grants a concession to a private company, the liabilities of the mayor transfer to the company. It is difficult to see how municipality-owned utilities could operate viably under the mentioned conditions.

On the other hand, the practice in Germany (Hames, 2000; Hietala, 1987) and The Netherlands is closer to that of the Nordic countries (Blokland et al., 1999). Thus, on a broader scale, we could speak about a Nordic-Dutch-German mode (Hukka and Katko, 2003) in contrast to the French one and the fully privately owned utilities in England and Wales. Yet, international financiers are forcefully urging developing and transition economies to adopt private-enterprise models, especially public–private partnerships through private operators as if the municipality-owned utility did not exist. Paradoxically, it is the most common mode in the donor countries.

The most critical researchers already speak of neo-colonialism, at least when external support is tied to concessions (or even private ownership). As Alexander (2002) states: ''Recently, the World Bank Director for Water and Power declared that water and sanitation loans to Africa will be 'out of question' unless they include private participation. This position represents an institutionalized hypocrisy. The industrialized countries that dictate conditions for access to development assistance maintain public provision of water [*merely production: authors' note*] for themselves, while requiring that developing countries renounce it. The same double standard exists in other policy areas.''

***Argument no. 2*: Utilities increase the debt burden of cities enormously, thereby making it more difficult for them to borrow for other important needs.**

Wuolle: ‘‘This hardly applies to the finances or loan terms of Finnish municipalities, not even in exceptional cases. A municipality that owns well-run, revenue-generating utilities as well as facilities whose operation is financed by tax revenue should be able to borrow enough to operate the latter, and with better terms, than if it did not own the former. Consequently, it is highly important that the accounting of revenue-generating utilities is straightforward and based on accepted standards, sufficient depreciation, etc.’’

In 1973, ten catchment area-specific publicly owned water and sewage works were established in England and Wales. At that time, the managers of the utilities consisted primarily of local administrators. In 1980, the conservative government eliminated the local representation. Originally, the utilities were allowed to take out loans according to their needs. After Thatcher came into power, limitations were placed on utilities' authority to take out loans, which resulted in gradual deterioration of the systems due to lack of funds.

Initially, water supply and sewage works were at the bottom of the privatization list. In 1989, the works were privatized whereby their assets also transferred into private hands (initially French, and later also to others). According to Okun (1992), this involved an ideological choice. It was also electioneering: there was no need to raise taxes when the assets were sold, which led to the privatization of English and Welsh water supply and sewage works. This was justified mainly by the fact that it would draw funds from the private sector for investments. However, the companies did not risk the funds of their owners, but borrowed the necessary funds from banks with the state as guarantor. Thus, the public sector assumed the risks and the private sector reaped the profits.

As Barraque (2003) points out, to make privatization attractive in 1989, the government cancelled the debt of the previous Regional Water Authorities. In addition, it offered a so-called ‘‘green dowry’’ to help the new private companies comply with the European Directives. Thus, ‘‘what anybody else than the Thatcherites would call subsidies amounted to 6.4 bn £, i.e. more than what the French or German governments give away to their water services in twenty years.’’

In the 1990s, several Finnish municipalities sold their energy utilities to the private sector in their need for cash. Some people are convinced that things are moving in the same direction also in the water sector. Yet, we should remember that energy supply and water supply are fundamentally different activities. Energy can be transmitted over great distances, but water or wastewater cannot. Thus, the scale of the activities is different; in the water sector, and the local level cannot be by-passed. Water supply and sewerage also have certain crucial obligations related to the environment, health, safety and social justice. Besides, it has now evident that the savings from private operation of electricity companies are largely gained by minimizing the number of local staff and increasing the risk of vulnerability. This was recently shown by the remarkably slow restoration of services following storms, especially in rural areas.

***Argument no. 3*: City governments will get mixed up in labour disputes.**

Wuolle: ''I consider this an exaggerated claim. The municipality always employs people, even if it has no utilities. Most often it has more employees working outside utilities than within. Moreover, the indispensable workers of such facilities are always specialists. Therefore, it is in the interest of the municipality to provide them good enough economic and other conditions to avoid any severe labour disputes.''

The number of the employees of Finnish water and sewage works compared to the people served is quite or very small, even internationally. This is partly due to the fact that utilities, especially the largest, have outsourced many non-core operations. Outsourcing has been the prevailing practice for a long time in capital investment projects, and half (if not more) of the goods and services needed to operate municipality-owned utilities are bought from the private sector.

***Argument no. 4*: It is probable, if not absolutely certain, that municipal enterprises operate at a loss or in any case have higher expenses than private ones since they do not have the same incentive for economical and carefully planned operation.**

Wuolle: ''I think the municipality can also overcome this type of drawback. Municipalities' utilities should not be considered homes for the elderly or social security, but must employ only qualified employees from top to bottom. The best incentive for top management is to allow them to share in the profits – this should be the case in both municipal and private enterprises.''

The required return on capital by a private entrepreneur will, in any case, be higher than the costs of servicing loans taken by the autonomous municipal utilities themselves, at least in Finland. There are examples from England and Wales in the 1980s in which the central government did not give, for instance, regional water authorities permission to borrow enough funds. Consequently, the authorities were unable to borrow money (Semple, 1993). Furthermore, in North Carolina and Florida, for instance, it has been noticed that public authorities run water supply and sewage works more efficiently since they are responsible to voters instead of shareholders (Gullet and Bean, 1997; Pontek and Wehmeyer, 1997). Examples of the opposite being true have also been cited, however.

In Finland, water and sewerage utilities are allowed to include the return on capital in their charges in accordance with the new law enacted in 2001, but it must be reasonable. In practice, that "profit" handed over to the owner (the municipality) should be lower than the return on investment that would be required by any private investor. It is another policy question as to whether such profits by municipality-owned utilities can be justified, especially from the viewpoint of the ultimate owners (the customers).

A comprehensive four-year assessment programme concluded in 2002, for instance, that there is no evidence that the form of ownership determines the level of efficiency, or that privatization itself leads to greater efficiency (SAPRIN, 2002, cited by Aegisson, 2002). Also, Braadbart (2002) states that "increased private sector involvement is no silver bullet." The SAPRIN study also reveals that when an increase in efficiency occurred, in most cases it did not derive from improved operations. Instead, profitability rose as a result of price increases, facilitated by a virtual monopoly situation and weak government regulatory mechanisms.

***Argument no. 5*: Municipal enterprises hinder development and the introduction of new inventions.**

Wuolle: This claim is completely outdated. Yet, it must be admitted that only sound financial management, where the necessary depreciation is taken, will enable municipal enterprises to keep abreast of the times with the rapid pace of technological development. . . . Municipal governments should set up some kind of a reserve fund for renovations besides taking the required depreciation."

This type of activity has, of course, been engaged in. Future investments can be estimated and preparations made for them, if desired. At least in Sweden and the United States, it is the custom for water and sewage works to contribute a small proportion per each cubic metre of water sold to a national sector R&D fund. The proceeds are used annually to finance agreed-upon research projects for which research institutes, mainly universities, compete. Finland would also need something like this (Vahala, 2001).

Observations and conclusions

As to water and sanitation services, it is ultimately a question of our values: What do we want in terms of these services? The authors' view is that municipal organizations can be criticized only as to how well they attain the set goals. Thus, the following statement by Wuolle is still well grounded: "In any case, I am of the opinion that municipalities must keep control of at least the retailing and planning of supply within their borders in order to remain master of the house and to promote municipal development."

In connection with this discussion, we can conclude that the core competencies of utilities must remain in public hands while services may be purchased from the private sector – even to a higher degree (see figure 12.1). Yet, municipalities or their utilities should not tie themselves to excessively long contracts so as to ensure that competition in outsourcing to the private sector is possible within this type of natural monopoly. Although the last-mentioned concept was introduced by John Stuart Mill as early as in 1848 (Sharkey, 1982), some policy makers a century-and-a-half later still tend to ignore this fact.

However, the demand for privatization of water supply and sewerage, despite its one-sidedness, has been beneficial in that the mere threat of it has forced public utilities to increase the efficiency of their operations ("Privatization Drives ...", 2000) and, it is hoped, also to increase their openness and transparency.

Recently, English and Welsh private water companies have sought to relinquish their ownership. The discussion about the roles of the public and private sectors in water supply and sewerage has continued since the latter half of the 19th century. It is now high time to examine the issue thoroughly.

Ultimately, the responsibility for providing water and sewerage services should rest with the local government. The local government, working together with the local people and the utilities, is in the best position to ensure that "good governance" is practiced. Good governance is participatory, consensus oriented, accountable, transparent, responsive, effective and efficient, equitable and inclusive, and follows the rule of law. It also assures that corruption is minimized, the views of minorities are taken into account, and the most vulnerable in society have a voice in decision-making. It is also responsive to the future needs of society. The central government should also enhance the building of local capacities for good governance, and provide appropriate institutional mechanisms to empower local government and communities to make necessary reforms as well as engage in capacity building to improve the performance of water and sewerage utilities and make new investments in services.

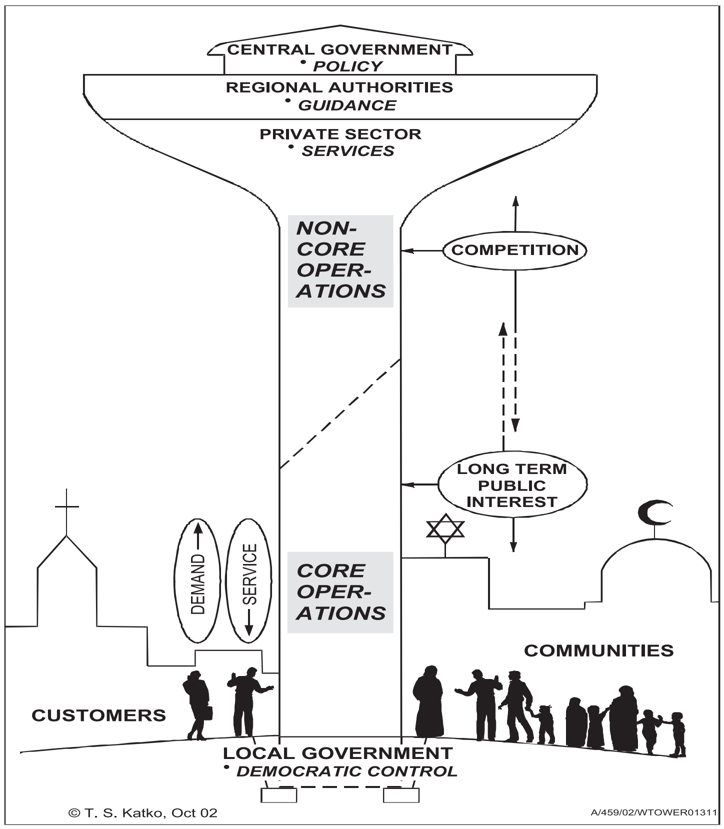

Figure 12.1 The most feasible form of public-private cooperation in water and sanitation services, based on historical and recent developments (*suggested by the authors; Seppälä et al., 1991, modified by Hukka & Katko, 2003*)

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III

Water technology and innovations

13

Old fluming dams near Vienna

Alexius Vogel

Austria once had numerous fluming dams, which were constructed for a special purpose: to float the newly cut timber through inaccessible forested mountain areas. These constructions, which can be traced back to at least the 13th century, were built where the stream had too little flow to float the logs unaided. The water was repeatedly impounded, then suddenly released through large outlet gates to produce an artificial flood wave that carried the logs down to the end of the logway section, where they were stopped by a wooden rack and hauled ashore.

In the long valleys of the Alps, fluming was started first by opening the gates of fluming dams on side brooks. Then, in the main valley, the logs were further transported by flood waves produced after the opening of the gates of main fluming dams (the dimensions and drain data of which were usually larger than those of the side dams). If a natural lake was situated within a logway section, the logs were caught at the point where the brook flowed into the lake, then further transported over the lake by means of physical strength. At the outlet of the lake, the logs were floated into the next logway section with the support of water delivered by the lake itself.

Among the construction materials used for the dam bodies, wooden, earthen, masonry and concrete fluming dams can be distinguished. The oldest types were timber structures that, except from the sealing compound of the wall on the upstream side, were constructed entirely of wood. Today, most of these remain only as ruins, because of their short durability; sometimes, though, there are old pictures to remind us of their

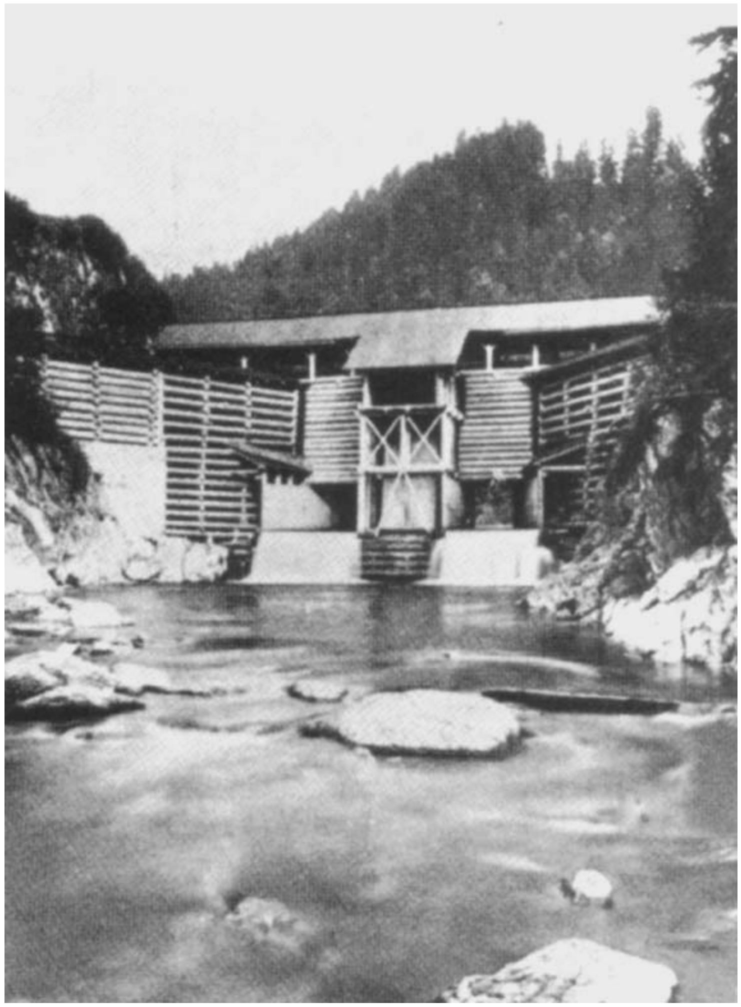

Figure 13.1 Archduke Johann fluming dam in Tyrol

former beauty, as in the case of the 12-metre high Archduke Johann Dam in Tyrol, which could discharge a total pondage of 230,000 m^3 within one hour (figure 13.1).

Today, with forests now served by modern forestry track networks, fluming dams have become more or less extinct. A few old fluming dams have been preserved for their historical interest; others await rediscovery and reintegration into the river systems (Vogel, 2001).

A network of fluming dams near Vienna

In 1756, during the reign of Maria Theresia, a network of fluming dams was constructed southwest of Vienna on the Schwechat River and its feeders. This created a path of logway sections with a total length of 104 km. Today, remains of the system are situated near the village of Klausen-Leopoldsdorf near Highway 21 (figure 13.2).

Once, this network consisted of a main dam plus eleven secondary dams and two additional downstream dams, which allowed about 270,000 m^3 of water to be dammed up. An average of about 51,500 m^3 of logs were transported each year to Vienna. The main dam (No. 1 in figure 13.3) was renovated in 1965 and is well preserved today, but the other structures survive only as ruins – though still visible for those who know the area and their locations (figure 13.3).

The Schwechat river had too little flow to float logs; therefore, a network of fluming dams was erected, though such a system normally was used only in the Alps. The water for the storages was impounded at the

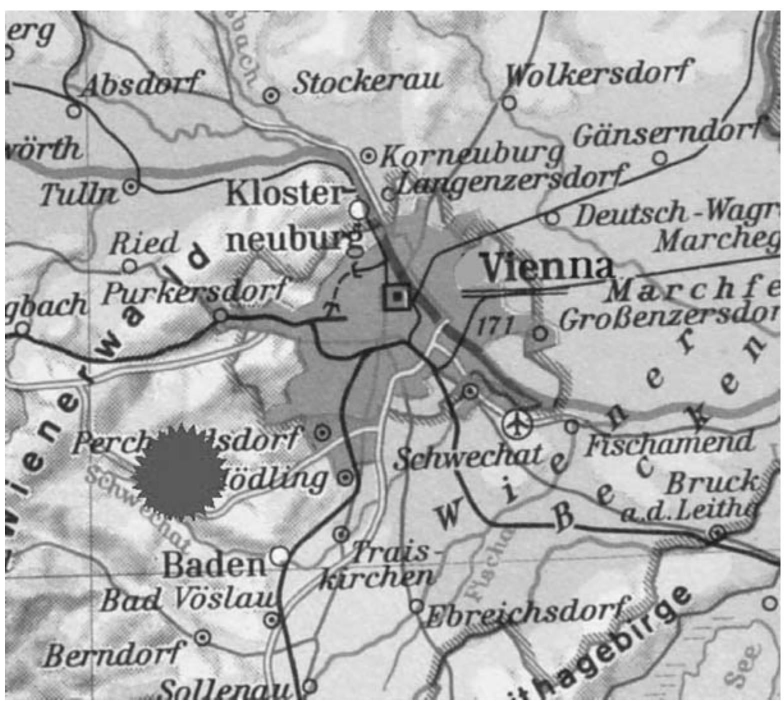

Figure 13.2 Location map

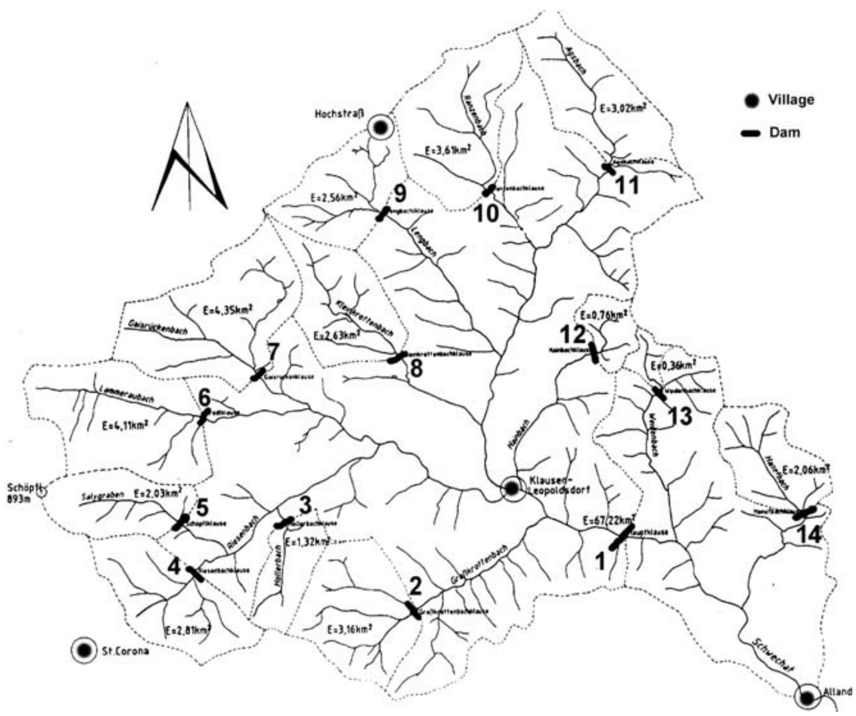

Figure 13.3 Dam sites near the village of Klausen Leopoldsdorf

times of snow melting, so only once-a-year floating was possible by opening the gates in a coordinated action.

The main dam

The so-called Maria Theresia's Fluming Dam (No. 1 in figure 13.3) was the main dam of the network. Originally constructed in 1667 as a timber dam, in 1756 the dam was reconstructed with an earth fill, sealed with clay and faced with ashlar (figure 13.4). It is the oldest surviving dam construction in Austria. It has an impounding head of 5.20 metres (m), allowing a storage capacity of 78,000 m^3. The dam has a crest length of about 85 m (figure 13.5), and is equipped with two 2.07-m wide by 2.84-m high gates, which could be closed by two wooden panels (figure 13.6). There were also two additional 6.90-m wide spillways, each of which could also be regulated by 3 wooden panels even when the gates were closed, and two steps for maintaining the flood gates – proof of the excellent hydraulic skills of the dam constructors.

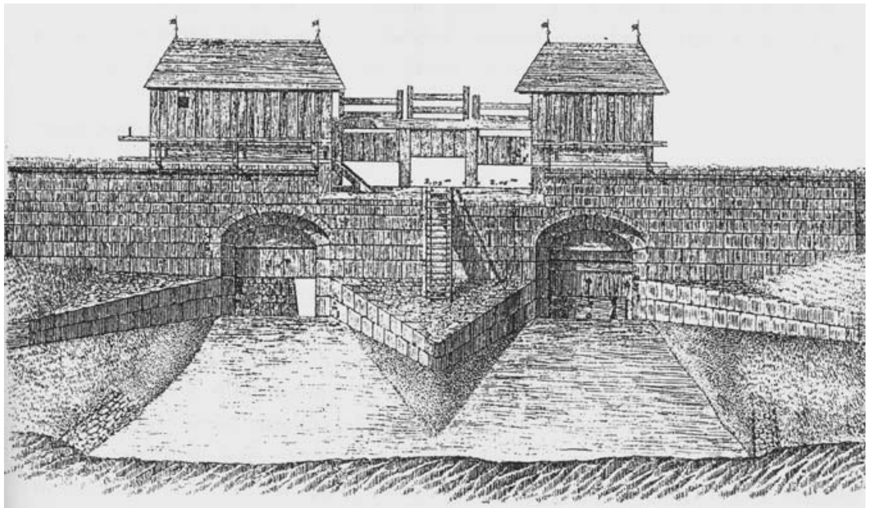

Figure 13.4 An old painting of the main dam, from 1885
Source: Förster, 1885

Figure 13.5 A downstream view of Maria Theresia's Fluming Dam

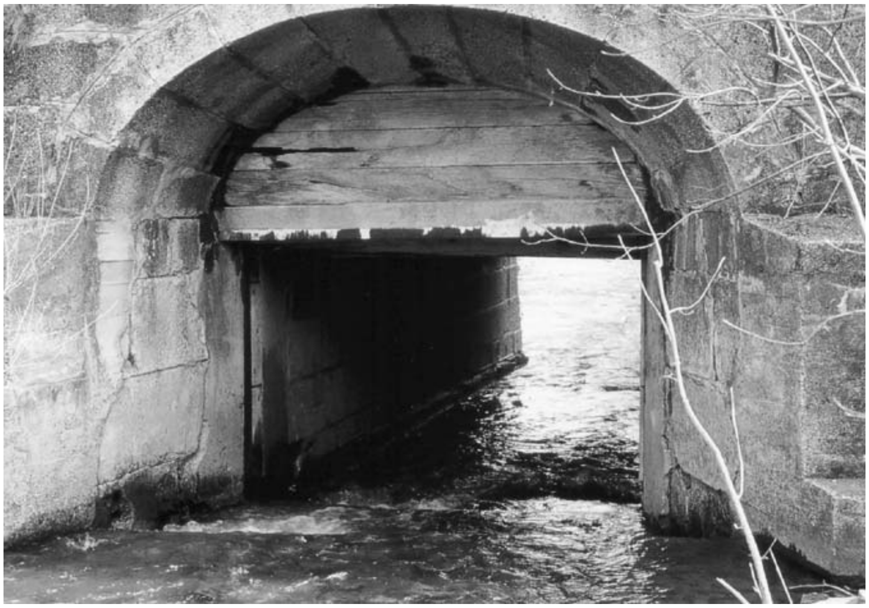

Figure 13.6 An upstream view of one of the renewed floating gates

Although this dam was used for the last time in 1939, the wooden superstructures of the gate houses were renovated in 1965. Even today, the Maria Theresia Fluming Dam has the appearance of a modern small dam construction (figure 13.7).

The secondary dams

The 11 dams on the tributaries of Schwechat River and two additional dams downstream of the main dam were necessary for a successful floating. Only the dam on Hollersbach creek (No. 3 in figure 13.3) has vanished completely; all the others remain as ruins. These secondary dams were earth fills with cores of clay, and in some cases faced with ashlar on the upstream side. Though the last floating season was in 1939, it was not until 1963 that the dam bodies were cut and the wooden gate constructions abandoned.

Riesenbach Dam – No. 4 in figure 13.3 – had a height of 6.20 m, a crest length of about 55 m and a crest thickness of 8.7 m. Its upstream slope, with an inclination of 1:1, was paved with rock to protect it from ice, waves and the depredations of animals. The downstream slope, with in-

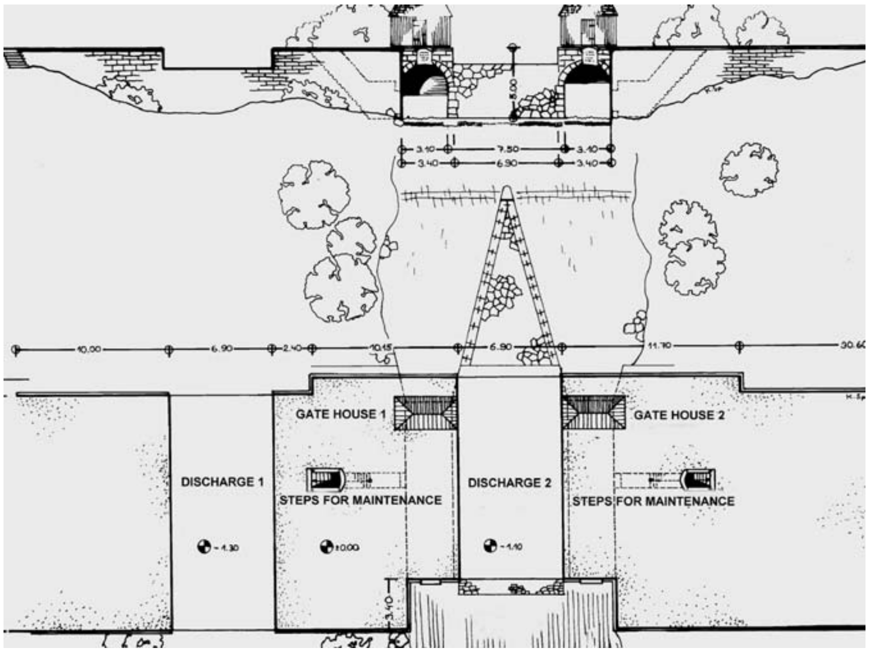

Figure 13.7 Front view and plan of Maria Theresia's Fluming Dam

clinations of 1:2.5 and 1:3, was much flatter and lined at the foot with two vertical walls of dry masonry. A floating gate was situated in a full masonry part, 14.25 m from the left abutment. The inflow on the upstream side was 0.64-m wide by 1.60-m high; it could be closed by a lifting gate in the form of a wooden panel (figure 13.8). When it was opened, the full content of 21,000 m^3 of water was able to escape within 1.5 hours.

Adjacent to the lifting gate, an 8-m long discharge tunnel lead through the dam body. This tunnel, with a width of 2.30 m and height of 2.70 m (figure 13.9), still exists today. At a distance of 11.4 m from the right abutment, the dam was further equipped with a 3.5-m wide spillway, which once was regulated by two 0.90-m high wooden sluice gates.

Riesenbach Dam is one of four secondary fluming dams in this area that are scheduled to be restored and preserved. The aim is to remind the public and coming generations about the efforts that once were necessary to build such constructions. It will be part of a project that will open access to this area by marked footpaths for public recreation and education (Bodi, 1993). This project has now been discussed for more than 10 years, and it is hoped that it will be executed in the near future (before the last traces of these dam constructions have vanished forever).

Figure 13.8 An upstream view of the floating gate of Riesenbach Dam

Gaisrücken Dam – No. 7 in figure 13.3 – is of very similar construction to Riesenbach Dam. It had a height of 4.50 m, a crest thickness of 7 m and a crest length of 66.2 m (figure 13.10). This earthfill dam with a core of clay had an upstream slope with an inclination of 1:1, which was paved with rock. At a distance of 20.7 m from the right abutment, a floating gate was situated in a full masonry part.

The inflow on the upstream side was 0.62-m wide and 1.61-m high, and could be closed by a lifting gate in the form of a wooden panel. When it

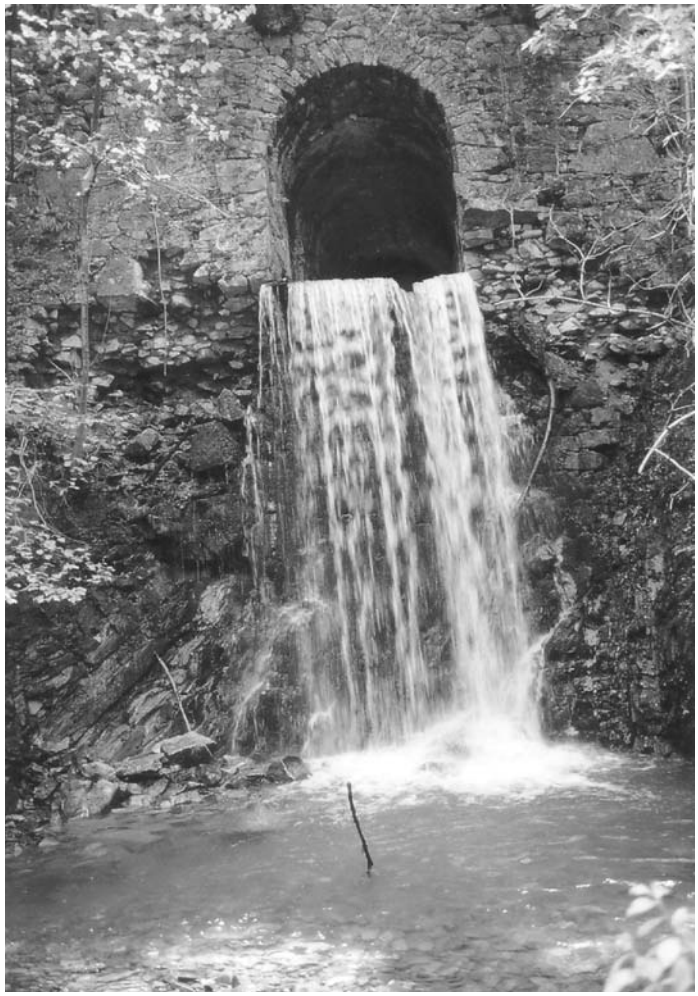

Figure 13.9 A downstream view of the discharge tunnel of Riesenbach Dam

was opened, the full content of 20,000 m^3 of water was able to escape within 1.3 hours. A 6-m long adjacent outflow tunnel, with a width of 2.3 m and a height of 2.65 m, collapsed some years ago. Today, this part of the dam body is heavily eroded (figure 13.11). Still existing is a small 3.2-m wide discharge canal, 16.25 m from the left abutment, which once was regulated by two 1.61-m wide wooden sluice gates.

Lengbachl Dam – No. 9 in figure 13.3 – was a 4.2-m high earthfill dam with a core of clay. Its upstream slope, with an inclination of 1:1, was

Figure 13.10 An upstream view of Gaisrücken Dam

Figure 13.11 A downstream view of the eroded part that once included the discharge tunnel

Figure 13.12 An upstream view of Lengbachl Dam

paved with rock. Because of the construction of a modern road, the dam lost 2 m of its former 67.9-m length. The crest thickness of the dam is 8.1 m. This dam was last renewed in 1928, and therefore is in good condition. At a distance of 7 m from the left abutment, there is a 2.04-m wide discharge canal that once was regulated by a 0.97-m high wooden sluice gate (figure 13.12); at 31.1 m from the right abutment, a floating gate was situated in a full masonry part.

The inflow on the upstream side was 0.63-m wide and 1.60-m high, and could be closed by a lifting gate in the form of a wooden panel. When it was opened, the full content of 18,800 m^3 of water was able to escape within 1.3 hours. The 7.3-m long adjacent outflow tunnel of masonry, with a width of 2 m and a height of 2.6 m, still exists (figure 13.13).

Kleinkrottenbach Dam – No. 8 in figure 13.3 – was a 4.4-m high earthfill dam with a core of clay. The overall crest length of the dam was 65.9 m; 32 m of the left wing had a crest thickness of 2 m. In this part, the upstream slope has an inclination of 1:1, while the downstream slope has an inclination of 1:2. The next 14.5-m long part of the dam was cut in 1963; only this part of the dam body once had a crest thickness of 8.2 m, because it was at this point the floating gate was situated. A 19.4-m length of the left wing of the dam still exists.

Adjacent to the main dam, a 26-m long secondary dam is situated with inclinations of 1:1 on both upstream and downstream sides (figure 13.14). An abandoned inflow on the upstream side was 0.64-m wide and 1.60-m high, and could be closed by a lifting gate in the form of a wooden panel. When it was opened, the full content of 18,200 m^3 of water was able to escape within 1.3 hours. A 7.1-m long adjacent outflow tunnel made of masonry once had a width of 2 m and a height of 3.23 m. The discharge canal near the left abutment has vanished.

Figure 13.13 A downstream view of the discharge tunnel of Lengbachl Dam

Figure 13.14 An upstream view of Kleinkrottenbach main dam

Grödl Dam – No. 6 in figure 13.3 – was a 4.5-m high earthfill dam with a core of clay; its length was 65.5 m. The paved upstream slope had an inclination of 2:3 and the downstream slope had an inclination of 1:2. At a distance of 13.1 m from the left abutment, an upstream sluice 0.63-m wide and 1.60-m high was situated; it could be closed by a lifting gate in the form of a wooden panel. When it was opened, the full content of 21,000 m^3 of water was able to escape within 1.5 hours. An 8.3-m long adjacent outflow tunnel of masonry was 2.25-m wide and 2.74-m high.

The dam was cut in 1963, and the gate construction was abandoned. The 3.5-m wide and 1.03-m deep discharge canal, which was situated 38.8 m from the right abutment, has vanished. Today, traces of the dam body can be seen only with difficulty (figure 13.15).

Schöpfl Dam – No. 5 in figure 13.3 – was an earthfill dam with a core of clay. The dam had a height 6.15 m, a crest length of 62.75 m and a crest thickness of 9 m. Its upstream slope, with an inclination of 1:1, was paved with rock; the downstream slope was flatter and lined at the foot with a vertical wall of dry masonry. A floating gate was situated in a full masonry part, 26.5 m from the left abutment. The inflow on the upstream

Figure 13.15 The remains of Grödl Dam

Figure 13.16 The remains of Schöpfl Dam

side was 0.63-m wide and 1.63-m high; it could be closed by a lifting gate in the form of a wooden panel. When it was opened, the relatively small content of 8,100 m^3 of water was able to escape within 1.3 hours.

An 8.4-m long adjacent outflow tunnel made of masonry was 2.29-m wide and 2.60-m high; it collapsed some years ago. The gate construction was abandoned in 1963. At a distance of 10.3 m from the left abutment, a 2.22 m wide discharge canal was situated; this was once regulated by a 0.75-m high wooden sluice gate. Today, Schöpfl Dam has been destroyed at the point of the old floating gate, and shows the typical form of a historical construction long forgotten by the public (figure 13.16).

With the forests now accessible by networks of roads, the old fashioned fluming dams have fallen into oblivion. Time has also made its own contribution by ravaging these old constructions that are unprotected from destruction by wind and water.

Today most of the old fluming dams lie forgotten in the forests, covered with a cloak of vegetation and silence. If a wanderer is fortunate enough to come upon one – sometimes near a modern highway, but more often after an arduous climb along overgrown paths – the murmur of the waters may whisper tales of past glory.

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14

The history and importance of the oldest torrent control in the Slovak Republic

Matúš Jakubis and Libor Jansky

The Slovak Republic, in Central Europe, is mountainous and has waterways extending a length of 49,775 km, of which 23,000 kilometres (46.2 per cent) are torrents. Historical records show that floods, torrents and avalanche disasters have struck mountainous and sub-mountainous villages since time immemorial. Heavy deforestation was carried out during the 13th and 14th centuries (from the negative influence of colonization, settlement, mining, metallurgy, wood-gathering, etc.) in the regions of present Central Slovakia.

Torrent controls originated in the 18th and 19th centuries, and are inscribed in the historical chronicles of various villages and towns. Some traditional measures to control torrents were adopted – such as stone barrages, stone crib dams, temporary ditch plank fences, longitudinal reinforcement of shores with stems, and even afforestation aimed at soil conservation in the mountain watershed of torrents. Although these measures were quite effective, flood disasters in mountainous watersheds were frequent and destructive for both humans and landscapes. One of the reasons for these flood disasters was the deforestation of the mountainous watersheds in the previous centuries.

The area of the contemporary Slovak Republic was, until 1918, a part of the Austro-Hungarian monarchy; it then became part of an independent Czechoslovakia. The first notes about torrent control on the territory that is now the Slovak Republic originated in the 18th and 19th centuries, in the historical chronicles of submontane villages and towns. The first law (“Law concerning precautions for the innocuous derivative of alpine waters'') came into force in 1884, and the first department of what is now called Wildbach- und Lawinenverbauung (WLV) was k.k. forsttechnische Abtheilung für Wildbachverbauungen. The organized regulation of endangered areas began on an official basis (although it has to be mentioned that the WLV had to cover the area of what is today Austria, northern Italy (Südtirol), Slovenia, northern Croatia (Dalmatien), the Czech Republic, Slovakia, and southern Poland (Schlesien, Galizien)). At the beginning of World War I (1914), the WLV had 15 subsidiaries covering the area of the monarchy.

''Modern'' torrent control activities in Slovakia began in 1923. In that year, a specialized office for torrent control was established in Turciansky Svaty Martin (now Martin) in Central Slovakia, led by Prof. Dr. Ing. Leo Skatula (1889–1974). This institution operated throughout the whole Slovak Republic. The first systematic torrent control, Jelenec, was situated in the Hornojelenska valley in Velka Fatra in Central Slovakia. Built in 1926–27, this torrent had many peculiarities: passages for fish, longitudinal reinforcement of the torrent bed with wood (pine and fir), the first stone-arched correction and sediment storage dam, and others.

During the 15th and 16th centuries, deforestation in Hornojelenecka Valley was severe, leading to floods and avalanches in the region. The first historical record about an avalanche in Hornojelenecka Valley was in 1751; it caused the deaths of 10 people. During the 16th century, professional commissions had been formed (in 1535 and 1563), but while they recognized the importance of the forests of Hornojelenecka valley, no significant protection effort materialized. This was one of the primary reasons for the large-scale avalanches in later years.

In the 20th century, there were two major disasters (in 1924 and 1925) that led to the loss of lives and destruction of resources. The 1924 avalanche had a height of 35 metres of front face and about 2,400,000 m^3 of cubage. It took the lives of 18 people in the Rybo settlement in Hornojelenecka Valley. The next catastrophe was on 13 July 1925, when a gigantic flood destroyed all of the valley (houses, roads, equipment, etc.). These catastrophes were the cardinal reason for the beginning of Jelenec torrent control as the first systematic torrent control on territory of today's Slovak Republic.

Some important characteristics of the watershed and Jelenec torrent

The watershed of Jelenec torrent is situated in the southeast part of Velka Fatra mountain (Central Slovakia), which is the dominating mountain in the watershed of Krizna (at an altitude of 1,574+ metres above

Table 14.1 Characteristics of the watershed

Parameters	Dimensions
Height of the torrent Jelenec	1400 m
The absolute uptake capacity	818 m
Average stream gradient	14.9%
Main stream length	5.5 km
Length of the tributaries	21.1 km
Stream density in the watershed	2.77
Valley line length	5.85 km
Watershed divide length	14.8 km
Average gradient of the slope of the watershed	47.2%
Height of the watershed	930 m above MSL
Average annual precipitation	1250–1600 mm
Average annual temperature	3.3 °C
Temperature at the highest point	2.7 °C
Geographical substratum	Limestone (calcites) and dolomites

mean sea level (MSL)). The lowest point in the watershed is the mouth of the Jelenec torrent, which extends to Starohorsky brook (582 metres above MSL) in the settlement of Horny Jelenec. The height of the watershed is 992 metres, and the watershed area is about 100 km^2. Today, forest covers about 77 per cent of the watershed and consists of *Picea abies*, *Abies alba*, *Pinus mugo*, *Pinus cembra*, *Larix decidua*, *Fagus sylvatica*, *Carpinus betulus*, *Acer pseudoplatanus*, *Sorbus aucuparia*, *Sorbus aria* and *Ulmus glabra*. From 1963 to 1982, an area of 36 hectares was afforested (with the aim of improving soil conservation and assuring the hydric function of the forest) using 219,900 young plants (seedlings).

The characteristics of the watershed are as shown in table 14.1.

Runoff equations

Maximal runoff $Q_{\max}(Q_{100})$ was calculated using the Lauterburg equation:

$$Q_{\max} = \alpha \cdot A \cdot \frac{32}{31 + A} \cdot 35 \cdot \frac{P_{hi}}{126} \ (\mathrm{m}^3 \cdot \mathrm{s}^{-1})$$

In this equation, α is the runoff coefficient ($\alpha = 0.50$), A is the watershed area (10.0 km^2) and P_{hi} is considered as the 1-hour precipitation intensity (40 mm$\cdot$h^{-1}).

Values calculated for area of Horny Jelenec settlement (mouth of the valley): maximal runoff $Q_{max} = Q_{100} = 43.5\ m^3 \cdot s^{-1}$; maximal specific runoff $q_{max} = 4.35\ m^3 \cdot s^{-1} \cdot km^{-2}$.

Values calculated for Valentova settlement (central part of valley; area = 6.30 km^2): maximal runoff $Q_{max} = Q_{100} = 35{,}30\ m^3 \cdot s^{-1}$; maximal specific runoff $q_{max} = 5{,}60\ m^3 \cdot s^{-1} \cdot km^{-2}$.

Values calculated for Rybo settlement (highest part of valley; area = 4,80 km^2): maximal runoff $Q_{max} = Q_{100} = 30{,}901\ m^3 \cdot s^{-1}$; maximal specific runoff $q_{max} = 6{,}44\ m^3 \cdot s^{-1} \cdot km^{-2}$.

The purpose and importance of the Jelenec torrent control

The Jelenec torrent control was established to:

- prevent torrent erosion (production, transport and sedimentation of gravel bed materials) – For this purpose, seven stone dams were constructed, with the highest having a height of 5 metres, 3,265 m from the outfall of the Jelenec torrent to recipient Starohorsky brook. This stone dam is, to the present time, one of highest dams in the Slovak Republic.
- reduce tangential pressure – Twenty-seven stone weirs with heights from 0.50 metre to 2 metres were constructed to reduce the tangential pressure of the water flowing in the torrent bed. The longitudinal slope of the torrent bed was between 1 and 5 per cent.
- strengthen the torrent bed and slopes, and protect the water course against erosion – Stone paving of 11,573 metres and 598 wood crib dams were constructed. The bed of Jelenec torrent had an area of 1,820 m^2 with wood (pine, fir) banking.
- provide innocuous discharge of extreme water conditions to three mountain settlements (Rybo, Valentova and Horny Jelenec). The water supply level was controlled so as to protect inhabitants, houses, plots, plants and equipment, valley roads, etc.

Ecological and environmental aspects of Jelenec torrent control

From ecological and environmental points of view, the realities of the Jelenec torrent control are as follows:

- The shoulder of torrent control in the landscape and nature is vulnerable, though directional bows are very good in the bed of the valley.

Table 14.2 Geometric characteristics of Jelenec torrent control

No.	Distance from the mouth in km (from – to)	LENGTH OF THE STRETCH (m)	Form of the discharge profile	Geometric characteristics of discharge profiles					Characterization of the discharge profiles	
				B (m)	b (m)	h (m)	1:m_1 slope on the left	1:m_2 slope on the right	Slopes	Bottom
1	2	3	4	5	6	7	8	9	10	11
1.	0.000–0.035	35	TU	5.00	3.00	0.80	1:0	1:2.5 (1:2)	Left (L): Stonewall, height 0.80 m, width 0.40 m, with cement mortar (CM) submerged Right (R): Natural (grass, woody plants)	Natural (sediments)
2.	0.035–0.575	540	TE	5.50	3.00	1.40	1:0.9	1:0.9	Stone ditch (flume) from stone paving, width 0.30 m, with CM masoned	
3.	0.575–0.725	150	TE	5.00	2.50	1.40	1:0.9	1:0.9	L+R: Stone paving, width 0.30 m, width CM masoned	With wood stabilized, barked logs – pine and fir, 0.16–0.20 m in diameter, 14 units, longitudinal situated
4.	0.725–0.775	50	TE	6.00	4.00	1.40	1:0.75	1:0.75	Stone ditch (flume) from stone paving, width 0.30 m, with CM masoned	
5.	0.775–0.925	150	R	4.00	4.00	1.40	1:0	1:0	L+R: Stone wall, height 1.40 m, width 0.50 m, with CM submerged	Natural (sediments)

6.	0.925–0.945	20	TE	5.00	3.00	1.20	1:0.8	1:0.8	Stone ditch (flume) from stone paving, width 0.30 m, with CM masoned	
7.	0.945–1.060	115	TE	5.00	3.00	1.20	1:0.8	1:0.8	L+R: Stone paving, width 0.30 m, width CM masoned	With wood stabilized, barked logs – pine and fir, 0.16–0.18 m in diameter, 17 units, longitudinal situated
8.	1.060–1.100	40	TE	5.00	3.00	1.20	1:0.8	1:0.8	Stone ditch (flume) from stone paving, width 0.30 m, with CM masoned	
9.	1.100–1.300	200	TU	4.80	3.00	0.80	1:11	1:11	Natural (grass, tree species)	Natural (sediments)
10.	1.300–1.850	550	TE	4.00	2.50	1.10	1:0.7	1:0.7	L+R: Stone paving, width 0.30 m, width CM masoned	With wood stabilized, barked logs – pine and fir, 0.16–0.18 m in diameter, 14 units, longitudinal situated
11.	1.850–2.050	200	TE	4.00	2.50	1.10	1:0.7	1:0.7	Stone ditch (flume) from stone paving, width 0.30 m, with CM masoned	
12.	2.050–2.200	150	TU	4.80	3.50	0.80	1:0.8	1:0.8	Natural (grass, tree species)	Natural (sediments)
13.	2.200–2.230	30	TU	4.40	3.30	0.80	1:00	1:1.5	L: Natural (grass, wood plants) R: Stone wall, height 2.0 m, width 0,40 m, with CM masoned	Natural (sediments)

Table 14.2 (cont.)

No.	Distance from the mouth in km (from – to)	LENGTH OF THE STRETCH (m)	Form of the discharge profile	Geometric characteristics of discharge profiles: B (m)	b (m)	h (m)	1:m1 slope on the left	1:m2 slope on the right	Characterization of the discharge profiles: Slopes	Bottom
14.	2.230–2.275	45	TU	4.00	3.00	0.80	1:0.7	1:0.7	Natural (grass, tree species)	Natural (sediments)
15.	2.275–2.600	325	TE	4.00	2.00	1.10	1:0.9	1:0.9	Stone ditch (flume) from stone paving, width 0.30 m, with CM masoned	
16.	2.600–2.810	210	TU	3.50	2.00	0.80	1:1	1:1	Natural (grass, tree species)	Natural (sediments)
17.	2.810–2.825	15	TU	3.30	2.00	1.00	1:0.8	1:0.5	L: Natural (grass, tree species) R: Stone paving, width 0.30 m, with CM masoned	Natural (stones, sediments)
18.	2.825–3.325	500	TU	3.20	2.00	0.80	1:0.8	1:0.8	Natural (grass, wood plants, stones, sediments)	Natural (stones, sediments)
Total length		3325								

Explanatory notes:
For of the discharge profile (column 4): TE – Trapezium equiangular, TU – Trapezium unsteady, R – Rectangle
B – column 5: bed width inside the banks (m)
b – column 6: bed width inside the bottom (m)
d – column 7: depth of the discharge profile (m)

The configuration of the valley and various natural obstacles (rocks, boulders, rare old trees, etc.) were strictly considered.

- The first stone weir (situated 125 m from the mouth) in the torrent control system is unique, carved in rock. The water flowing out of this weir gives the landscape a natural waterfall appearance.
- In another stone weir (2,250 m from the mouth) is a fishway (passage for fish). It was the first fishway in torrent control in the Slovak Republic. This stone weir has a height of more than 2 metres; the other stone weirs are lower, and fish can naturally jump over. Autochthonous fish (*Salmo trutta morpha fario L.*) have been found in the Jelenec torrent since time immemorial.

One of the most challenging situations for the project engineers was that the bed of the valley (only 15–20 metres in some places) was quite close to the torrent valley road, houses, small fields and farmyards, and farm buildings. But the problems were resolved in a very substantial way by the project engineers.

From the requisition in some tight passages of the valley, the water in the torrent cross-sections must very rapidly flow. In these tight passages, tight and deep flow (discharge) profiles were constructed. The bed in these profiles was stabilized with wood; thin-barked logs (pine and fir 16–20 cm in diameter) with a low roughness coefficient were used. This wood was preferable due to its price, easy workability and lower weight. Pine and fir barked logs, some as old as 75 years, sub-serve this function. Since the wood is always under the water surface, the chances of rotting are less. To this day, these sections are free from erosion damage.

The geometric characteristics of the discharge profile of the Jelenec torrent control were always adapted strictly in harmony with the landscape and the nature and character of the environment. As table 14.2 shows, the discharge profile was often set with regard to these conditions.

Unfortunately, the project logs of this historic torrent control system were lost during World War II. Only the manuscript of the "Technical Report" from April 1926 has survived, with the signature of author and project engineer Prof. Dr. Ing. Leo Skatula.

Conclusion

Built in 1926–27, the Jelenec torrent control is the oldest systematic torrent control system on the territory of the Slovak Republic. In many parameters, it serves as an example for modern, contemporary planning and projection of torrent control in Central Europe. This historical construction is now within the territory of Velka Fatra National Park (declared on 6 March 2002), and has long served various protective functions for humans, the landscape and the environment.

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15

Lessons learned from Qanat studies: A proposal for international cooperation

Iwao Kobori

General situation surrounding Qanat studies

A Qanat is an underground subterranean water channel in dry regions that serves as a source of drinking water. Almost all researchers on Qanat have focused on its origins, diffusion and dispersal; only a few studies have been conducted for its rehabilitation. As Qanat systems (see figure 15.1) are globally distributed, even at the present time, re-evaluation of such systems with appropriate case studies are highly recommended.

The system is known by different names in different regions: it is called *Foggara* in Algeria; *Falaj* in Oman; *Karez* in Iran, Afghanistan, Pakistan and China; and *Khattara* in Morocco. The regional imbalance of case studies is another problem to be tackled in the future. For example, in the Iranian case (including Afghanistan), scientific contributions mainly by local institutions are not well known by international scientific groups because of the language barrier. Fortunately, as a result of the first international conference on Qanat, held in Yazd, Iran, in 2000, the Iranian government has decided to establish an International Qanat Research Centre in Iran, in collaboration with UNESCO. Publications of this Yazd conference include a glossary and bibliography on Qanat, which may constitute the first challenge of Qanat studies. A water museum has already been built in Yazd, with a rich collection of Qanat tools and related documents (such as those on water sharing).

In the case of China, the "Proceedings of the International Conference on Karez Irrigation," published in 1993, includes 39 original papers by

Figure 15.1 A Qanat system in *In Belbel*, Algeria

Chinese and foreign scholars covering the past, present and future of Karez. (The conference was held in 1990, in Urumqi.) This publication represents a milestone for the development of Karez studies in China. I have organized a Sino–Japanese joint mission for Karez studies in Xinjiang from 1987 to the present. Nowadays, two or three Japanese groups are doing research in the field, directly or indirectly, in connection with Karez studies (including advanced technologies such as global information systems). And in Trufan, a Karez museum has been established, which includes our joint activities on Karez research.

In the case of the Sahara, although there was a hiatus between the French colonial era and the post-independence era, there are abundant materials to be re-examined. Recently, local authorities, such as Wilaya de Adrar (Department of Adrar), have organized international workshops, such as the one on Foggara in 1996. Starting with field research in the Algerian Sahara from 1961, and especially during the past 20 years, I have studied structural changes of oases with Foggara. It is my observation that the Ministry of Agriculture and local governments of Algeria are interested in rehabilitating existing oases with Foggara. Recently, the Algerian government categorized Foggara as a National Cultural Heritage, and they expect it to be recognized by UNESCO as a World Cultural Heritage.

Based on my own observations, regions such as Iran (including Afghanistan), Pakistan, Oman, the Sahara and Xinjiang are the main areas where we should continue research and sustainable development of the Qanat system. However, we also should have small-scale, intensive case studies in Syria, Palestine, the Arabian peninsula, Mexico, Peru, Chile and even Mediterranean Europe.

My personal experience

I started my research on Qanat and Karez Oases in 1956, when I extensively observed Qanat in Iran and in West Asia, at first as a member of the Tokyo University Iraq–Iran archaeological mission. Since that time, I have extended my field work to other parts of the world, to confirm Qanat systems *in situ* as a geographer. The results of those surveys have been published in various national and international journals and proceedings. (A part of my collected papers were also published, in Japanese and English, in 1996.)

As it is difficult to conduct global research alone, I have concentrated on carrying out intensive research on the evolution of Qanat oases in three regions: Tidikelt (Algeria), Palmyra Basin (Syria), and Turpan Basin (China). I also have visited Iran several times to refresh my knowledge on Iranian Qanat, and have collected first-hand information on Falaj in Oman, the Arabian peninsula in general, Khattara in Morocco, Karez in Turkmenistan, and small, similar systems in Latin America and elsewhere.

Reasons for the decline of the Qanat system

Through my research and observations, I have found that this unique and indigenous technology (probably invented in the Iranian plateau) is now in danger of fading away if we do not give serious consideration to the future of the Qanat system. The two main reasons for the decline of the Qanat system are:

- *Changes in the socio-economic backgrounds concerning Qanat construction*: Construction of a Qanat requires considerable pre-investment and a number of skilled and ordinary workers. For example, Arbab (landowners) in Iran had played a big role in Qanat construction, but difficulties in securing suitable workers and the introduction of pumping wells have changed the balance between Qanat and modern wells. Digging an underground Qanat is difficult and brings the risk of accidents, and maintenance operations are not easy.

Figure 15.2 Inside a Qanat system

A village's younger generation prefers to work in urban areas to obtain higher income, rather than perform hard labour in rural areas. This has been a common reason for the reduced adoption of the Qanat system.

- *Technical problems*: There have been several technical improvements, including the use of concrete pipelines for tunnels, replacing animal power with tractors, recharging water pumped up to the Qanat, etc. However, partial support does not solve the difficulties in digging the deep shaft and long underground tunnels required during construction of a Qanat (see figure 15.2). Ambitious technological innovation such as robots may solve the problem, but are probably difficult to implement because of the initial high investment cost.

In the case of Xinjiang, I must mention that the Song Yudong group, in close collaboration with Xinjiang local authorities and peoples, have published several comments on how to revitalize existing Karez systems, including an overall plan for protection and improvement of existing Karez. The planning and layout of a Karez should be based on the overall planning of the water resources and hydrogeological conditions of the locality; harmonization between the economy, social development and environment protection; and coping with conflicts between Karez, pumping wells and canal linings. The experience from Turpan Prefecture on water resources development can be summarized as follows:

- Diverting river water nearby for irrigation in the upper reaches of the river.
- Diverting spring water for irrigation of areas near the outlet mountain valley marginal fringe of the alluvial fan.
- Abstracting water from Karez and pump wells for irrigation at the middle and lower reaches of the river.
- Building pump wells at the lower places of Karez to minimize mutual interference.[i]

These proposals are not only for Xinjiang Karez, but may be applied to Qanat in Iran or Foggara in the Sahara as a whole.

Urgent need for bilateral and international cooperation

Under the above-mentioned situation, we need precise and detailed information on each region. For example, very recently the Iranian Ministry of Agriculture published a very extensive directory on agricultural land that includes abundant information on Qanat. In Xinjiang, there is accumulated hydrological information on Qanat in Turpan that will be useful for future sustainable development of existing Qanat systems. And recently, international organizations such as UNESCO and United Nations University (UNU) have shown interest in supporting Qanat studies, either through the International Hydrological Programme that covers member states or the Traditional Technology in Drylands Programme that supports young researchers in Qanat countries. In the case of UNU fellowships on traditional water management in dry areas, there are already six young Fellows in Syria, Oman, Tunisia and Yemen.

Besides the present and future of Qanat systems, we still need to carry out international research projects on the origin and diffusion of Qanat. For this purpose, increased cooperation among developed and developing countries is extremely important. It should not be restricted to holding workshops or conferences, but also proceed to actual exchange of researchers, administrators, and diggers (Moqqani in Iran or Kunchang in Xingian). For example, the Xinjiang Karez people might visit Iran, or vice versa, to exchange their experiences face to face.

For international networking, it will be necessary to prepare lists of researchers[ii] and bibliographies on Qanat in each region, and to translate precious information on Qanat written in several languages into other languages. The first international conference on Qanat was held in Iran in 2000, and another international conference stressing the application of Qanat technology in modern tunnel digging was held in 2003 in Luxembourg. Those events presented a good opportunity to enhance concrete cooperation and commitment from international institutions, researchers and decision makers on various interrelated issues. An important European Union programme on a comprehensive survey on Qanat around the Mediterranean basin was held in 2004, allowing a real opportunity for local researchers to be involved in a well-supported programme.

Finally, we must think about the role of future generations who will continue our efforts to preserve the unique Qanat system. While there is some information on Qanat in university texts, I think that public interest in the Qanat system may not be sufficient. For the conservation of this excellent cultural heritage, some teaching programmes on Qanat should be established for school children.

Notes

i. Song Yudong et al., ‘‘Research on Xinjiang Karez,’’ in the Proceedings of the First International Symposium on Qanat.
ii. Not forgetting to include social and human scientists, because research on Qanat systems is not only a technical issue but also very much related to socioeconomic and cultural issues of local communities that are involved with the Qanat system.

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16

Computational fluid mechanics analysis of the Roman siphon at Aspendos, Turkey, and a PreColumbian Chimu hydraulic control system in the Jequetepeque Valley, Peru

Charles Ortloff

New world systems: the Jequetepeque Canal

Early surveys of canal and irrigation agricultural field systems on the north coast of Peru were conducted by Kosok (1965). Later, more detailed survey and mapping of the Jequetepeque Valley systems (Eling, 1986), intravalley Moche Valley systems and Moche-Chicama Intervalley systems (Ortloff, 1993) were reported. While these studies largely constitute the extent of north coast canal system survey and mapping, the next logical phase is computational fluid dynamics (CFD) analysis of the hydraulic functioning of known systems, so as to discover the degree of technical innovation.

While the historical, architectural, cultural and artistic achievements of the north coast Chimu Empire of ancient Peru have been described in the literature (Keatinge, 1988), recent field studies have noted evidence of hydraulic engineering structures to control and manipulate water flows. Since all major valleys under Chimu control show evidence of massive state-sponsored, hydraulic canal infrastructures to support irrigation agriculture, it follows that hydraulic science was co-developed to provide tailored flow-rate canals to supply field systems distant from river inlets. As considerations of soil type, crop type and water demands, alternate field system watering strategies, valley topography and defence from drought and large rainfall runoff events influence canal design and placement, an accompanying hydraulic science with flexibility to design and modify canals according to these considerations is expected in the archaeological record.

Most probably, observations of water flow phenomena over time served to provide a database for the empirical design principles used for canal layout and design. While no Chimu writing systems are known today, calculation and data storage devices existed (although their application to hydraulic design methodology, water resource allocation and historical climatological data records is unexplored). As canal delivery flow rate relies on bed slope angle, canal cross-section, wall roughness and flow characterization (subcritical, critical, supercritical), allied technical disciplines related to route layout, surveying, water delivery sequencing and routing through multiple canal branches are key technologies for understanding a complete picture of Chimu hydraulics practice.

An investigation of a recently discovered, 14th-century canal hydraulic feature of the Chimu Talambo-Farfán Canal, located in the Jequetepeque Valley (figure 16.1), shows the remains of a Chimu canal system associated with the site of Farfan (though some upstream canal segments are associated with earlier valley occupation by Gallinazo and late-period Moche occupants in the period from 400 to 800). The distal end of the 35-km long Talambo-Farfán Canal crosses a sequence of deep erosion-incised gullies (*quebradas*) in the foothill region of Cerro Faclo by means of three large earth-fill aqueduct structures level to the land surface height before encountering the distal Hoya Hondada aqueduct (see figure 16.1). Due to the large depth and width of this *quebrada*, a long, low aqueduct design deep within the *quebrada* was selected with a steep, 40-degree downward approach chute from the upstream bluff.

After passage over the aqueduct, the canal continues down the western sidewall of the *quebrada* to field systems located on the southern boundary of the Pampa de Faclo, approximately 8 km south of the ancient city of Pacatnamú. The effect of a high flow rate and supercritical flow down the steep chute would be to create a massive hydraulic jump at the junction with the low slope aqueduct, which would lead to severe canal bed erosion and overflow from the aqueduct. Unless a number of upstream hydraulic controls are in place to limit both the velocity and flow rate of water entering the steep angle chute, aqueduct destruction is guaranteed. The following analysis details the ancient Chimu hydraulic engineering solution to ensure aqueduct survivability.

Engineering analysis of the Jequetepeque Canal

Past the extensive field systems bordering the Farfán Sur area, which provided part of the agricultural base of the Chimu administrative centre of

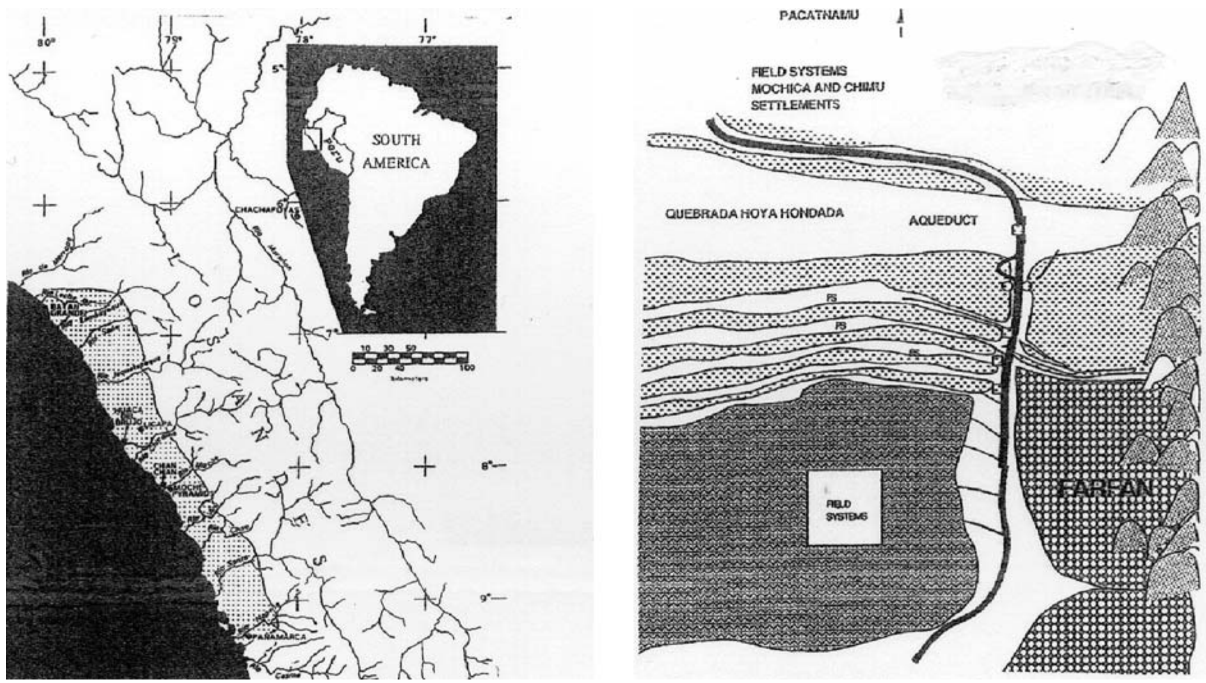

Figure 16.1 A map of Peru showing Jequetepeque Valley and the Hoya Hondada Aqueduct in the vicinity of the city of Farfan

Farfan, the canal enters a foothill region west of the Cerro Faclo coastal mountain range, which is cut by many deep *quebradas* transverse to the canal direction. The deep *quebradas*, formed over time from successive El Niño rainfall runoff events sculpting erosion channels in the soft soil deposits, formed natural obstacles to canal extension. To bridge the multiple *quebradas*, a series of large earth-fill aqueducts and many small aqueduct structures were constructed to extend the Talambo-Farfán canal to the vast Pampa de Faclo.

While the aqueducts upstream of the Hoya Hondada *quebrada* were built at the height of the opposing cliff faces to maintain the small bed slope of the canal, as the canal approached the largest and westernmost Hoya Hondada *quebrada*, a different aqueduct design strategy was utilized. Due to the extreme width (100 metres) and depth (20 metres) of this *quebrada*, a high aqueduct design typical of upstream designs would have the disadvantage of acting as a massive dam structure impounding runoff water to great depth, subjecting the aqueduct to breakthrough and undermining failure. While many Chimu aqueducts have large boulder bases or stone-lined culverts to permit flow passage, such preservation strategies fail when the impound water height becomes high and the water volume accumulation rate upstream of the dam far exceeds the flow rate capacity of culvert structures.

For the Hoya Hondada aqueduct, a different design strategy was utilized: the aqueduct was set low in the *quebrada*, about 5 metres from the natural *quebrada* bottom surface with a long, 40-degree steep chute joining the high elevation part of the canal to the low aqueduct. Although the aqueduct is deep within the *quebrada*, a low slope canal on the opposing *quebrada* sidewall exists to lift the canal onto the Pampa de Faclo surface to provide water for field systems.

The hydraulics problem associated with the steep chute relates to the rapid gravitational acceleration of water and the formation of a large hydraulic jump at the channel-aqueduct slope change junction. The severity and height of the large Froude number hydraulic jump is sufficient to destroy the aqueduct by erosion processes unless hydraulic controls are in place upstream of the aqueduct to dissipate stream energy and/or reduce the flow rate so as to reduce the strength of the hydraulic jump to a level that does not imperil the integrity of the aqueduct structure. Provided flow control and energy dissipation can be accomplished by an upstream hydraulic control structure, the aqueduct structure can resist damage from channel bed erosion.

The channel upstream of the Hoya Hondada chute and aqueduct indicates that an energy dissipation hydraulic structure was installed to influence flow behaviour. The hydraulic structure consists of two pairs of opposing boulders with a 70-cm separation distance between each boulder,

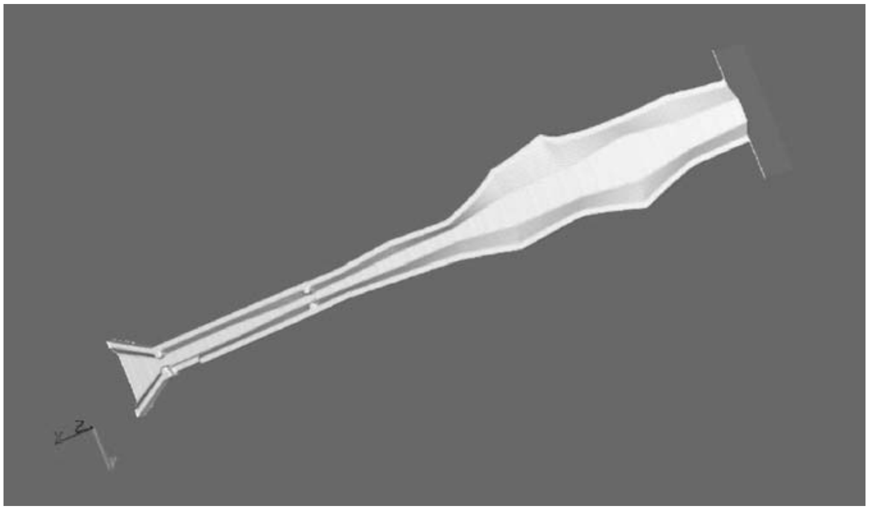

Figure 16.2 A FLOW-3D CFD model of the dual choke structure upstream of the Hoya Hondada aqueduct

and a 13.2-m streamwise separation distance between boulder pairs. The boulders are roughly cylindrical and are higher than the canal banks. The channel containing this structure has variations in width and sidewall angle; between the boulder pairs, a side overflow weir is in place that leads to a channel on the downstream side of the Hoya Hondada aqueduct. The hydraulic function of the control structure can best be described by use of CFD methods involving a numerical solution (FLOW-3D 2001) of the governing Navier-Stokes equations. A computer model (figure 16.2) of the channel geometry with boulder pairs in place was first constructed; the details of water flow in this hydraulic control structure revealed the underlying Chimu hydraulic strategy through analysis of the flow patterns.

The results of CFD analysis are shown in figure 16.3 for trial input flow rate values from 1 to 8 m^3/s, corresponding to the appropriate normal depth at the entry $x = 0.0$ m station. The range of trial flow rate values was investigated to determine the conditions under which the dual choke system activates. As the trial channel flow rate increases, apparently past a certain critical flow rate the water height increases ahead of the downstream constriction, and the side weir is activated to release water from the channel, thereby decreasing the exit channel flow rate. As the trial water velocity entering the channel increases, the water velocity in the constriction (throat) between boulders continually increases as the

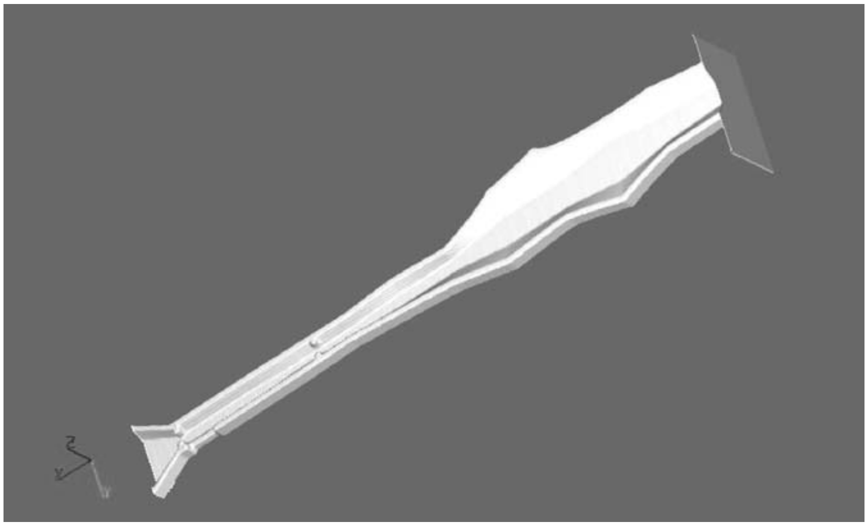

Figure 16.3 A computed water flow pattern showing water release from the side weir for a volume flow rate of 3.5 m^3/sec

backed-up upstream water level increases. At a critical height of the upstream water level, where the throat Froude number approaches unity, the throat is considered choked (i.e., the flow rate through the choke achieves a maximum value independent of upstream water height). The upstream choke apparently activates at inlet velocities past about 7 m/s, while the downstream choke apparently activates at inlet velocities about 3 to 5 m/s.

This difference is due to increases on the Froude number in the zone downstream of the first choke, because of water gravitational acceleration on a hydraulically steep slope (i.e., the water velocity increases while the depth decreases in the zone before the second choke). Since flow into the second choke is supercritical for input flow rates examined at the $x = 0.0$ m station, the second choke acts to form a hydraulic jump, and the flow rate is again limited by critical conditions at the second throat. As the choked flow rate of the downstream choke is less than that of the upstream choke, the difference must be equal to the flow rate shunted over the side overflow weir. With the double choke structure, the maximum transmissible flow rate appears to be on the order of 4 m^3/s (figure 16.4), which is considered a ''safe'' flow rate to sustain the downstream aqueduct without significant hydraulic jump damage. (Note that for flow rates less than about 3 m^3/s, the chokes are essentially inactive and permit water passage without restriction or side weir overflow.)

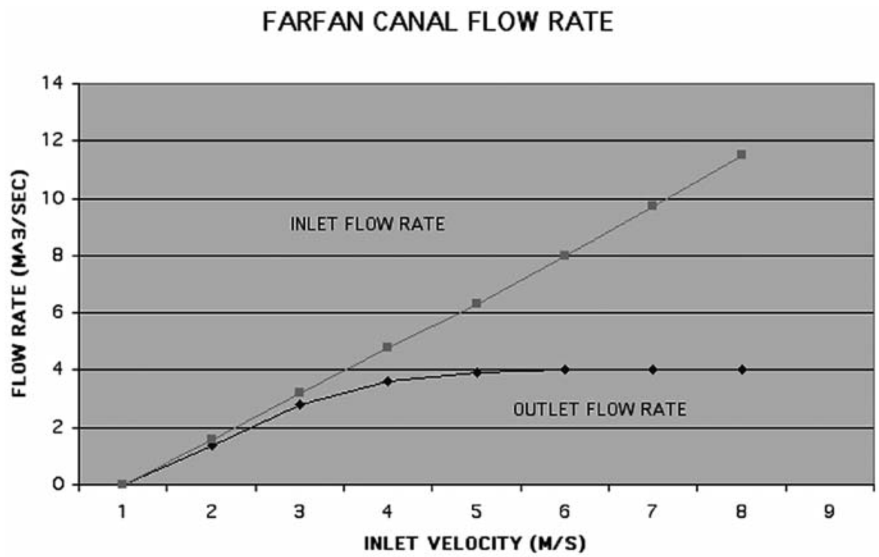

Figure 16.4 A chart showing the inlet flow rate compared to the modified outlet flow rate due to side weir overflow induced by the choke system

The double choke system is augmented with a further downstream energy dissipation system on the steep slope channel. Figure 16.5 shows that a channel bifurcation exists about 30 metres downstream of the double choke system, at the 115-m contour. The left downstream channel is at a lower slope and circles a small hill before rejoining the main channel at a junction point upstream of the chute. The subtracted subcritical velocity stream from the lower slope channel, acting on the reduced flow rate supercritical stream, has the effect of creating an energy dissipating hydraulic jump at the channel intersection downstream from the dual choke system; this has the effect of weakening the chute-aqueduct downstream hydraulic jump yet further.

The net effect of the energy dissipation controls and the weir structure is to limit the channel flow rate (and entry velocity) onto the Hoya Hondada aqueduct, thus limiting hydraulic jump erosive damage. Although a large part of the steep slope chute is no longer extant, there is indication that stones placed in the chute bed may have provided a further energy dissipation mechanism to reduce stream velocity. Since the canal is occasionally subject to massive El Niño rainfall runoff from the nearby Cerro Faclo mountain range, large flow rates in a canal could easily destroy the Hoya Hondada aqueduct by creation of a massive hydraulic jump at the channel-aqueduct junction. By diverting water over the side weir and us-

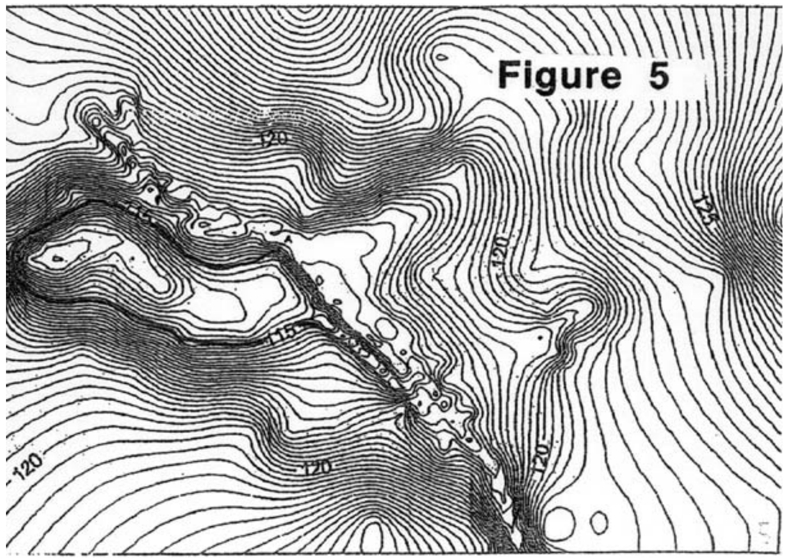

Figure 16.5 A bifurcation canal at the 115-m contour leading water from the main canal, and shown reintroducing subcritical water back to the main flow as an energy dissipation mechanism

ing energy dissipation structures, excess water and energy are removed from the canal to provide a protective hydraulic feature to preserve the aqueduct. As the canal can support up to 4 m^3/s before weir overflow activation, this flow rate represents a sustainable maximum value to a location 35 km from the river inlet.

This flow rate may be achieved, despite evaporation and seepage losses, by blocking all other canal branches to direct all flow to settlements and agricultural fields on the Pampa Faclo. Apparently, the water flow rate x delivery time = water volume delivered through each canal branch to a field sector was a known entity to sustain crops in that sector according to their importance; the assignment of water volumes, therefore, was probably carefully metered for maximum agricultural productivity. As settlements on the outlying Pampa Faclo were somewhat remote from the Farfan centre and only accessible over very rough terrain, it may be surmised that hydraulics engineering expertise of the highest order was utilized to extend agricultural land resources to meet the demands of population increase. The present analysis gives insight into the technical base available to Chimu hydraulic engineers.

Previous studies (Ortloff, 1993) have noted evidence of elements of hydraulic controls to regulate water flows in inter- and intra-valley Chimu canal systems. The present study adds a further example of a hydraulic control device used to limit water flow rates in critical canal sections – presumably as a defensive measure against aqueduct washout during El Niño events. Other examples of steep-slope channel constrictions formed by opposing stones set with a narrow opening are numerous within the Farfán field system area. Basically, all channel constrictions of this type create a hydraulic jump ahead of the constriction with a high-height, low-velocity zone entering the throat. This hydraulic control then permits low-velocity water to enter the low-slope field systems to permit an effective irrigation system characterized by low-velocity water flows that promote seepage into agricultural field plots.

Old world systems: the Aspendos siphon

The ancient city of Aspendos, located about 50 km east of Antalya and about 12 km north of the southern coast of Turkey, was initially founded as the Hellenic colony of the Argives; it was already known as Aspendos by Greek historians Thucydides and Zenophon in their lifetimes. In 133 BC, the city came under Roman rule, and extensive urban development followed, accompanied by a water delivery system in the form of a large inverted siphon system.

The importance of the city derived from its commanding position on the Antatalya-Side-Pergammon-Sillyon-Selge and Pisidian commerce routes, as well as its position on the Eurymedon River where Mediterranean access was possible. The city's role as an inland port city and commerce centre was noted by Strabo, who commented upon its exports of salt, wheat, wool and oil that gave prosperity to the city in Roman times from its central position on north-south trade routes within western and central Turkey.

Characteristic of the importance Rome placed on its eastern economic outposts that served as conduits for resource transfer to central state authority, major state-sponsored building projects were instituted to demonstrate dominance. As such, the siphon system incorporated the highest technology available to Roman engineers and represented an exercise of a technology base that, when later analysed by modern CFD methods, provides insight into Roman civil engineering practice. Through surviving Roman administrative and engineering texts related to water management and distribution (Vitruvius, 1999; Evans, 1994; Herschel, 1973), prescientific notions survive related to aqueduct and siphon engineering details; however, it is likely that much more was known, but not recorded, by the field practitioners of Roman civil engineering.

Since no further descriptive material is available from ancient sources, the next recourse to discover ancient civil engineering practice is use of modern CFD methods to investigate siphon hydraulic behaviour. By such analysis, insights into the unwritten accomplishments of Roman engineers can be extracted from their surviving engineering works. From a survey of the complete Aspendos system (Kessener, 2000), precise measurements of siphon dimensions are available and serve as the basis of the technical analysis to follow.

The Aspendos siphon system (figures 16.6 and 16.7) consisted of three main siphon legs (2, 4, 6) joined by (non-surviving) elevated open tower basins (3, 5). A shallow header tank (1) with a side overflow weir accepts water from a channel originating at a distant spring, while the distal end of the siphon system contains receiving tank (7) leading water to a distribution system within the urban core. Based on the dimensions shown in figure 16.6, the total siphon system length was 1.67 km, with sector (1), (2) and (3) lengths of 0.592, 0.924 and 0.154 km, respectively. The header tank (1) to receiving tank (7) height difference was 14.5 m, and tower (3) and (5) heights are estimated to have been about 38 and 32 m, respectively, above the lower horizontal level reference plane segments of the siphon. The use of elevated, single or multiple tier, arched structures to support horizontal siphon pipeline segments (venters) as well as elevated tower constructions is characteristic of the Aspendos siphon design.

A top-view indicates that some angle changes are evident at the elevated towers (16 degrees at tower (3), 55 degrees at tower (5)). The piping system carried by the arched support structure consisted of joined 0.8-m^3 stone blocks with a 30-cm central cylindrical bore hole. The block ends were cut to form socket attachments, with a sealant used to cement individual ends together to render the joints watertight. It is estimated (Kessener, 2000) that about 3,200 cored blocks originally made up the total siphon pipeline length. Interestingly, several of the blocks contain small 3-cm diameter perforations from the central cylindrical core to the outside surface; the hydraulic function of these remains unclear from the Vitruvian text. While some contemporary authors attribute these perforations to cleaning/drainage holes (Hodge, 1983), other authors (Smith, 1976; Kessener, 2000; Fahlbusch and Peleg, 1992) assign hydraulic functions variously related to entrained air release, pressure relief and programmed leakage to regulate head.

The function of the elevated tower open basins is also controversial – first, because they are conjectural (as the physical remains no longer exist) and, second, because the hydraulic function of the elevated basins is unknown. To add further controversy as to the understanding of Roman siphon engineering practice, the Roman author Vitruvius mentions that *colliquiaria* are key to successful siphon usage, although the meaning of the Latin term is not provided. (Additional Vitruvuian cautions relate to

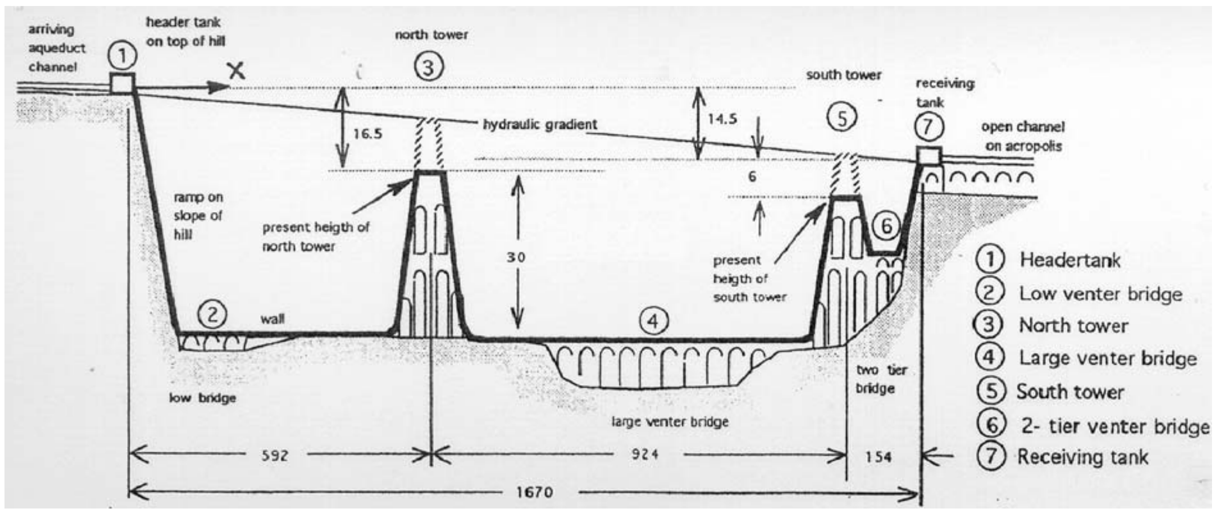

Figure 16.6 Aspendos siphon dimensions

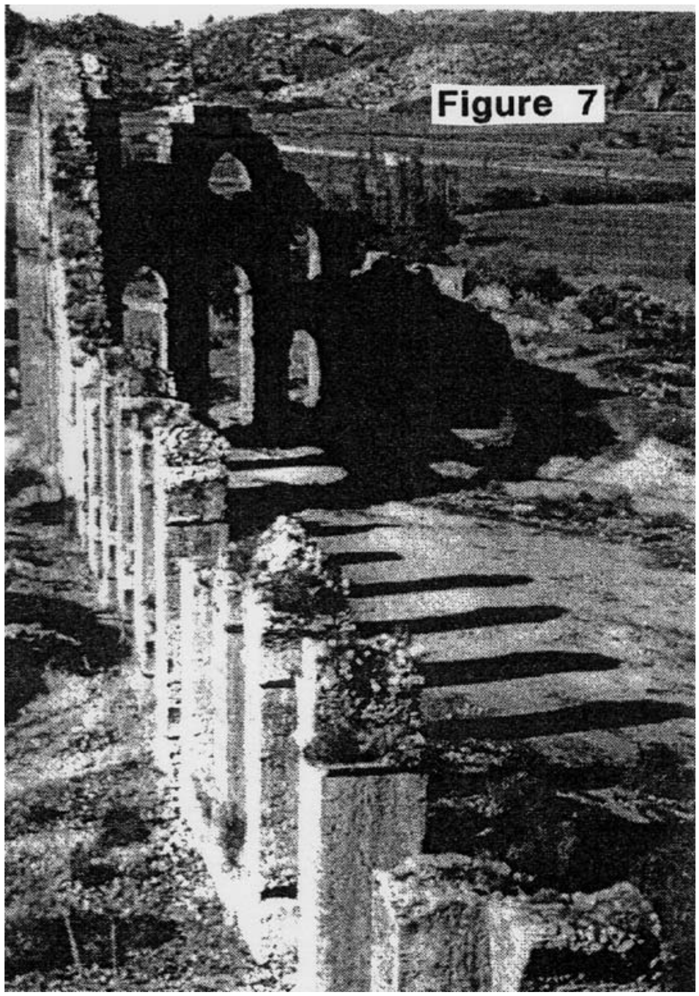

Figure 16.7 Remains of the South Tower

the slow filling rate required in initiating siphon flow to avoid large force oscillations.) Unfortunately the term *colliquiaria* occurs nowhere else in Latin literature, and the technical meaning of the word is lost. That hydraulic phenomena are described in prescientific terms by Vitruvius adds to the confusion regarding the meaning of *colliquiaria*, as various modern translations provide an interpretation that represent hydraulic devices or principles which may not have been known in Roman times.

Discussion of results for the Aspendos siphon

The steady state inlet-to-outlet pressure difference Δp in the circular cross-section piping is usually described in terms key parameters in a Fanning chart (as shown in figure 16.10). Here, $\Delta p = f(L/D)(\rho/2)U^2$, where f is the Fanning friction factor, L the pipe length, ρ the water density, D the pipe diameter, and U the average flow velocity; $Re =$ Reynolds number $= UD/\nu$, where ν is the water kinematic viscosity. The Fanning friction factor is also dependent upon ε, where ε is the root-mean-squared wall roughness height. For an ε/D value, figure 16.10 gives the empirical relationship to relate Δp to the Reynolds number, from which the flow rate within the piping $(U\pi D^2/4)$ can be determined.

Note that the empirical relations shown in figure 16.10 apply throughout a wide Reynolds number range characteristic of both laminar and turbulent flows. While a Fanning chart is usually applied to steady-state flows, it can also be used for long-period, low-flow-rate transient flows, provided the key parameters can be locally estimated. To gain insight into siphon hydraulics behaviour for different ε/D values, transient flow velocities and pressures are solved for the siphon geometry shown in figure 16.6 (Ortloff et al., 2002).

The input flow into the header tank is assumed to enter the piping impulsively, and the siphon is assumed to be initially filled to the level of the receiving tank. While $\varepsilon/D = 0.001$ represents a smooth wall, medium range $\varepsilon/D = 0.01$ values are likely representative of the hand-manufactured, chipped, interior wall roughness found in sample piping sections located on site. Figures 16.8 and 16.9 show the progression of flow rates in successive siphon legs 1, 2 and 3 (corresponding to legs (2), (4) and (6) in figure 16.6) for ascending f values given a constant input flow velocity of 1.0 m/s in the turbulent Re range.

Note that while steady state Re is nominally on the order of 2.0×10^5, the start-up Re values can vary somewhat due to varying transient velocity in the different legs. The f values are relatively constant, however, for typical turbulent $Re > 10^4$ values, due to the turbulence induced by large wall roughness ($f > 0.005$), and are used in the analysis. Portions of these curves exceeding the input flow line indicate backflow coupling, i.e., oscillatory backflow into upstream legs through the elevated tanks. Since three elevated, open surface basins (3), (4) and (7) separate siphon legs (2), (4) and (6), the output flow rate into each successive leg is as indicated in figures 16.8 and 16.9. For high wall roughness ($\varepsilon/D = 0.010$, $f \approx 0.01$), small oscillations with but a long time to achieve steady state conditions occurs, while for low wall roughness ($\varepsilon/D = 0.004$, $f \approx 0.006$), backflow coupling between siphon legs occurs but yields shorter times to achieve steady-state conditions. Intermediate f values, in combination

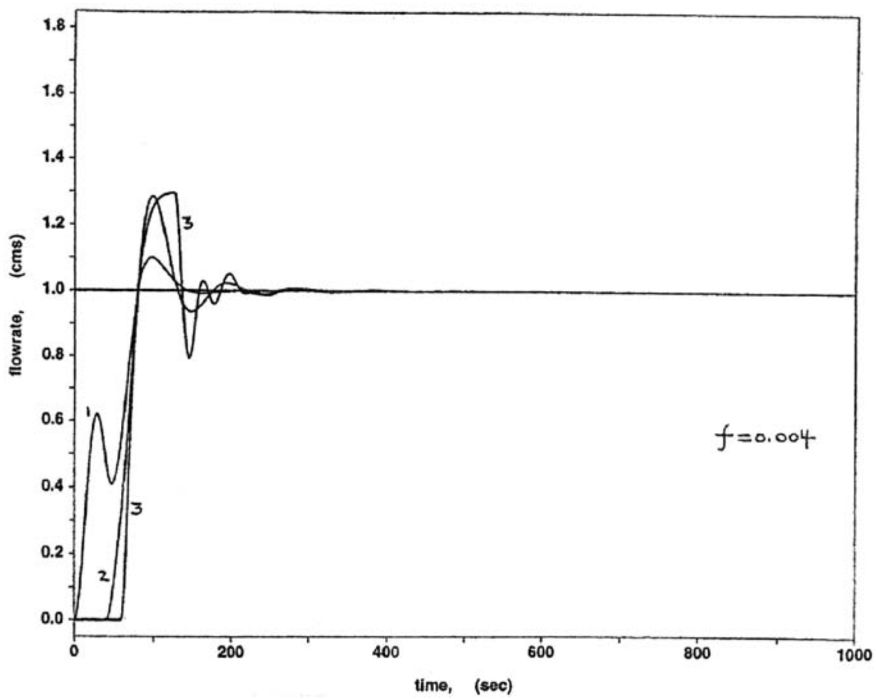

Figure 16.8 Flow rates (m^3/s) in siphon legs 1, 2 and 3 for $f = 0.004$, indicating oscillatory backflow amplification (flow rate normalized to inlet conditions)

with slowly increasing flow rates into the header tank up to 1.0 m/s, most likely represent the best working design compromise.

The outline polygon shown in figure 16.10 represents the typical transient siphon operating *Re* range and f boundaries. The best start-up operating conditions are most likely achieved at some central location within the polygon. However, note that excessive wall roughness limits the achievable steady-state flow rate, so that f and ε/D should most likely remain in the lower half of the polygon as a practical design option. While conditions during transient start-up may approach the polygon boundaries due to fluid column oscillations, use of Vitruvius' advice to limit header tank inflow rate (''the water is to be evenly and sparingly admitted from the fountain head''; Vitruvius, 1999) to eliminate pressure surges is next examined.

Figure 16.11 shows the results of limiting the inflow rate to the header tank so that the pipe inlet flow ramps from 0.0 to 1.0 m/s in 30 minutes for $f = 0.05$. This indicates that oscillatory behaviour in successive lines 2, 4 and 6 is strongly damped at low to moderate f values $(0.01 <$

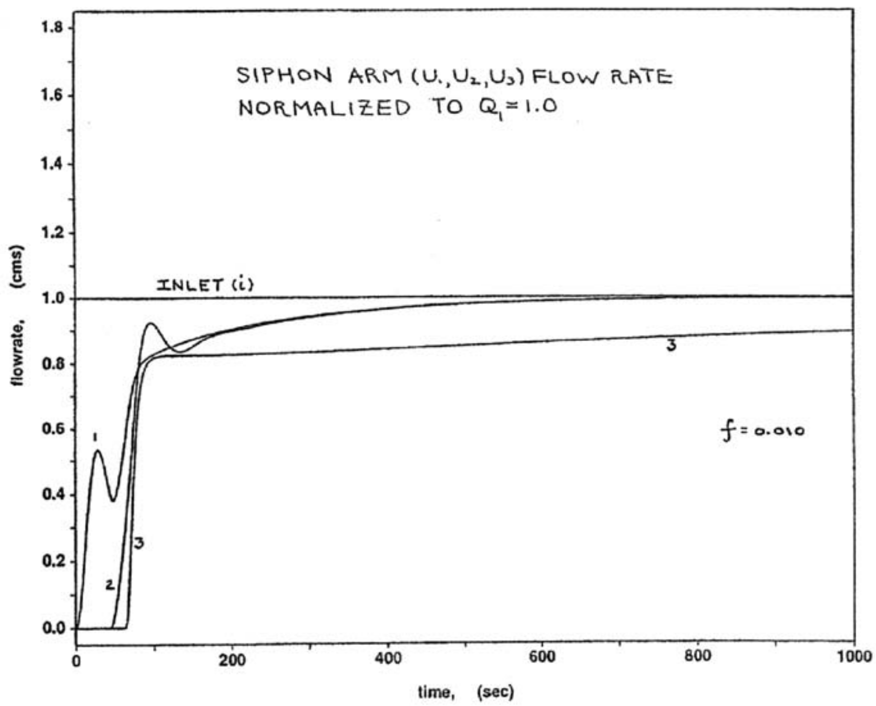

Figure 16.9 Flow rates (m^3/s) in siphon legs 1, 2 and 3 for $f = 0.010$, indicating smooth transfer of water from successive siphon legs (flow rate normalized to inlet conditions)

$f < 0.005$), so that steady state behaviour is achieved in about 11 to 16 minutes during filling, and backflow coupling is largely eliminated. Results at $f = 0.01$ show that yet more severe damping occurs. Here, it is assumed that the siphon is initially filled to the level of the receiving tank. Clearly, the slow filling rate has a beneficial effect in limiting start-up oscillations from developing as the momentum of entering fluid is reduced, thus reducing an energy source to initiate fluid column oscillations.

Figure 16.12 shows that discharge flow rate Q for pipe flow, represented in terms of the Reynolds number as $Re = 4Q/\pi D\nu$, is proportional to the pressure gradient Δp for laminar flows for $10^3 < Re < 10^4$ depending on wall roughness ε/D and free stream turbulence levels (in figure 16.12, $a = D$, $\eta = \mu$ and $\nabla p = \Delta p$/unit length). For fully developed turbulent flows, Re is found experimentally to vary as $(\Delta p)^n$, where n lies in the range between 0.5 to 0.6 depending upon ε/D. The laminar and turbulent portions intersect around $Re = 10^3$, but the gradual transition between

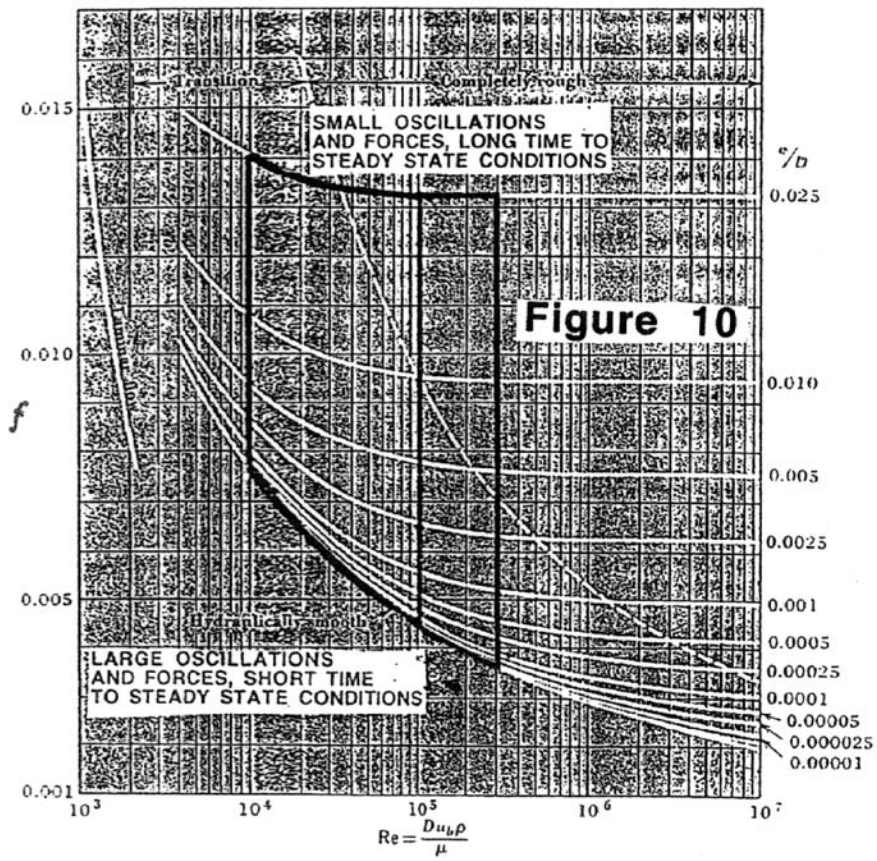

Figure 16.10 Fanning chart showing friction factor (f) as a function of Re for different ε/D roughness values (polygon represents operating range of the siphon)

curves occurs well above $Re = 10^3$. When the discharge rate is increased slowly from zero, the first departures from laminar conditions are observed at an upper critical Re value as high as 10^5 for smooth walls ($f \ll 0.001$), no local roughness disturbances, and a rounded inlet shape; otherwise, for non-smooth walls, laminar-turbulent transition occurs about $Re = 4{,}000$. When the discharge rate is reduced from a high value, laminar flow is not fully restored until Re falls to a lower critical value close to 2,300.

Within the hysteretic transition range between the two straight lines, intermittency is observed. The source of the intermittence may arise near the entry region, where the flow becomes locally turbulent and

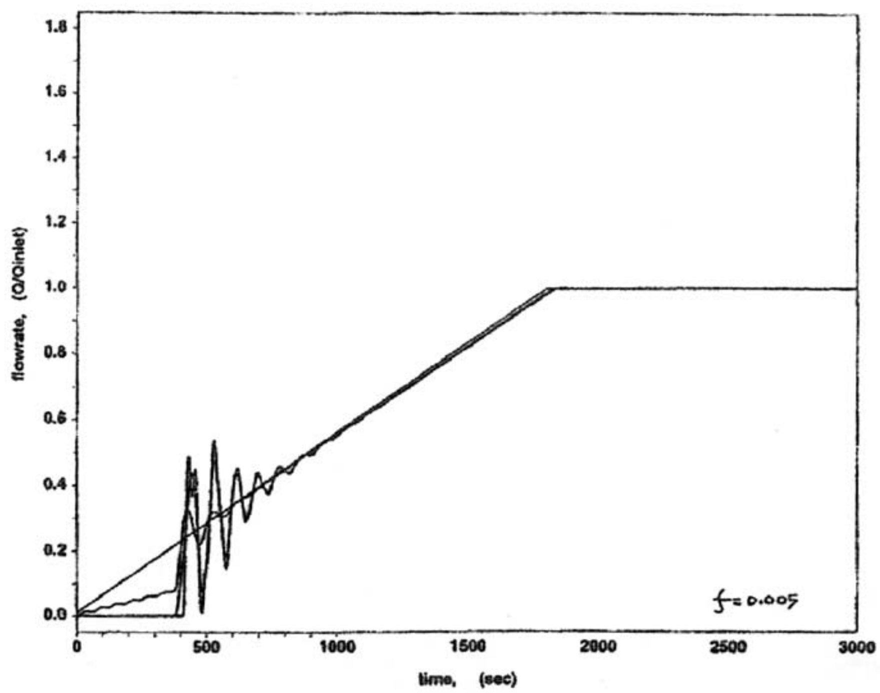

Figure 16.11 Siphon flow rates in successive legs showing the influence of slow filling

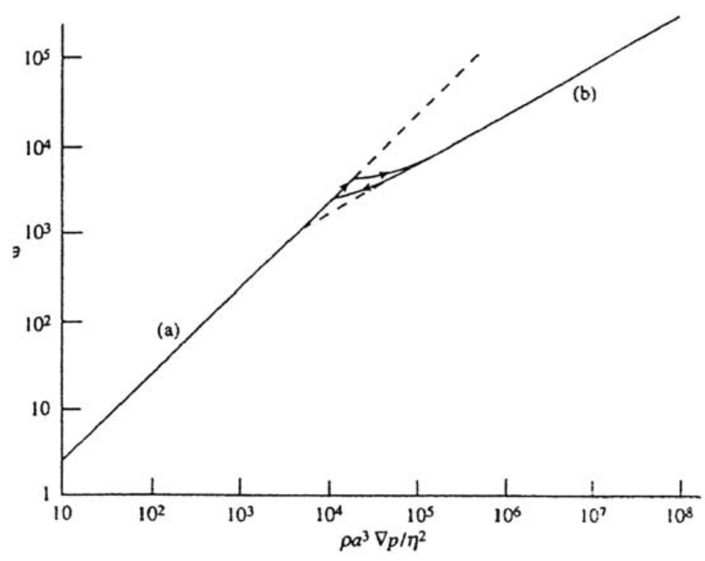

Figure 16.12 *Re* vs. pressure gradient chart for pipe flow

reaches the upper critical value and then spreads downstream, forming a "turbulent slug" (a zone of highly concentrated turbulent flow). From mass flow continuity, the mean velocity must be the same in the slug as it is in front of the slug, where the flow may be moving under laminar conditions. This implies that the pressure gradient is larger in the slug than in front of it and, thus, if the pressure drop along the pipe is constant once a slug has formed, the pressure gradient in the laminar fluid must be less than it was previously. The slug, therefore, locally reduces Q and U within it, and these parameters continue to decrease as long as the slug is increasing in length. When they have fallen such that Re is only about 2,300, relaminarization occurs near the entry zone. The slug may continue to increase in length if the velocity U_F with which its front end travels exceeds that of its rear end, U_R. Provided that the slug is expelled from the pipe, the initial conditions are reset and the described process is repeated.

In cases for which piping lengths are large, roughness varies along the length, and elevated open surface basins occur along the piping, with multiple translating, interacting slug zones that can emanate pressure waves that propagate and reflect throughout the system and can lead to chaotic discharge rates. Complications arise at the interfaces of laminar and turbulent flows, for example, at $Re = 4{,}000$, $U_F \approx 1.5U$ and $U_R \approx 0.7U$ (Faber, 1995), which is intermediate between the zero wall U value and the pipe axis $2U$ value. The U_R/U ratio falls steadily towards zero for $Re > 4{,}000$ while U_F/U remains relatively constant, indicating growing turbulent slug length. For $Re < 4000$, U_R/U rises while U_F/U falls; at the lower critical Re value, both become approximately equal.

Below the lower critical value, the flow is laminar because turbulent slugs shrink rather than grow. While steady state Re values for the Aspendos siphon are estimated to be no less than 5.0×10^4, local ε/D roughness can vary along the piping length (at cemented block junctions, for example), leading to local friction factor changes and, ultimately, local internal pressure changes. In combination with transition effects arising from turbulent slug formation in the critical Re range, the possibility of nonsteady discharge rates is high without an active damping mechanism. For $f = 0.01$ (see figure 16.9), fluid transfer from successive basins to the receiving tank shows little fluid oscillatory behaviour and large damping effects from the successive basin transfer process. The basins, in this case, serve as accumulators to damp the successive transfer of fluid energy between siphon legs by limiting the upstream propagation of pressure waves and providing fluid energy absorption mechanisms through sloshing. For $f = 0.001$, oscillatory behaviour in siphon legs occurs with little energy absorption by fluid friction effects and limited energy absorption by open tank sloshing effects, resulting in chaotic delivery rates to the receiving tank. Values $0.008 < f < 0.006$, typical of chipped block interior surfaces, appear to result in adequate damping between siphon legs and promote rapid transition to a steady-state flow rate condition from an impulsive start. Slow-filling at similar f values further reduces oscillatory and backflow effects (see figure 16.11).

The source of fluid energy to initiate siphon leg oscillations during initial filling and start-up may come from a variety of sources. Among these are:

- a supply rate to the header tank exceeding acceptance flow rates to individual siphon legs (this may be somewhat balanced by the header tank overflow weir);
- the momentum imparted to water already in a siphon leg from inflows;
- overflow from successive open basins to successive siphon legs during filling, imparting momentum to water already in siphon legs; and
- open channel flows in steep angle siphon leg segments, resulting in an upstream-moving hydraulic jump that drowns inlets and results in piping flow rate change and head/elevated tank time-varying head.

While this latter effect may be reduced by backflow drainage from the header tank overflow weir, head tank surges can still drive oscillations. Many of these effects can occur in successive siphon legs with upstream/downstream interactive feedback through open basins that drive fluid column oscillations through complex interactive effects.

The next question is the possible meaning of the Vitruvian term *colliquiaria*, and its relevance to the hydraulic behaviour of the siphon. *Colliquiaria* could possibly relate to:

1. the function of observed transverse holes leading from the piping core to outside atmosphere,
2. pressure relief valves to limit pressure excursion values to safe limits,
3. drainage holes to facilitate cleaning,
4. release openings to let entrapped air escape from the system,
5. elevated head tanks to reduce siphon leg water column oscillations, or
6. overflow weirs in the receiving head tank to limit input flow rate.

While the presence of the elevated open basins may serve to satisfy the items 4 and 5 in the list, and many of the other suggestions have practical merit, research was focused on the ubiquitous nature of transverse holes. Since the formation of turbulent slugs and oscillatory fluid column behaviour characterize siphon start-up and increase the time to achieve steady-state operation with a constant discharge rate to the receiving tank, some mechanism to reduce pressure and velocity oscillations along the siphon lines would help to induce a steady flow rate.

If small transverse holes are present through some of the blocks, then some additional leakage can occur. This implies that although some leakage occurs from the holes (which also provides for entrapped air to be forced from the system on long horizontal stretches of the siphon), the leakage can help reduce the local Reynolds number to modify the formation of turbulent slugs and, thus, reduce the possibility of fluid column oscillations. While some drainage leads to head loss and minor water mass loss within the siphon piping, it can also limit pressure excursions to diminish fluctuating forces acting on the block joints, thus limiting leakage. The leakage mass loss also promotes relaminarization as the Reynolds number decreases, reducing wall friction forces. Only a few holes are required on occasional blocks to achieve these benefits, as the (overpressure) turbulent slugs and/or pressure waves ultimately travel past dispersed open holes and diminish intensity by a head change adjustment.

Field observation allows the conjecture that accumulations of calcium carbonate deposits on the siphon superstructure away from the open basins could arise from occasional transverse hole leakage effects. In essence, the transverse holes may fine-tune the siphon flow rate to achieve low start-up oscillations and steady delivery flow rate at minimum input head tank depth. Tests were run to duplicate the *Re* range of the siphon using clear tubing and an adjustable leakage valve placed near an adjustable head and flow rate source. In addition to results verifying the above conclusions, several new effects were observed to explain the possible function of leakage holes. It was observed that air bubbles originating from the header tank inflow were effectively purged by outflow from the leakage holes placed downstream from the header tank, limiting their further travel in the piping. Secondly, it was observed that for cases in which an elevated tank head temporarily exceeded that in an upstream tank (as can occur during oscillatory start-up), the holes released a burst of water and thus served as an additional damping mechanism to limit upstream propagation of water column oscillations. In this case, a downstream tank head increase served to increase back-pressure resistance, causing temporary water bursts from the leakage holes exceeding the nominal leakage rate. The leakage effect limits tank sloshing and helps to promote steady state siphon behaviour.

A third effect relates to cases for which the siphon may operate with partial flow in some of the downward angled legs. As long as a positive head is maintained between the upstream piping water level and the next elevated tank, the siphon will transfer water. As flow resistance is low for internal piping segments supporting partial, supercritical flow (that terminates in a hydraulic jump to set the downstream full flow water level), some savings in friction head loss can be achieved. This (probably non-optimum) operating condition then relies on the transverse holes to admit air into the air space above the partial flow region to help eliminate partial vacuum regions and flow surging.

In summary, fluid mechanics models describing the transient hydraulic behaviour of the Aspendos siphon system have shown that internal piping wall roughness is a key parameter to determine not only steady-state flow rate but also the start-up oscillatory behaviour. For large wall roughness ($f = 0.01$), small amplitude start-up oscillations occur, but siphon leg (6) reaches steady state conditions only after a long time (>2 hours); additionally, large wall roughness limits the ultimate flow rate.

For small wall roughness, (e.g., $f < 0.004$), large start-up oscillations and forces occur, but the time to reach a steady state flow rate is much shorter. This suggests that an intermediate f value, about equal to that internal wall roughness occurring during hand chipping manufacture ($f \approx 0.006$), represents a design optimal strategy, perhaps achieved fortuitously. While these conclusions are based upon a start-up strategy of admitting water into the header tank at a given velocity, assuming an initial water height in the siphon equal to that of the receiving basin, further calculations made assuming a slow ramp entry velocity yield interesting results. At a slow entry velocity (piping velocity ramped from 0.0 to 1.0 m/s in 2,000 sec, or approximately 1/2 hour), steady state is achieved in about 500 sec for $f = 0.005$ and in 200 sec for $f = 0.01$. This indicates that slow filling greatly reduces the time to achieve steady state conditions, and confirms an observation suggested by Vitruvius some 2,000 years ago. The elevated tower basins serve as the ultimate release points for trapped air and as accumulators to damp the transmission of pressure waves generated between siphon segments during transient start-up.

The shallow header tank with an overflow weir at 1.0-m height serves both to limit the entry flow rate and damp backflow-caused sloshing transient head changes that help drive line oscillations. For a slow-filling procedure and an intermediate f value, the Aspendos siphon design is able to limit the duration and magnitude of oscillatory start-up compression forces on joined siphon blocks to limit leakage and system breakage.

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17

Roman hydraulic technology and problems in modern pressurized pipeline systems

Paul Kessener

Efficient transportation of water has always played a key role in the exploitation of water resources, whether for domestic use or for industrial and agricultural purposes, or for the conveyance of waste water. In August 2002, a colloquium was held at Delft, The Netherlands (initiated by Delft Hydraulics and the Technical University Delft, together with major Dutch organizations responsible for state waste-water handling), to discuss the problem of pressure losses in national sewer pipeline systems. Investigations over a period of more than 10 years (1990–2000) had shown that air entrapped at local high points accounted for major losses in the discharge capacity. It was calculated that the prevention of air-entrapment could reduce operational energy costs by up to 30 per cent, apart from the costs of redesigning because of insufficient capacity.

Ancient pipeline systems used for freshwater transport were usually gravity-driven conveyance systems that operated at times under conditions of fully filled conduit flow at considerable pressure (up to 20 bar). Entrainment of air at the intake of these conduits occurred in the old days, just as it does today. This chapter discusses problems arising from air entrapment for ancient pressurized conduit systems, as well as the solutions that Roman engineers applied to cope with these problems. The newly re-attained view that air entrapped in modern sewer pipeline systems may be the cause of considerable pressure losses might have been considered at an earlier stage, with great savings made possible, had modern engineers paid more attention to the history of water transport.

Pressure losses in modern sewer pipeline systems

The discharge capacity of modern pressurized sewer pipeline systems is often assumed not to change over time (i.e., pumping performance is assumed to remain constant). In reality, though, discharge capacity often drops from design capacity, but may go unnoticed because of oversized pumping facilities and the absence of monitoring equipment. Pipeline suppliers generally mention wall roughness as the main factor for pressure losses, but the effects of scaling, bio-films and deposits are often underestimated.

For the 60-km long sewer system of the Hoogheemraadschap West Brabant in The Netherlands, which transports about 15,000 cubic meters of waste water per hour by means of pipes up to 1,800-mm diameter, pressure loss was found to be much higher than designed, and with considerable variation over time. This meant that the discharge capacity had been significantly reduced, which could only be compensated for by higher pumping effort (leading to an increase of up to 30 per cent in operational energy costs). Eventually, it was found necessary to design a new pipe system.

Over a 10-year period, possible causes for the decrease in capacity were investigated. It was found that scaling, although present, had only a minor effect on pipe resistance, while the formation of bio-film sometimes tended to decrease the resistance by effectively changing wall roughness to a lower value (although some increase might be expected for thick and irregular bio-films because of reduction of the pipe diameter). Deposits at the pipe bottom may occur for low flow velocities, but this was not seen in the systems investigated. Surprisingly large amounts of gas were retrieved from the system at local high points, however, which turned out to consist mainly of nitrogen (in contrast to the expected bio-gases, methane and carbon dioxide). The conclusion of the investigation, which was greatly hampered by the absence of monitoring apparatus in the original design, was that the main factors for an increase of pipe resistance and capacity loss in the large-diameter pipe systems were air entrapment at intake points, and the unexpected behaviour of air pockets and air bubbles at high points, especially under discontinuous operating conditions (Kamma and van Zijl, 2002).

Roman pressurized pipeline systems

In Roman times, freshwater was usually transported – sometimes over great distances – by means of open channels sloping down from source to city. The oldest aqueduct of Rome, the Aqua Appia, dates from the

3rd century BC. During the Pax Romana (2nd century AD), prosperity increased enormously in the Roman Empire. Almost every city, small or large, acquired an aqueduct or added to an existing one, to meet the growing demand for increased luxury and the popularity of bathing, as well as the growing population. Gaul alone counted over 300 aqueducts (Hodge, 1992). The supply of running water became a standard feature, financed by the emperor or by private funding (with the benefactor mentioned in an inscription). Aqueducts frequently ended in a lustrous, decorated *nymphaeum* (a decorative fountain wall) or *castellum divisorium* (a distribution chamber or tank) as a demonstration of pride and respect for the technical achievement. Behind all this stood the often-anonymous Roman engineer, whose task it was to bring good quality water to the city, often at an elevated location.

To transport water to the desired spot, the engineer had just one driving force at his disposition: gravity. Although this was the only available driving force to transport water in large quantities over great distances (table 17.1), it was also a very convenient one. As long as one took care that the water could flow downhill from source to destination, it would do so, and it would get there all by itself. The effort was to build a channel to meet this condition, which meant careful surveying over great distances, and the construction of (if necessary) very long tunnels and huge bridges.[i] If a valley was too deep or too wide to circumvent, or to be crossed by a bridge, an inverted siphon was applied. This device carried the water to the other side of the valley in a closed pipeline under pressure according to the principle of communicating vessels, a technique that originated in the Hellenistic era (figure 17.1). Table 17.2 lists some classical siphons,[ii]

Table 17.1 Lengths of some classical aqueducts

		Km
Constantinople	(Turkey)	250
Carthago	(Tunisia)	132
Cologne	(Germany)	95
Rome (Aqua Marcia)	(Italy)	91
Rome (Annio Novus)	(Italy)	87
Lyon (Gier)	(France)	75
Rome (Aqua Claudia)	(Italy)	69
Lyon (Brévenne)	(France)	66
Rome (Anio Vetus)	(Italy)	64
Rome (Aqua Traiana)	(Italy)	58
Pergamon (Kaikos)	(Turkey)	50
Nîmes	(France)	50
Arles	(France)	48
Cherchel	(Algeria)	45

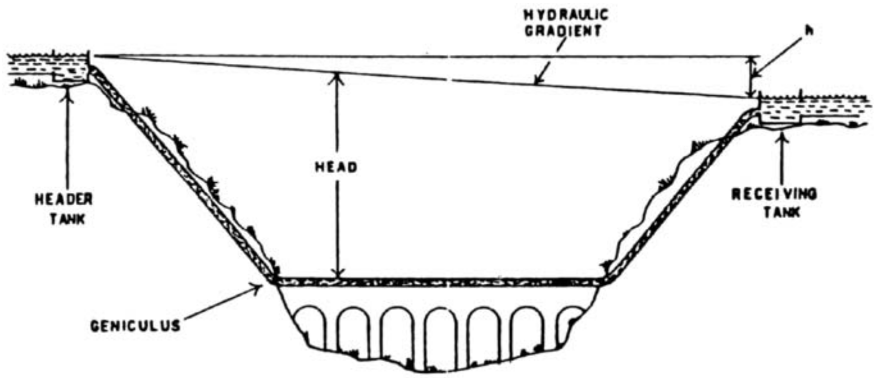

Figure 17.1 An inverted siphon

some of which attained a considerable length (see Kessener, 2001; Lewis, 1999).

For the pipes of these siphons, several materials were used: lead, stone, concrete, ceramics/terracotta, and combinations of these. Disregarding concrete, the conduits were made of prefabricated elements; their lengths varied from 40 to 70 cm for terracotta pipes, 50 to 100 cm for perforated stone blocks, and up to 3 m for soldered lead pipes. The pipe elements were fit together by sliding one end into its larger neighbour (with one end of the pipe being slightly narrower than the other; terracotta pipes) or by means of a male/female socket and flange system (stone pipes, terracotta pipes). The joints were then sealed by means of an expanding oil/quicklime mixture.[iii] For lead conduits, the pipes were cast or made of lead sheets bent into a pipe and soldered at the seam. The joining of lead pipes was done either by means of male/female joints sealed with an expanding mixture (sometimes applying a stone intermediate) or by soldering the pipes together at the joints.

Some fragments of lead piping from siphons have survived. In 1992, Hansen investigated 33 lead pipes recovered from the Rhône over a period of many years (1570–1825) and now preserved at the museum of Arles (Hansen, 1992). The 3-m long pipes, 10- to 12-cm in diameter with a continuous soldered seam along their length (figure 17.2), were part of a siphon that crossed the Rhône on its riverbed, between Arles and Trinquetaille. Before these pipes were soldered together, one end was slid into the next pipe and a large iron nail was driven through the middle, perforating the walls of both pipes. A thick layer of solder was then applied from the outside, covering the ends as well as the nail (which, in some pipes, can still be seen sticking inside, and which must have inter-

Table 17.2 Length, maximum depth, and hydraulic gradient for some classical siphons

Place	Aqueduct	Siphon	Material	Length (m)	Max. depth (m)	Hydraulic gradient (m/km)
Smyrna	(Turkey) Kara-Bunar	Kara-Bunar	ceramic/stone	4400	158	1.1 (?)
Lyon	(France) Yzeron	Craponne-Lyon	lead	3600	91	9.2
Lyon	(France) Mont d'Or	d'Ecully	lead	3500	70	3.1
Lyon	(France) Brévenne	Grange-Blanche (Ecully)	lead	3500	90	4–5.6
Pergamon	(Turkey) Madradag	Pergamon	lead	3250	190	12.6
Alatri	(Italy) Alatri	Alatri	lead	3000	100	9 (?)
Lyon	(France) Gier	Beaunant (l'Yzeron)	lead	2660	122	3.0
Lyon	(France) Yzeron	Grezieux-Craponne	lead	2200	33	3.2
Aspendos	(Turkey) Aspendos	Aspendos	stone	1670	45	8.3
Lyon	(France) Gier	Soucieu (le Garon)	lead	1210	94	4
Laodikeia a/L	(Turkey) Laodikeia	Laodikeia	stone	800	50	26
Lyon	(France) Gier	St. Genis (la Durèze)	lead	700	79	8.3
Lyon	(France) Gier	St. Irénée (Trion)	lead	575	38	4
Oinoanda	(Turkey) Oinoanda	Oinoanda	stone	500–700	22	6–16
Lyon	(France) Mont d'Or	Cotte-Chally (R. Limonest)	lead	420	30	19
Patara	(Turkey) Patara	Delik Kemer	stone	260	20	18.5

Hydraulic gradients marked with ? indicate uncertainty on the precise location of the beginning and/or ending of the siphon.

Figure 17.2 Lead pipes of the Rhône siphon, conserved at the Arles Museum (depot)

fered with the flow to some extent). Hansen notes that the soldered joints are not to be considered as weak spots in the pipeline (''waren nicht das schwache Glied der Kette''), indicating that the soldering material was as strong as the leaden wall of the pipe itself.

The pipes that were utilized for siphons may be subdivided into two categories: the 1st category comprises conduits made of lead pipe elements soldered together at the joints, while the 2nd includes all pipes that have joints sealed with a lime-oil mixture. Soldered lead conduits may be considered homogenous, because in principle the soldering of joints and seams is as strong as the material of the pipe wall. This is not true for the 2nd category of conduits, as these have joints sealed with a weaker lime-oil mixture. It may be derived that the minimum pressure needed to burst homogenous pipes perpendicular to their length is at least twice the pressure needed to burst the pipes lengthwise. Thus, the 1st category of conduits will burst along their length like a sausage in a frying pan. The 2nd category of pipes, on the other hand, with joints sealed with the classic oil/quicklime mixture, are not homogenous because of the weaker sealing material. Such conduits are not very resistant against forces directed along their length, as the tensile strength of the sealing material is much less than that of stone or ceramic (or lead, for that matter). These pipelines are susceptible to bursting at the joints.

The choice to use either the 1st or 2nd category of pipes determined what kind of provisions had to be taken to guarantee proper functioning of the siphon and avoidance of damage. To understand this, the effects of water flow in a closed conduit must be evaluated. Factors to be considered are static water pressure, drag of flow, inertial thrust, presence of air, and pressure surges/water hammer.[iv]

Classical siphons and effects of flow in closed conduits

Static pressure

For a siphon filled with water but without flow, one need consider just the effects of static pressure. At any point in the pipeline, the vertical distance between that point and the free surface of the water determines the static water pressure. For a pipe element in a straight section of the conduit, the water exerts an outward force on the inner wall all along the circumference of the bore, resulting in a zero net force, and nothing will happen provided that the tensile strength of the pipe wall material is sufficiently high.

This is all quite obvious until we arrive at a bend. The *geniculus* element making up the bend, whether vertical or horizontal, will experience a net force directed outward along the bisector of the angle of the bend: $F = 2 \cdot p \cdot A \cdot \sin(\alpha/2)$, where $p =$ inside pressure in N/m^2, $A =$ the cross-section of pipe in m^2, and $\alpha =$ the angle of the bend. It is easily understood that for a U-turn, with $\alpha = 180$ degrees, this force is at its maximum, while for a straight section, with $\alpha = 0$ degrees, the force is zero. The pressure p in a siphon h meters deep (h meters of water column) is $p = \rho \cdot g \cdot h$, where $\rho =$ the specific mass of water $= 1000$ kg/m^3 and $g =$ the acceleration of gravity $= 9.81$ m/sec^2.

For a bend with an angle of 30 degrees, having a pressure of 40 m of water column and a pipe diameter of 28 cm (a situation that occurs for the Aspendos siphon), the force amounts to $F = 2 \cdot 1000$ kg/m$^3 \cdot 9.81$ m/sec$^2 \cdot 40$ m $\cdot (\pi/4) \cdot (0.28$ m$)^2 \cdot \sin(15°) = 12{,}507$ N, or about 1,275 kgf. For the Madradag siphon at Pergamon (figure 17.3; see Garbrecht, 1978; Fahlbusch, 1982), due to its great depth (over 190 m, deepest of all the siphons), these forces could be quite considerable even at bends with a small angle. The conduit, made of 3-m lead pipe elements joined by lead sleeves, was kept intact by securing each pipe element in a large perforated stone slab (figure 17.4), while the pipeline as a whole was buried underground.

Generally, for a 2nd-category conduit, the force exerted on a *geniculus* element will be transmitted to neighbouring elements only as far as the bonding by the sealing material goes. To keep such a pipeline intact, the *geniculus* element must be kept from being pushed out of position – that is, a counteracting force of equal magnitude must be provided. For a pipeline made of elements of the 1st category (lead pipe elements soldered together), this does not apply, as no net force except gravity will be exerted on the *geniculus* since the section that makes up the bend is bonded to the neighbouring sections by the soldering that transmits forces away from the bend. The pipeline as a whole must be fixed some-

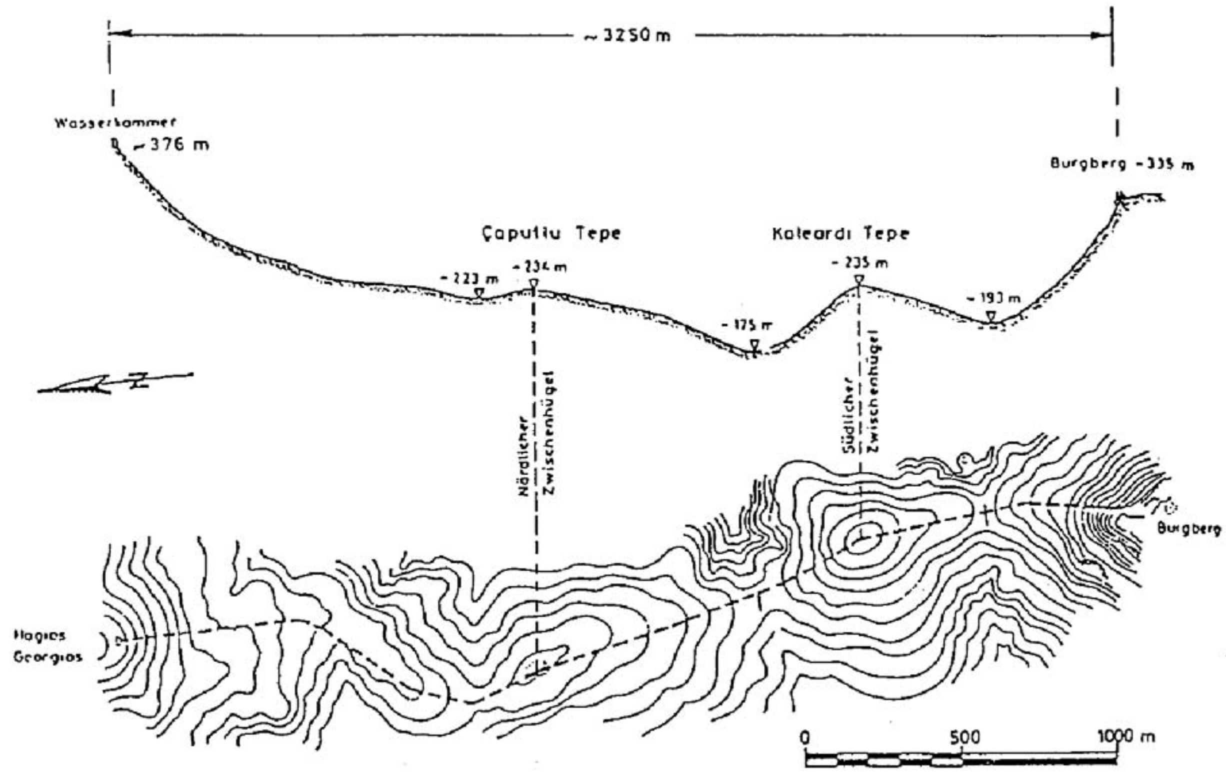

Figure 17.3 The Madradag siphon at Pergamon

Figure 17.4 Perforated stone slabs that secured the Madradag pipe line (top of Çapultu Tepe); top of hill in the distance: Pergamon acropolis

where on its turn, but it is not important at what point; even the friction forces between the conduit and the terrain on which it is laid may suffice.

For pipelines of the 2nd category, however, special precautions have to be taken. The pipe elements at the bends must be prevented from moving from their place by constructing proper foundations (vertical bends), by adding weights or sand ballast, or by connecting the elements to each other, such as by metal clamps (horizontal bends).[v] For 1st-category pipelines, the *geniculi* were not preferred spots for damage from static pressure. These conduits would burst anywhere along their length whenever the inside pressure would get too high (which occurs where pressure is highest, in the deepest part of the siphon).

Drag of flow and inertial thrust

We also have to consider forces exerted by the flowing of the water. For straight sections of a running siphon, we have to look at the force between the inner wall of the pipeline and the water (''drag''). As the velocity of the water directly at the surface of the inner wall is zero, this drag is mainly governed by the viscosity and turbulence of the water. The effect is that each pipe element is subject to a force in the direction of the flow of the water, which has a constant value per unit length of conduit at any position along the siphon (disregarding variations in diameter and of roughness of the inside surface). The overall effect of this drag relates to the loss of head between the header tank and the receiving tank.

For the stone Aspendos siphon, for instance (see figures 17.5 and 17.6), the loss of head is 14.5 m over a length of 1,670 m (Kessener, 2000). This is about 0.008 N/cm^2 per m of conduit (internal diameter 0.28 m). If each pipe block were 50 cm in length, the net force exerted on each pipe element by the drag of flow would be 2.62 N, or the equivalent of a weight of about 270 grams (which may safely be disregarded in view of friction forces between the pipe blocks and the underground).

At bends, where the direction of flow is changed, a force is exerted onto the element that makes up the bend (the *geniculus*), which is sometimes referred to as "inertial thrust." This force relates to the change of impulse (impulse is defined as a vector with a magnitude of mass times velocity) of the water in order to go round the bend. As the magnitude of the mean velocity of the water is necessarily the same everywhere in a pipe of constant diameter, the change of the direction of the impulse is all that matters. For a small mass m of water with velocity v going round a bend of angle β, the change of impulse (a vector) is directed along the bisector of the inner angle of the bend, with the magnitude dP of the change of impulse amounting to $2 \cdot m \cdot v \cdot \sin(\beta/2)$. For water moving with mean velocity v in a pipe having a diameter D, we may consider a thin slice of water of thickness dx. This slice of water has a volume of $\pi/4 \cdot D^2 \cdot dx$ and, consequently, its impulse P (not to be confused with the pressure p) is $P = \rho \cdot \pi/4 \cdot D^2 \cdot dx \cdot v$, where ρ is the specific mass of water (kg/m^3) and v is the mean velocity of the flow (m/sec).

The mean velocity v in the pipe may be estimated from the Darcy-Weissbach formula: $v^2 = (8g/\lambda) \cdot (Rh \cdot \Delta H/L)$, where $g =$ a gravitational constant (9.81 m/sec^2), $Rh =$ the hydraulic radius of the conduit ($= D/4$ for a filled conduit), $D =$ the diameter of the pipe in m, $\Delta H =$ loss of head in m, $L =$ the length of conduit in m, and $\lambda =$ the friction factor (a dimensionless factor, related to the roughness of interior wall of the conduit and to the Reynolds number). This velocity was generally not very high for classical siphons. For the Aspendos siphon ($D = 0{,}28$ m, $\lambda \sim 0{,}043$) as well as for the Pergamon siphon ($D = 0{,}175$ m, $\lambda \sim 0{,}026$), flow velocity was about 1 m/sec at full operation, which is average walking speed.

The magnitude of the change of impulse dP thus equals $dP = 2 \cdot \rho \cdot \pi/4 \cdot D^2 \cdot dx \cdot v \cdot \sin(\beta/2)$. The force F required to bring about this change is $F = dP/dt = (2 \cdot \rho \cdot \pi/4 \cdot D^2 \cdot dx \cdot v \cdot \sin(\beta/2))/dt = 2 \cdot \rho \cdot \pi/4 \cdot D^2 \cdot (dx/dt) \cdot v \cdot \sin(\beta/2) = 2 \cdot \rho \cdot \pi/4 \cdot D^2 \cdot v^2 \cdot \sin(\beta/2)$. For a velocity

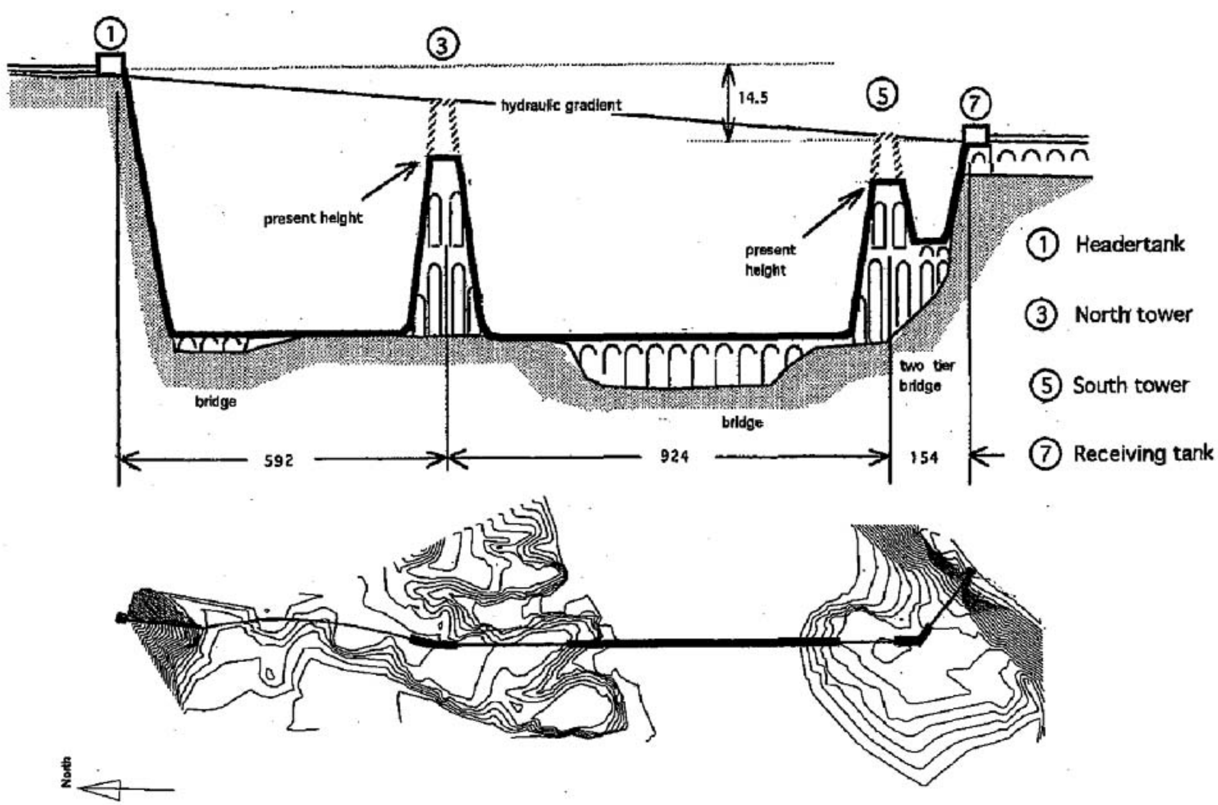

Figure 17.5 The Aspendos siphon (distances in metres)

Figure 17.6 Stone pipe element of the Aspendos siphon

$v = 1$ m/sec, a pipe diameter of 0.28 m, and an angle of 55 degrees, as at Aspendos, and ρ being 1000 kg/m^3, F amounts to $F = 2 \cdot 1000 \cdot \pi/4 \cdot (0.28)^2 \cdot (1)^2 \cdot \sin(27.5°) = 57$ N. This force is small compared to the forces exerted by static water pressure, and may be disregarded as well.

Air

Air may interfere with siphon operation in several ways. At the downstream side of high points incorporated in the siphon, air pockets may appear during start up (figure 17.7).[vi] These air pockets reduce the head available to run the siphon – the less, however, the deeper the siphon is, as the air pockets are compressed to smaller size. The Madradag siphon at Pergamon had two intermediate high points, but due to the compression of the air pockets, flow would be reduced to only 90 per cent of maximum. Yet, there was a threat in this case. At the header tank, air may be entrained into the conduit and transported towards the air pockets, adding to their volume.[vii] The loss of head would then be increased, and the head driving the siphon would become reduced – which eventually could result in a complete stop of the flow.

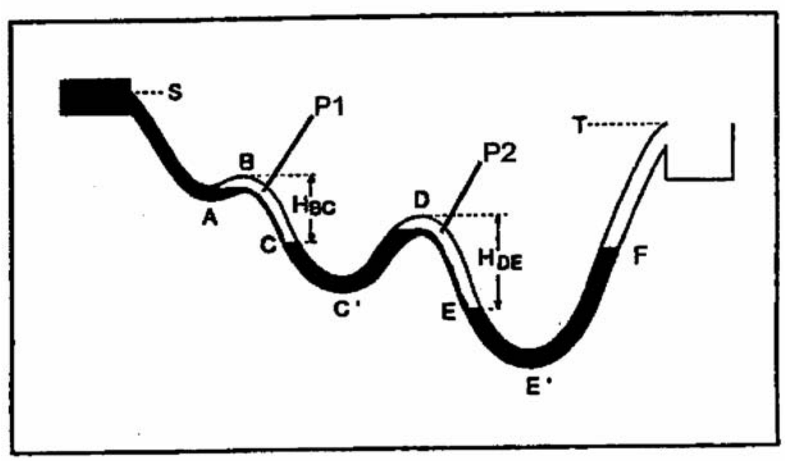

Figure 17.7 Air pockets at high points in a siphon
If the total of vertical heights of compressed air pockets ($H_{BC} + H_{DE}$) exceeds the available head (H_{ST}), the siphon will not start

On the other hand, at the bottom of the air pockets, a transition from free surface flow to fully closed conduit flow occurs, where air may be entrained into the water again due to the mixing of air and water. Entrained air bubbles may again move with the flow, away from the air pocket, now reducing its volume. Whatever effect is greater determines what will happen.

The conduct of air bubbles in a sloping conduit is determined by bubble size, conduit diameter, slope angle, flow velocity, roughness of the pipe interior, and viscosity of the water. An air bubble will move downward with the flow if the flow velocity exceeds a certain critical value, *Vcr*. It may be derived that $Vcr = (4 \cdot g \cdot Db \cdot \sin \alpha/(3 \cdot Cb))^{1/2}$, where $g =$ the acceleration of gravity $= 9.81$ m/sec^2, $Db =$ the diameter of the bubble in m, $\alpha =$ the slope angle of conduit, and $Cb =$ the drag coefficient of air bubble (Falvey, 1980). *Vcr* is related to the bubble diameter *Db*: the larger the bubble, the higher the *Vcr*, and the faster the water has to flow if the bubble is to move in the direction of flow. Thus, the steeper the slope angle and the larger the bubble size, the less readily bubbles will move with the flow.

As the air bubbles will accumulate at the crown of the conduit, it is necessary to correct for the fact that the water velocity near the pipe wall is smaller than in the centre of the conduit (which applies for air bubbles with a small diameter compared to conduit diameter). The result is that the critical value of the *mean* velocity in the conduit, *Vm*, *cr*, above which small air bubbles will move with the flow, will be higher. Vm, cr is related to both diameter Dc of the conduit and the diameter Db of the air bubbles, as well as to the roughness k of the inner wall of the conduit: $Vm, cr = ((\log(3.4 \cdot Dc/k)/(\log(15.1 \cdot Db)/k)) \cdot (4 \cdot g \cdot Db \cdot \sin \alpha/3)^{1/2}$ (Aksoy, 1997).

Matters become increasingly more complicated when bubbles coalesce to form air pockets. Of such air pockets, or "slugs," it is known that the rise in velocity in downward sloping conduits is greater than in vertical conduits, with a maximum for slopes of about 40 degrees (Falvey, 1980). In downward sloping conduits, these slugs may move upstream against the flow, a condition referred to as "blow back." Such a slug may "collect" small downstream-moving air bubbles at the front, while at the downstream end of the slug, air bubbles may be entrained again into the flow and move downstream. In general, the relation between flow rate and air bubble/slug motion is represented in a graph from Falvey (figure 17.8).

From the considerations discussed above, it may be shown that for the Madradag siphon, the air pockets at the high points were purged out by

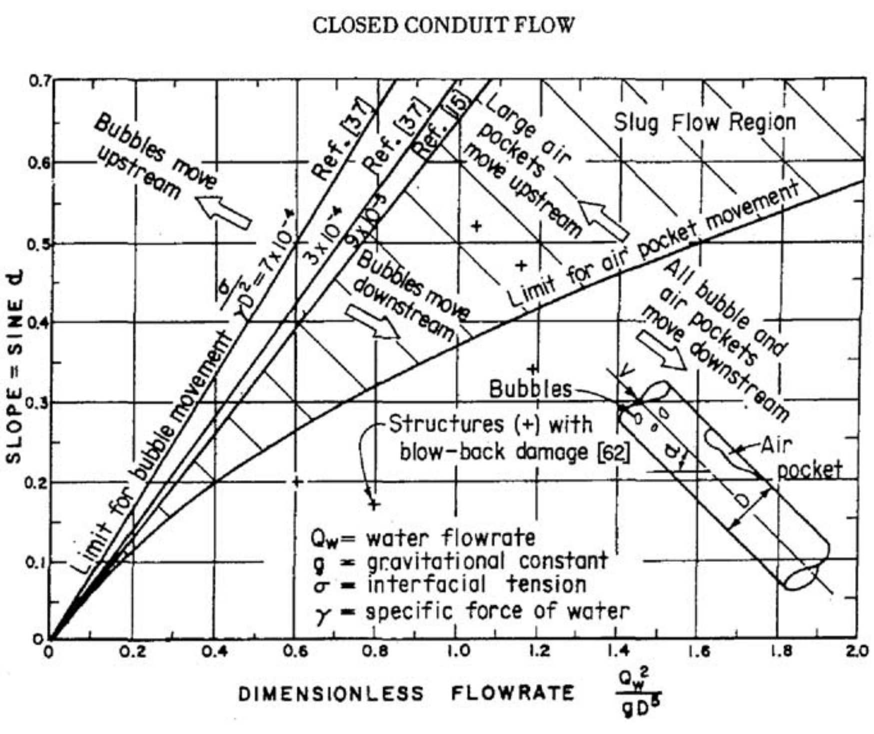

Figure 17.8 Conduct of air bubbles and air pockets in closed conduits

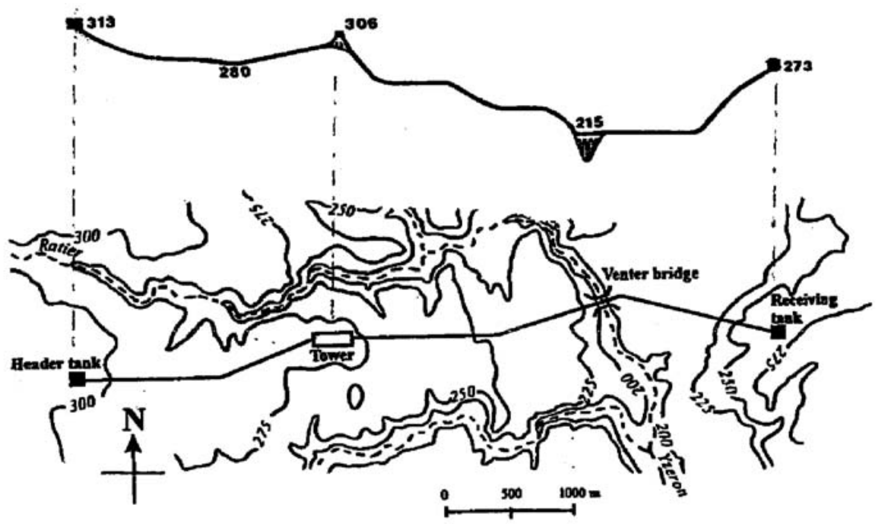

Figure 17.9 Siphon of the Yzeron aqueduct at Lyon

the water flow itself, whereby the siphon automatically evolved to full capacity. The important factor is that the sloping of the pipe down from the header tank is much steeper than downstream from the high points. We may wonder whether the Pergamon engineers were aware of this effect, but the siphon operated as expected, and miraculously transported water uphill to the top of the acropolis, no doubt to the amazement of its citizens.

In contrast, for the Yzeron siphon at Lyon (figure 17.9; Burdy, 1991), made of lead pipes soldered together, a reverse situation occurred. Here, the slope downstream from an unavoidable high point in the terrain is much steeper than down from the header tank. Because of the air pocket at the high point, the siphon would start up at only 60 per cent of full capacity, and subsequently evolve to a complete standstill, had not the 16-m high intermediate tower (remains now known as "les Tourillons"), with a sloping ramp and an open tank on top to release the air, been built (figures 17.10 and 17.11).

On the other hand, the stone siphon at Aspendos had two huge hydraulic towers up to 40-m high. This siphon could not have been started at all because of air pockets at these high points if the tops of the towers had not been equipped with open tanks (Kessener, 2000). But in this case, the high points were not dictated by the terrain. It does not seem to make much sense building such enormous towers, with open tanks on

Figure 17.10 Remains of the hydraulic tower at "les Tourillons," south view; photo dating from about 1900

top to release air, which would not have been necessary if the towers had not been built.

Pressure surges/water hammer

Apart from air pockets reducing the flow or even preventing start up, and entrainment of air causing siphons with high points to evolve to a complete standstill, air in pressurized conduits may give rise to "water hammer" effects. A water hammer is defined as a pressure surge caused by a substantial and sudden change of the velocity of the water flow (e.g., by the closure of a valve). The water hammer effect is at the base of the 18th-century invention of the hydraulic ram. By the action of the hydraulic ram, which works on the principle of automatic and repeated sudden closure of a valve, water falling from any height is made to raise a portion of itself to a greater height – between 10 and 40 times the height of fall (Stern, 1983).

Figure 17.11 Remains of the tower at ''les Tourillons'', present state, north view

It is not known, however, if classical siphons were equipped with valves or shutters. But pressure surges may result from the presence of air inside the conduit – i.e., air escaping from leaking spots. If an air bubble or air pocket moving with the flow passes along a leaking spot, air will be released into atmosphere, which occurs at a much faster rate than the leaking of the heavier water. Hence the water column upstream from the leaking spot will be accelerated until the air pocket is released, after which it decelerates again.

The magnitude of the pressure shock arising from the associated sudden change in water velocity, which occurs as soon as the air pocket has escaped entirely from the conduit, may be estimated as follows: $dH = 0.5 \cdot c \cdot dV/g$, where dH = the pressure rise in m of water the column, c = the velocity of sound in water = 1,000 m/sec, dV = difference in velocity of the water inside the conduit upstream from the leak just before and just after the air has passed through the orifice, and g = the acceleration of gravity = 9.81 m/sec^2. dV may be calculated on the basis of continuity, as the decrease of the volume of the air pocket relates to the outflow of compressed air through the orifice: $dV \cdot Ac = Va \cdot Ah$, where $Ac =$ the conduit cross-section in m^2, $Va =$ the velocity of compressed air escaping through a leaking orifice in m/sec, and $Ah =$ the cross-section of a leaking orifice in m^2.

Va may be derived from air flow through small orifices at high back pressures (Falvey, 1980). For an orifice of 12-mm diameter, at gauge pressure of 4 bar (about the equivalent of a pressure of 40 m of water column), the airflow through the orifice is about 0.05 m^3/sec. The resulting velocity Va of air escaping from the orifice is about 440 m/sec, which is supersonic (noise). Hence, for example, for the lowest section of the Aspendos siphon, $dV = Va \cdot Ah/Ac \approx 0.8$ m/sec, whence $dH = 0.5 \cdot 1000 \cdot 0.8/9.81 = 39$ m of water column. This means that for the Aspendos siphon, discarding factors that may have a diminishing effect (such as the presence of much air elsewhere in the conduit), a water hammer caused by a leaking orifice of 12-mm diameter may result in a sudden pressure increase of almost 100 per cent.

The release of the compressed air into atmosphere may be accompanied by hissing noises and water sputtering out, which no doubt impresses the onlooker who thus becomes fully aware of the elevated pressure inside the conduit. The generated shock wave runs along the pipeline, and at bends of 2nd-category pipelines the these waves cause a short and sudden increase of the force, which tends to dislocate the *geniculus* element, on top of the force from static pressure. Such increases may repeatedly occur, exceeding the counteracting forces applied to meet the static pressure. Once a seal between pipe elements starts leaking, the water flow in the conduit will be increased because of the water escaping through the new leak, and more air may be entrained at the start of the line, adding to the occurrence of shock waves. In the end, the leaking may be increased to the extent that the header tank is emptied more quickly than the supplying aqueduct brings water in, whereby large air pockets periodically enter the conduit. The siphon enters the last phase of its destruction when all water that enters the conduit comes out at the destroyed point, alternating with pressurized air pockets noisily escaping into atmosphere.

Clearly, the start up of siphons, whether or not they have high points in their course, and especially of 2nd-category siphons, must be carried out with the utmost care, as these problems will undoubtedly arise if the air is not slowly driven out of the system. During an uncontrolled start-up, when large amounts of water are suddenly introduced into the conduit, large air pockets will form in the horizontal section of the siphon and become increasingly compressed. These air pockets will move with the flow, and once they arrive in the upward leg, the pockets may rise even faster

Figure 17.12 South tower of the Aspendos siphon, having a bend of 55 degrees

than the water itself, expanding because of decreasing pressure and causing water to flow backwards underneath the pocket. This gives rise to pressure surges in the conduit and, at times, violent expulsion of air and water at the end of the line. Moreover, oscillations of the water column may occur, adding to the forces exerted on the conduit (Ortloff and Kassinos, 2003).

At Aspendos, two huge "hydraulic towers" were built at horizontal bends in the siphon's course (figure 17.12). By these towers, the stone siphon was split up into three consecutive siphons, effectively eliminating the horizontal bends altogether. Thus, the detrimental effects from both static pressure and water hammer/pressure surges were prevented.

Once the Roman engineer had decided that horizontal bends were to be included in the course, the best option was to build towers at the bends. As a consequence, the towers had to be equipped with open tanks on top to release the air at these constructed high points. From considerations on the course of the Aspendos siphon, and the terrain it crosses, it turns out that this was cheaper than constructing a (longer) siphon with no horizontal bends and no towers (Kessener, 2000).

Discussion

The problems encountered when applying pressurized pipelines in ancient times were caused by static pressure and, more importantly, by the effects of the presence of air inside the conduit, either at start up or when in operation. The difficulties relate to the characteristics of the conduits – whether they are of the 1st or 2nd category. The archaeological remains confirm that the ancient engineers were acquainted with these problems (though maybe not always realizing them in full, e.g., at Pergamon), and that they knew how to counter the problems for specific situations (Yzeron siphon: a hydraulic tower designed as an air vent to prevent air pockets from stopping flow; Aspendos siphon: hydraulic towers to prevent destruction from water hammers at horizontal bends).

Roman author Vitruvius (25 BC), who included in his ten books on architecture a chapter on water transport, mentions these problems and suggests measures to solve them (Kessener, 2001). He advises introducing ashes into 2nd-category siphons before start up to seal possible leaks. This method of curing leaks has survived to our time, as some preparations for repairing leaking car radiators depend on a similar principle of expansion of organic material that gets stuck in the leaking orifice.

For classical siphons, the loss of water from leaks was not such a problem, but the water hammer effects resulting from air escaping could threaten the integrity of the entire system. Vitruvius also advises that air should be released by means of "*colliviaria*," a word that does not appear elsewhere in all Latin literature. These devices refer to provisions to release air, preventing air pockets from stopping the flow. As the classical siphons operated under gravitational conditions, with a reduced pressure head driving the system, problems from air pockets at high points became quickly apparent. For modern systems under pumping conditions with high pressures, such problems may go unnoticed for a long time, leaving engineers puzzled by unexplained reduction of capacity. But the general hydraulics that governs modern conveyance systems are the same as those in the old days: the principles of nature have not changed in 2,000 years.

Notes

i. For survey techniques, see, for example, Grewe, 1998.
ii. By convention, "siphon" in the archaeological sense refers to an inverted siphon.
iii. Malinowski, 1979, discusses sealing materials for aqueducts and pipelines under pressure.
iv. For a discussion, see Kessener, 2000.
v. The pipe blocks of the Delik Kemer siphon of the Patara aqueduct (Turkey) were originally prevented from both horizontal and upward movement by metal clamps (Stenton and Coulton 1986).
vi. Figure adapted from Corcos, 1989.
vii. On entrainment of air into conduits, see Knauss, 1983.

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18

The Sadd el Kafara: The oldest high dam in the world

Henning Fahlbusch

More than 100 years ago, while travelling back from an expedition to the mountains between the Nile Valley and the Red Sea, the German scholar and explorer Georg Schweinfurt discovered the remains of the Sadd el Kafara in the Wadi Garawi (Egypt). The site is located about 35 km south-southeast of the Egyptian capital, Cairo. Schweinfurt knew immediately that he was standing in front of a very old structure. Based on his wide experience and knowledge of ancient Egyptian culture, he was able to date the weathered, cover slabs of the dam correctly to the Old Kingdom. But he was hardly aware then that the remains belonged to one of the oldest dams in the world.

As far as is known, only the dam of Jawa in northern Jordan is older than this dam in Egypt. But the dam in Jawa is only 5 metres in height, comparatively less imposing. Therefore, it seems reasonable to call the Sadd el Kafara, with its possible height of 15 metres, "the oldest high dam in the world."

The situation at the dam site remained unchanged until the 1970s. At the northern and southern edge of the *wadi*, parts of the dam were well preserved, although the centre had long-since washed away. But during the last war between Egypt and Israel, in 1975, a bulldozer deformed the southern wing of the dam into a ramp, on which the track from the *wadi* led to the upper terrace (figure 18.1, background). The fact that the remains of this important engineering structure had been further demolished by humans caused an initiative for a thorough documentation

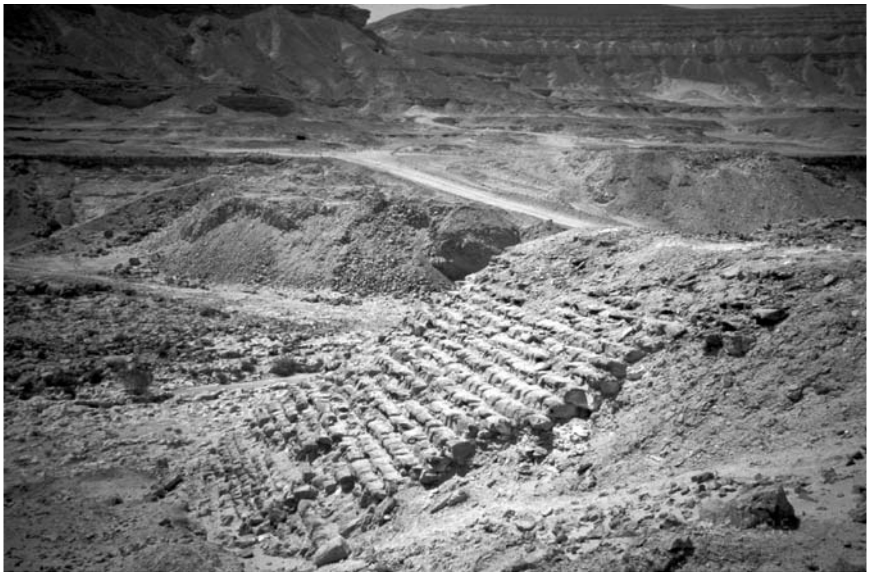

Figure 18.1 Remains of the southern part of the dam

of the dam. This was the correct decision, because since then the ramp has been widened and the structure further destroyed.

Based on a grant from the DFG (German Research Foundation), research work was carried out as a joint venture between the Leichtweiss-Institute for Water Research of the Technical University Braunschweig, the National Water Research Centre (under the chairmanship of Dr. Abu Zeid), and the Ain Shams University, Cairo. A team of ten foreign scientists, together with Egyptian colleagues and quite a number of labourers, cleaned, measured and documented the remains in 1982. This chapter briefly outlines the results of these efforts.

The geographical, geological and meteorological situation

The Wadi Garawi is one of the valleys that drain the rocky desert of the Jebel Galala between the Red Sea and the Nile Valley after rainfalls. The landscape is characterized by horizontal layers of various rock formations, into which the Wadi Garawi has cut deeply.

A thick vein of alabaster runs in a north-south direction in the mountains. This highly esteemed stone was quarried, particularly during the Old Kingdom, even in the reaches of the upper Wadi Garawi. A quarry-ditch running over several kilometres proves that the stone material has been thoroughly removed. Schweinfurt's initial idea of a link between the two human activities in antiquity here in the desert, – i.e., the construction of the dam and the quarry – therefore seems to be logical.

The parameters of the climatic situation of the Wadi Garawi were determined at the meteorological station at Heluan. The climate is arid, with high temperatures (mean annual temperature: 21°C), high evaporation rates and little precipitation. The average annual rainfall amounts to just 25 to 30 mm. However, sporadic rainfalls can occur with high intensity and in a relatively high amount. Statistically, precipitation of 8 mm/day occurs in Heluan once every year, and a rainfall of 20 mm/day once every 4 years, causing flash floods due to the high runoff-rate. Such comparatively intensive incidents in the steep and narrow *wadis* are often disastrous. It has been reported that a settlement in the neighbourhood of Wadi Garawi was completely destroyed by just such a flash flood at the end of the 1970s.

The inclination of about 1 per cent in the *wadi*, which was determined by our survey-team, is relatively steep. Therefore, the storage volume created by a dam is small. The stored volume behind a dam of 8.5-m height would be just 100,000 m^3, and that of a dam of 15-m height not more than 620,000 m^3.

As the catchment area of the Wadi Garawi at the dam site amounts to about 170 km^2, the relatively small storage volume of the Sadd el Kafara would have been quickly filled up. Garbrecht and Bertram (1983) calculated that a rainfall of 18 mm over just 35 per cent of the catchment, with a runoff factor of 60 per cent, would have completely filled up the storage created by a dam of 13.5 m in height. An 8.5-m high dam with a possible storage capacity of 100,000 m^3 would, therefore, certainly have been filled annually.

The dam

The width of the *wadi* at the dam site is roughly 110 m. The structure would today be called a multilayer earthfill dam; it was constructed on the cleaned, rocky bottom of the *wadi* (elevation about 110 metres above mean sea level). The lower width of the dam was determined as nearly 90 m, and the crest width as more than 60 m (figure 18.2). These dimensions are exceptionally large. The levelling of the structure showed an inclination of the downstream face of 30 degrees, and a photogrammetric analysis of the upstream face revealed that this was bent. The lower part has an inclination of 45 degrees, while the upper part is flatter with an angle of 35 degrees.

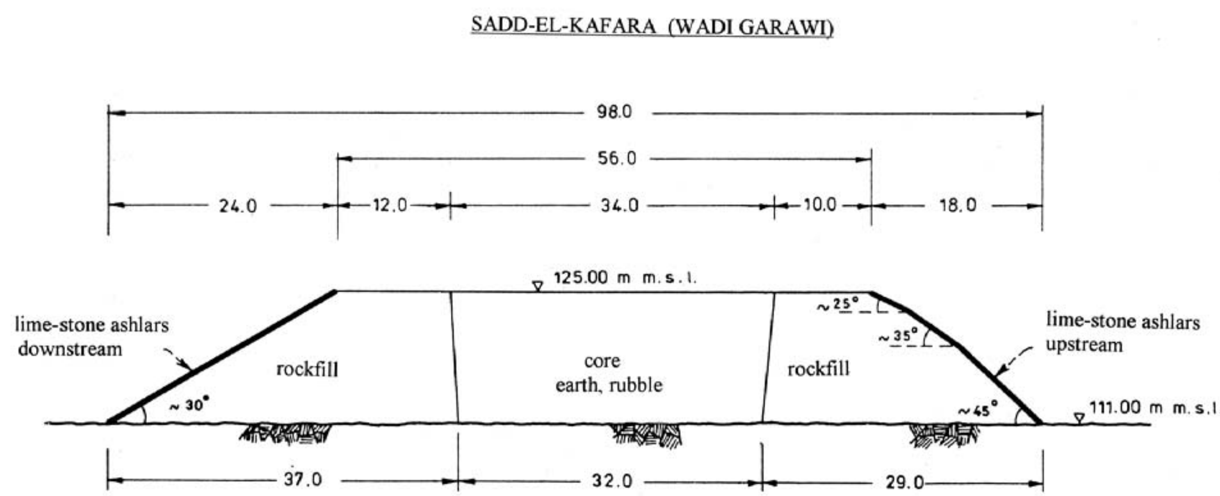

Figure 18.2 Cross-section of the dam

The cross-section shows that the core of the dam consisted of rubble, silty sands and gravel. On both sides, upstream as well as downstream, there then comes a layer of riprap without sand or gravel parts. These layers are covered by carefully chiselled limestone slabs. The size of the slabs varies: the average height, width and length are 30 cm, 45 cm and 80 cm, respectively. The stones have been used in the covering layer with the smallest surface towards the outside. This stepped cover of slabs characterizes the outline of the Sadd el Kafara (figure 18.3). On the upstream face, there remained 31 steps at the northern side and 13 steps at the southern side.

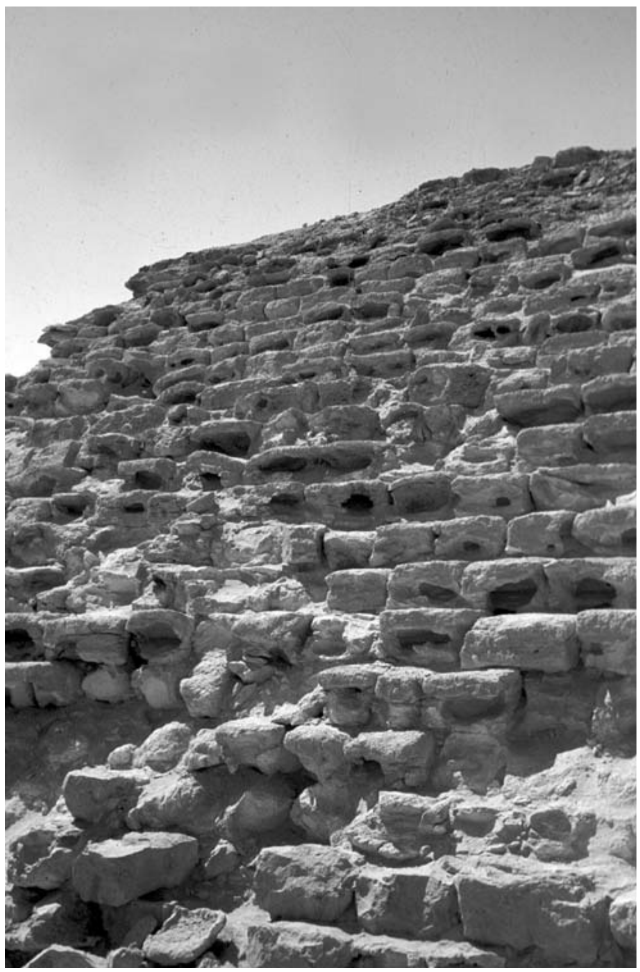

Figure 18.3 Limestone ashlars of the upstream cover

The stones are fairly weathered, especially in their cores. This phenomenon is also known from other structures dating back to the Old Kingdom – for instance, the Cheops Pyramid. Physical and chemical weathering are caused especially by moisture, which infiltrates into the stones. The longer the moisture remains in the stone, the more salts that are dissolved; therefore, the destruction is most severe in the core of the stone, as the longer the moist spot is in the shadow, the longer the moisture remains.

This is particularly true for the inside of the stones. So, when the weathering process has started, it is a self-perpetuating phenomenon until nothing but empty shells remain. And it is only a matter of time until these shells are destroyed too. The dissolution of salts depends on the temperature; the warmer it is, the more salts that are dissolved, which results in the quicker destruction of stones in the warmer parts of the structure. The downstream face of the dam is warmed by the sun in the afternoon and evening, but the upstream face in the morning has a time when the air is still cool. The different warming processes can thus explain the different degrees of destruction of the cover slabs at the downstream face in comparison with those of the upstream face.

The analysis of the remaining structure revealed an important detail. The various layers of the southern wing of the dam are complete from the edge of the *wadi* until its centre, where the material has been washed away. However, this is not the case at the northern wing. Figure 18.4 shows that the downstream side opposite does not reach the centre of the wadi, whereas the upstream side does. This cannot have been caused by a dam failure, because in such a case the erosion line would have been straight and parallel to the *wadi*-line as on the southern side. The consequence is logical; the Sadd el Kafara was destroyed before the dam was completed.

This hypothesis is backed up by another fact: the surface of the crest on both the southern and the northern parts is not smooth. Many heaps of earth are lying there, slightly eroded over the course of time. The work on the dam obviously had been suddenly terminated. It is, therefore, impossible to determine the exact height of the crest. Based on the topography, it can be assumed, that the elevation according to plan should have been about 125 metres above mean sea level, which means a dam height of roughly 15 m.

The construction procedure

The floods that have eroded the central part of the dam left the remains of the structure at its flanks. The preserved parts are 24-m long at the

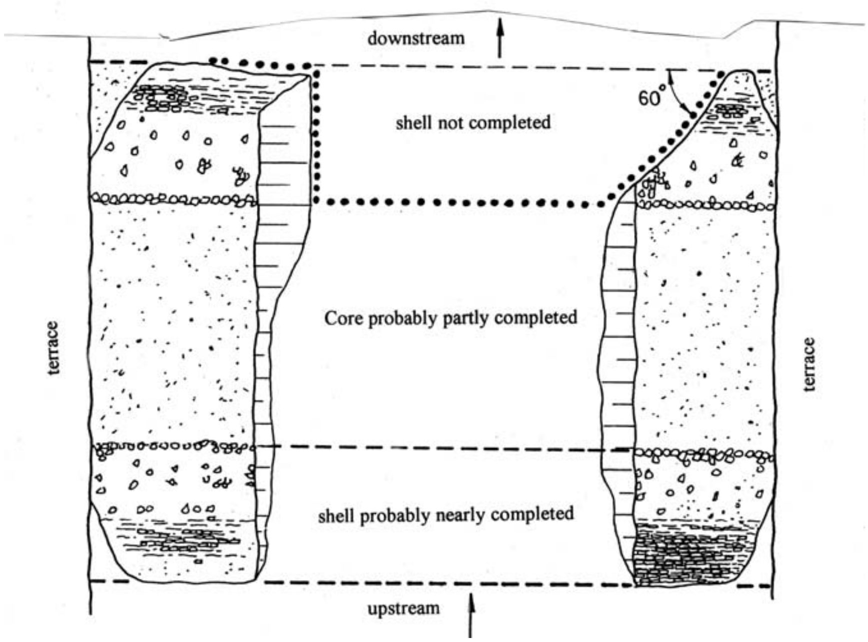

Figure 18.4 Plan of the dam

northern side, and 27-m long at the southern side. Small-scale cleaning work revealed details of the dam's cross-section in the nearly vertical surface at the break. The results enabled conclusions to be drawn about the sequence of the dam's construction. Obviously, the rip-rap layers were built as supporting elements for the core at the upstream and the downstream sides. Where the riprap layers and the core join, the stones were set up as a slightly inclined dry wall against the rubble-fill (figure 18.5). The lines of the various layers of the core indicate that the rubble was just put against the dry wall. Probably the central core was built at the same time. The material was obviously taken from the neighbouring terraces, or from quarries upstream and downstream of the dam (figure 18.6). It was probably transported in baskets by many labourers to the construction site. This method of transporting material was common in ancient Egypt, and is still in use today.

At the southern part, a sharp bend in the upstream dry wall and horizontal layer indicate an interruption of the construction process (elevation about 118.5 metres above mean sea level). At the downstream side, this is confirmed by a horizontal step in the dry wall. Before putting the stone-slabs on the riprap, this was probably smoothed by a thin layer of gravel.

Figure 18.5 Dry wall and rubble fill of the dam

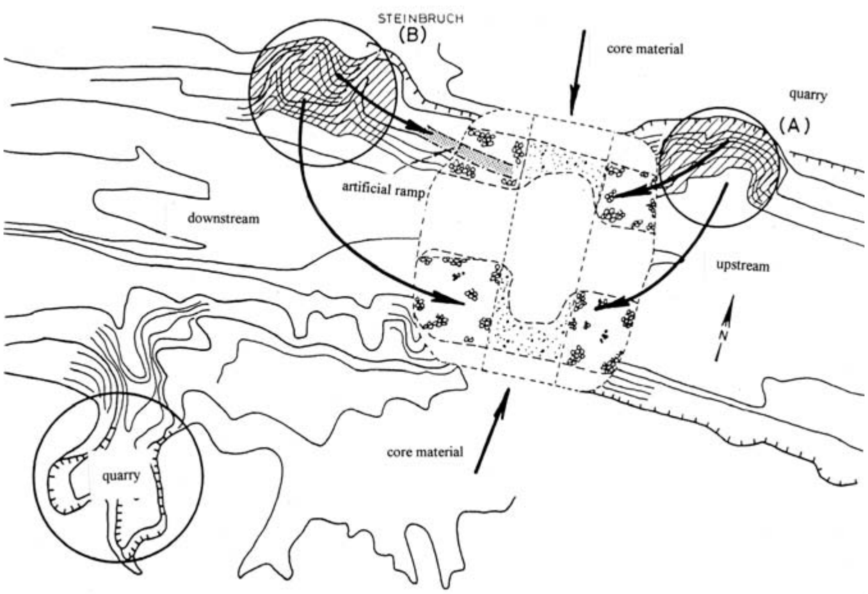

Figure 18.6 Quarries and ways for material transport at the site

The slopes of the embankment of the *wadi* are extremely steep. The labourers who had to carry the material for the core from the terraces to the middle of the *wadi* had to climb up and down. Small ramps as paths for the workmen can still be seen today at the point where dam and embankment meet.

There is another ramp to be mentioned. At the northern flank, a relatively slightly inclined, wide ramp leads from the quarries at the edge of the *wadi* to the remaining core of the dam. It can be assumed that the covering stone slabs, with a weight of more than 200 kg each, were transported on this ramp. They were too heavy to be carried, and so were therefore most probably moved by means of a slide or by using rollers or wheels on this ramp. A definite end of the ramp could not be determined because the stones of the downstream riprap layer covered it. Garbrecht and Bertram (1983) assumed that the level of the end of this ramp corresponds to the above-mentioned bend and step of the riprap, indicating an interruption of the construction procedure.

After investigating the various works necessary, Garbrecht and Bertram calculated a total construction time of at least 8 years (assuming 350 labourers working simultaneously at the site). These people lived in huts, the remains of which had already been discovered by Schweinfurt. Dreyer and Jaritz (1983) investigated them more closely and identified at least 14 buildings, which must have had different functions based on their position and size. The largest building measured 34 m $\times$ 13 m, and was later extended by a further 12.5 m (the different kind of construction of the wall in the extension points to this interpretation).

Much pottery was found in the various buildings. Because they are comparable to the shards that were found in the dam, it can be concluded that the dam and buildings date from the same time.

Dating of the dam

The weathered covering slabs had already indicated that the dam must be very old. Dreyer and Jaritz (1983) dated the structure – based on detailed analysis of the pottery, especially beer jugs – to the Old Kingdom; or, even more precisely, to the time of the 4th or 5th dynasty. A C_{14} analysis of charcoal found in the huts confirmed this dating.

Purpose of the dam

Today, dams generally are constructed as multipurpose structures: water power, irrigation, drinking water supply, flood protection, and shallow water increase are the most common reasons for a modern dam. The use of water power and an increase of shallow water (for instance, to improve the shipping conditions) do not make sense in the Wadi Garawi. Storage of water for irrigation also was not necessary in view of the good agricultural conditions in the Nile Valley, only a few kilometres away.

Keeping in mind how disastrous, sporadic flash floods can occur in the *wadis*, the construction of the Sadd el Kafara for flood protection at least seems to be plausible. But who or what was to be protected? We do not know this yet. A settlement may have existed at the Ain Fisha spring at the mouth of the *wadi*. There might even have been a harbour at the Nile, worthwhile to protect. But we have no archaeological proof of any kind.

Schweinfurt assumed a connection between the dam and the alabaster quarries. He supposed that the dam would have stored drinking water for the slaves. Garbrecht and Bertram quite rightly questioned this opinion. The stored water would have been emptied relatively quickly due to the large seepage losses through the dam. Even the engineers in the Old Kingdom knew that seepage and infiltration losses could be prevented by sealing the structure with a layer of mud from the Nile, but no evidence of this has been found in or around the structure. It seems that the ancient constructors accepted and tolerated these losses of water. Hence, the normal usage of modern dams does not offer a convincing reason for the construction of the Sadd el Kafara. The question is whether there could be another purpose for the dam.

Stadelmann pointed out, in a personal discussion, that the transport of many of the big stones for monumental buildings in the Old Kingdom was eased by using wetted mud from the Nile. The friction on such moist mud is very small, and the application of this method is proved by a relief. Figure 18.7 shows a huge statue drawn on a sledge along a way of Nile mud, which was moistened with water poured from a kind of bucket.

In order to transport thousands of alabaster stones from the Wadi Garawi to the river Nile, a path of Nile mud might have been constructed. For a path 2 m in width, with a thickness of 50 cm, a quantity of mud of only 10 per cent of the volume of the Sadd el Kafara was needed. It had just to be brought from the Nile Valley. Under these circumstances, it can be imagined that a dam would have been constructed halfway between the quarries and the river in order to have the necessary water available at the best position.

The location of the dam can thus be explained logically. When constructing the mud-way in the *wadi* downstream of the dam, seepage losses through the dam were not only acceptable but possibly welcome. A possible link between human activities in the Wadi Garawi (quarrying and dam building) can be explained logically by this hypothesis. Again, how-

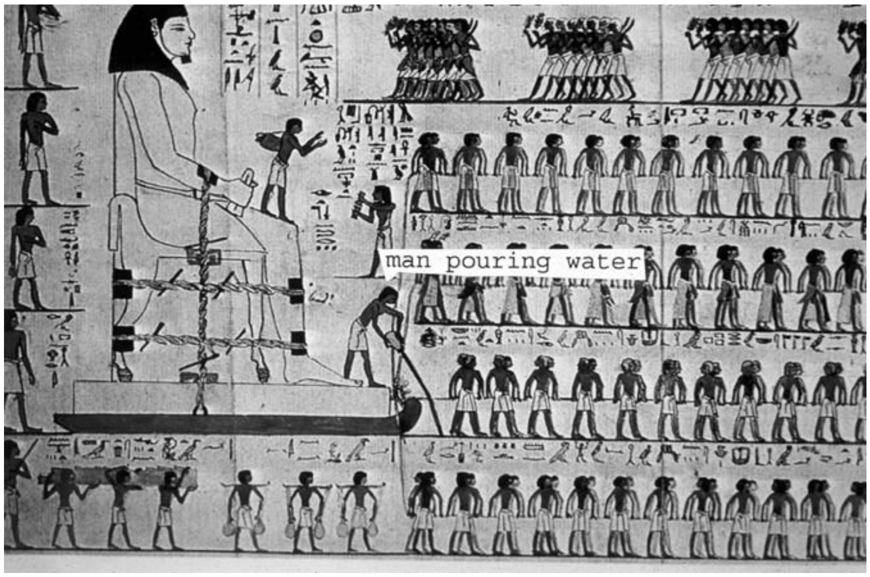

Figure 18.7 Transport of a huge statue on a wetted path of Nile mud (from a grave in Wadi el Nachla near Deir el-Berscha)

ever, nothing is proved; there are no traces of a mud-way visible, but one should keep in mind that the structure was never finished.

Conclusions

It seems to be fact that the Sadd el Kafara was destroyed before it was completed. But was this dam, with its extremely large dimension, really the first structure of its kind in Egypt?

It seems not unlikely that the first crest of this multilayer dam was at a level of 118.5 metres above mean sea level. Thus, the horizontal layers in the core, the bend in the dry wall in the upstream part, and the horizontal step of the dry wall in the downstream part as well as the wide ramp for the transport of the stone slabs can be explained: They would have been part of a first stage of the dam.

For an unknown reason – probably the obviously small storage volume – it was decided to increase the height of the dam. It can only be speculated about any reason. However, the raising of the structure above the elevation of the southern neighbouring terrace would have had one big advantage: No flood, however big, would ever have been able to destroy the dam, because the water would have flown around the structure on the southern terrace, which thus would have functioned as a spillway. This has been proved by testing a model in a hydraulic laboratory.

In order to increase height of the dam, the former camp for the workmen would have been used again, and probably also been enlarged. This explains the extension of the main building. Before the work could be finished, however, a big flood destroyed the dam, and because of this catastrophe, work was terminated.

If this assumption is correct (the evidence at the dam and in the camp point to two different construction or even operation phases and, therefore, to an interruption of the construction process), the next question – how such a large structure could be accomplished – could be answered: The development was done in steps at the Sadd el Kafara itself.

Many questions, especially concerning the purpose of what was probably the first high dam in history, are still unanswered. However, the analysis of the structure revealed that in the time of the Old Kingdom, a splendid plan for a dam had been constructed. If the dam had been finished, it would have functioned until the storage was filled up with sediment. A flood catastrophe prevented this. But the courage and daring of the master builders are to be highly esteemed, even 4000 years later.

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19

The design principle of historical curvilinear oblique weirs

Koichiro Sakitani, Yu Nakai and Osamu Shinohara

The Kohdo intake weir is at a point about 3.5 km from the mouth of the Matsuda River, which runs through Sukumo city in the westernmost part of Kochi prefecture. While the Kohdo weir has been reconstructed into a movable weir, except for a small part that has been preserved, it formerly was a fixed intake weir with a unique shape.

The Kohdo weir originally was built from one side of the river to the other, curving downward and obliquely across the river. A weir with a plane profile like that of the Kohdo weir is generally called a curvilinear oblique weir.[i] While weirs in recent times (when materials and technology were well developed) are built straight and perpendicular to the river, a curvilinear oblique weir had an elegant curve that, in turn, created a water-rich scenery deemed attractive by those who viewed the river.

The origins of the curvilinear oblique weir go back to the fief of Tosa (the former name of Kochi) in the 17th century. The person believed to have built the Kohdo weir was Nonaka Kenzan (1615–1663), who served as a magistrate in Tosa for 27 years. The era in which Kenzan lived was a period when rice paddy fields were developed on the largest scale throughout history across Japan. Kenzan built multiple weirs; a flood-resistant weir that could draw adequate amounts of water into paddy fields was one of the greatest challenges facing engineers at that time.

Although the curvilinear oblique weir, with its distinctive shape, endured for a long time, the underlying design principle is no longer fully clear. In this research, investigations and analyses were conducted on the locations and placements of seven weirs in four rivers, all built by Nonaka Kenzan, to develop a hypothesis about the design principle of curvilinear oblique weirs.

The two major existing opinions on the design principle of curvilinear oblique weirs are the ‘‘downstream edge of an alternating bar’’[ii] theory and the ‘‘ito-nagashi’’ theory (an oral tradition in Kochi prefecture).

Theory 1: ‘‘Downstream edge of an alternating bar’’

On riverbed forms and the flow

The routes of a river, as determined by strong riverbanks (rocks and embankments), is defined as the ‘‘river course.’’ Rivers on alluvial plains run along the river course at a time of high water, and meander or divide into streams in the river course at periods of low water. This is because the usual water current on the riverbed is formed by the accumulation of earth and sand from mountains encroached by flood pressures. In other words, the current at the period of low water is influenced by the form of and location of the riverbed, and vice versa.

The action of encroachment, conveyance and accumulation of rivers, which can be likened to the metabolism of living creatures, forms distinctive features for each river. Alternating bars, full of ‘‘ups’’ and ‘‘downs,’’ is one form of riverbed. On alternating bars, the current goes from shallows with a flat riverbed and small-grain materials (figure 19.1, near cross-section 5) to rapids with a steep river course and materials of rela-

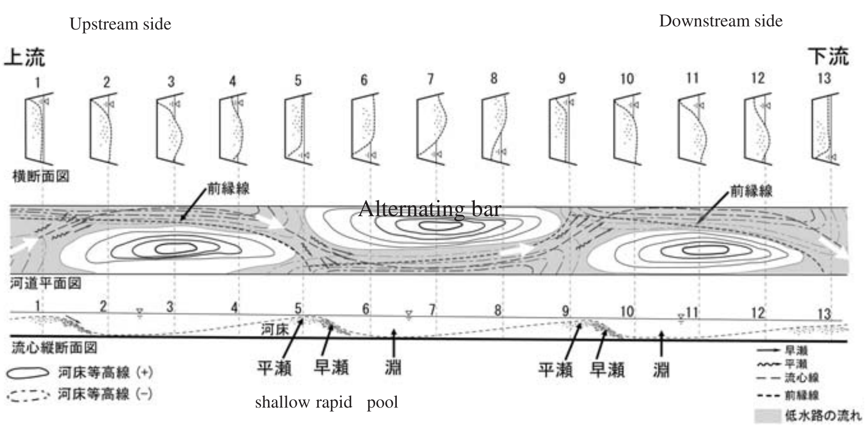

Figure 19.1 Alternating bars

tively large grain size (figure 19.1, cross-section 5 to 6), and then to a deep pool near one riverbank (figure 19.1, near cross-section 6 to 7). The currents eventually go to a pool on the opposite bank. One riverbed unit, with a regular, recurrent sequence of ''shallows → rapids → pool,'' is called an alternating bar. The hydraulic conditions that influence alternating bar formation include river width, riverbed slope, flow of the river, river depth, velocity of the current and riverbed materials (and their relative density). The edge of this alternating bar is called the downstream edge.

A major factor of alternating bar formation is the movement of earth and sand at flood times. Alternating bars have characteristics that differ depending on whether the river course is straight or curved: in a straight river course, the alternating bar moves downstream, preserving its form, while in a curved river course, each alternating bar is in a fixed location and the water route will be stabilized at low water (Koide, 1970 and 1972; Iguchi, 1979; Suga, 1992; Yamamoto, 1994; Kinoshita and Miwa, 1974).

On the downstream edge of an alternating bar

In the midst of past discussions about general oblique weirs (including curvilinear oblique weirs), Miwa (1972 and 1978) suggested that ancient oblique weirs were constructed along the curved downstream edge of an alternating bar. He summarized the characteristics of ''curved oblique weirs'' (his expression; they are commonly called oblique weirs) as follows.

The characteristics of ''curved oblique weirs'' are that:

- They are located in a river with natural or man-made riverbanks, and placed on an alternating bar stabilized with the curve of the river course.
- They cross the river course with a long, slanted curve along the crest of an alternating bar (heightened part of riverbed) and are placed low.
- The intakes are made near the edge of the weirs.

Furthermore, Miwa has shown by hydraulic model testing that ''curved oblique weirs'' built along the downstream edge of an alternating bar have validity, as follows:

- Since ''curved oblique weirs'' are placed at the point where flood flow is widest on an alternating bar, and the density of the streamline is lowest, forces from flood flows are quite small at every point of the weirs.
- Since ''curved oblique weirs'' are built connecting the heightened parts of the riverbed, which are relatively close to the water surface, the height of the weirs can be low compared alternative construction. Therefore, the construction is easier.

- Since "curved oblique weirs" have the characteristics mentioned above, riverbed scouring below the weirs is small, and local scouring is less likely to be formed.
- Since intakes are made near the edges of the weirs, the intakes are not subject to flood water and the intake sluices can be simple.
- "Curved oblique weirs" are made along the line of alternating bars that are also riverbed forms, and so hardly change the riverbed form from that present before the weirs' construction.

Examination of the "downstream edge of an alternating bar" theory

Figure 19.2 illustrates the "downstream edge of an alternating bar" theory. The oblique weir is ideally placed at this point, in terms of weir's safety against flood pressures.

Weirs should be built along the downstream edge of an alternating bar to ensure safety against flood flows and for ease of construction. Experi-

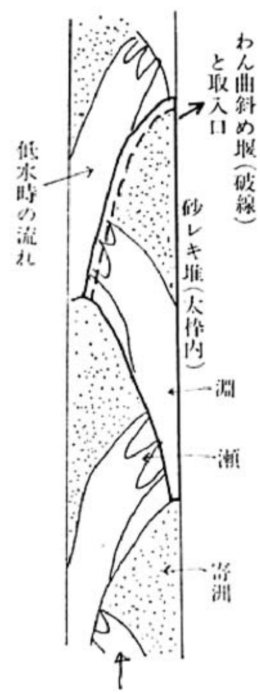

Figure 19.2 An alternating bar and curvilinear oblique weir

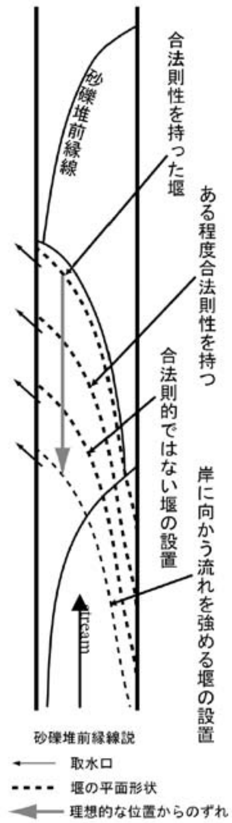

Figure 19.3 Relation with alternating bar and curvilinear oblique weir

mentation has shown that scouring is formed downstream and the safety of the structure is reduced if the weir is placed too far from the ideal point (Miwa, 1978). Actual oblique weirs, however, are placed upstream so that intakes are at points where the current at low water is at the riverbank in consideration of the intake's facility (figure 19.3). In other words, weirs were placed away from the ideal point in terms of protection against floods.

The ‘‘downstream edge of an alternating bar'' theory is special in that the weir's safety against flooding is the first consideration. Also, in terms of the weir's plane profile, it is believed that since it is placed in relation to an alternating bar, it crosses the river course with an oblique curve. In other words, the weir's plane profile characteristically matches the shape of the alternating bar.

Theory 2: The ‘‘ito-nagashi’’ theory

On the ‘‘ito-nagashi’’ theory

In Kochi prefecture, regarding the formation process of a curvilinear oblique weir’s profile, the ‘‘ito-nagashi’’ theory is an oral tradition that dates from old times. According to the story, Kenzan ‘‘stretched a line (rope) connecting both banks, and decided on the weir’s profile based on the line shape formed by the current pressure.’’ Ohtoshi (1998) tried to verify this theory by a hydraulic model test with the Kohdo weir, a remnant of one of Kenzan’s weirs, as a model.

Examination of the ‘‘ito-nagashi’’ theory

The ‘‘ito-nagashi’’ theory is very interesting as a means to determine the profile of a curvilinear oblique weir. Ohtoshi’s experiments were special in that they used the Kohdo weir as a test subject. While the results of the hydraulic model test did not offer solid evidence that the weir complied with the ‘‘ito-nagashi’’ theory, neither did it disprove the theory.

When the weir is seen at the actual site, figuring out how the curve was designed does not seemed to be an easy task. In terms of structural design, the authors do not consider the ‘‘ito-nagashi’’ theory to be mere oral tradition.

The investigations and analyses

Research investigation and analyses were done for seven weirs representing Kenzan’s remnants in Kochi prefecture. The distribution of these weirs is shown in figure 19.4. All of the weirs in this research had lengths within the 100 to 500 metre range, widths within the 10 to 25 metre range and heights of between 1.5 and 3.0 metres. The investigations and analyses were done regarding the locations of the weirs, the placements of the weirs and the riverbed fluctuations around the weirs.

Analyses of the weirs’ locations

Analysis was made to grasp each weir’s location in relation to its surrounding topography, beneficiary areas and bed slopes. Three of the weirs are located in the Monobe River: Yamada weir, Noichi-kami weir and Noichi-shimo weir. Each of these weirs shows stark differences of characteristics regarding their location and surrounding topography (figure 19.5).

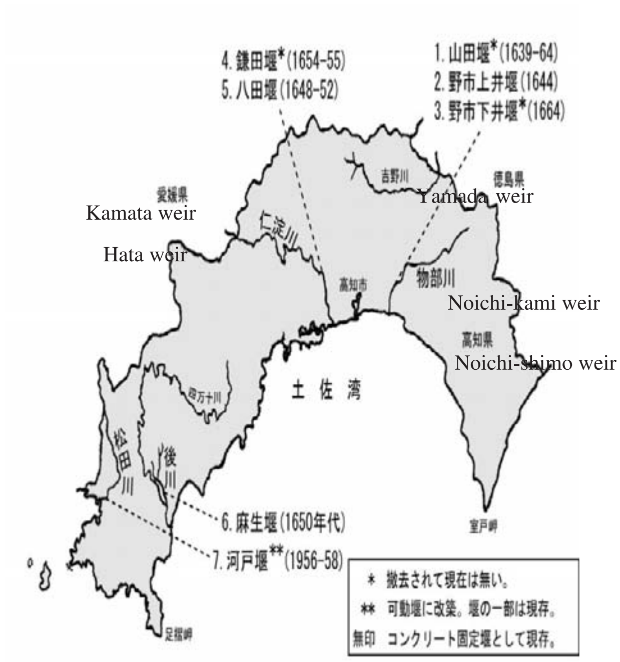

Figure 19.4 Distribution of curvilinear oblique weirs

Yamada weir – This weir, 10 km from the mouth of the Monobe River with a bed slope of 1/350, is located at the vertex of the alluvial fan. The apex is the optimum point for distributing water widely to the beneficiary area; the intake is on the right bank side, distributing water to a beneficiary area of about 1,700 hectares (ha). However, this point is subject to immense flood pressure and, furthermore, a large amount of earth and sand would pile up, requiring hard labour for maintenance and management. The reason for the weir being at this point was that the Yamada weir in the Monobe River and the Hata weir in the Niyodo River were major starting points of an inland water transportation route in the fief toward Urato Bay.

Upstream, the river touches the mountain on the right bank side and curves a little toward the left bank side. Also, the weir was built obliquely, with a little similarity to a straight line and at the point where the river width starts to increase. The weir is thought to have been placed with a location pattern that is different from those of other weirs.

Noichi-kami weir – This weir is 8 km from the mouth of the Monobe River, with a bed slope of 1/270. In contrast to the Yamada weir upstream, which was taking water to the plain on the right bank side of the

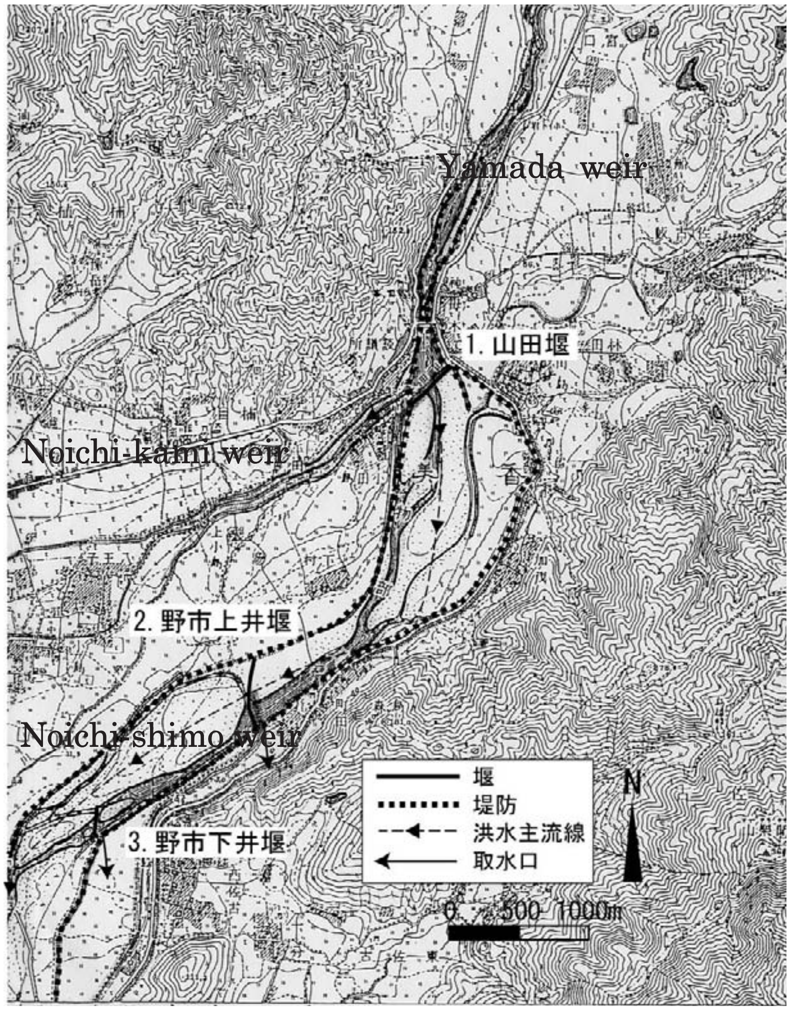

Figure 19.5 Monobe River and Yamada weir, Noichi-kami weir and Noichi-shimo weir

River Monobe, the Noichi-kami weir was built for the opening of a new paddy field in beneficiary area (460 ha) on the left bank side of the river. The weir was placed at a point immediately after a large curve made by the mountain on the left bank side of the river, and the intake was placed at the foot of the mountain on the left bank side.

This kind of location, with a high altitude, is effective as a water distribution starting point. The flood flow will be weakened by hitting the mountain above the weir. The intake on the mountain side leads water for about 300 m to the beneficiary area along the channel. Regarding the weir profile, the weir crosses the river obliquely with a moderate downward curve. This is the typical example of a curvilinear oblique weir.

Noichi-shimo weir – This weir, 7 km from the mouth of the Monobe River, has a bed slope of 1/270 to 1/290; it is located at a point 1 km lower than the Noichi-kami weir. Despite its close proximity to the beneficiary area (about 200 ha), there are no mountains on the intake side, nor are there any curves of river course upstream. Based on the weir's profile, it is thought to have had a complex form, with an oblique part leading water to the intake side and a part that is at a right angle to the heightened bank. The authors believe, with high probability, that Noichi-shimo weir was placed with the major purpose of supplementing the intake of Noichi-kami weir.

As mentioned above, analyses of the topography clarify the relation of each weir with the surrounding topography, beneficiary area and river course alignment. The same investigations and analyses were done for the Niyodo River, Ushiro River and Matsuda River.

Analyses of the weirs' placement

To determine the relation between the status of the streams before weir construction and their placement, the estimated downstream edge of the alternating bar was analysed. The alternating bars can judged based on the river course alignment with some degree of confidence. Analysis of the topography of the Monobe River is shown in figure 19.6. The analyses of the estimated downstream edge of alternating bars make it possible to infer how the weirs were placed in relation to the alternating bars.

Yamada weir was located at the vertex of the alluvial fan, which makes difficult to draw the downstream edge of the alternating bar. Therefore, analysis of the relation between the alternating bar and the weir's placement is omitted.

Noichi-kami weir was located crossing two alternating bars, with a stable pool above the intake; it crosses a rapids with a downward curve. The weir crosses a shallow area. Weirs in other rivers – such as Hata weir in the Niyodo River, Asou weir in the Ushiro River and Kohdo weir in the Matsuda River – were similarly placed. It can be concluded that all these weirs crossed the parts of shallows over two alternating bars. Construction in the shallow areas was easier, with little change of longitudinal or cross-sectional profile, and these placements had high water sealing capability due to the fine and dense riverbed materials.

Noichi-shimo weir was placed close to the edge of an alternating bar; there was no pool near the intake, and the weir was almost parallel to

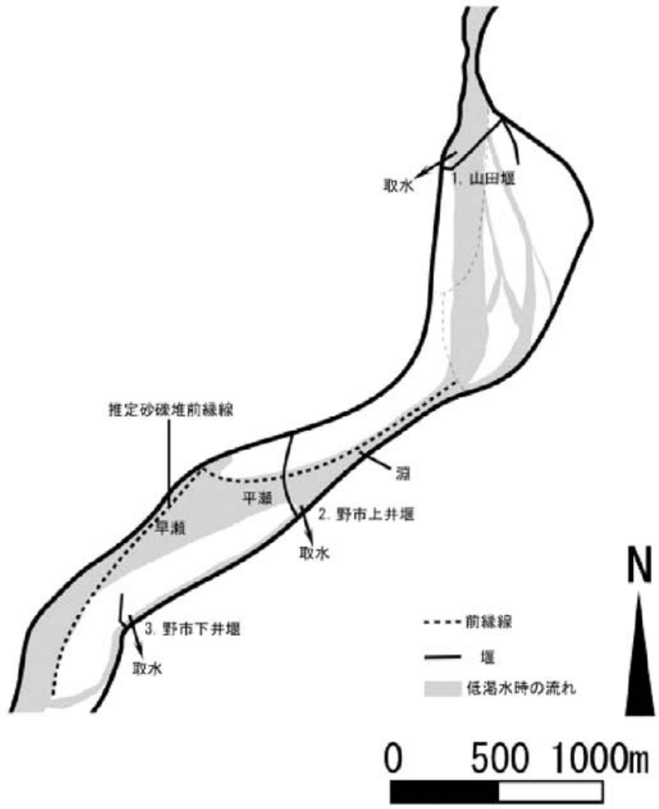

Figure 19.6 Relation between the estimated downstream edge of the alternating bar and the weir's placement

the downstream edge. The relationship between river course alignment and the location of this weir is different than that for other weirs; the relationship of the alternating bar and placement of the weir is also unique.

As mentioned, the relationships between the alternating bar and the placement of the weir depends on how the weirs were located. The main cause is thought to be variety in the status of the riverbed at the locations of the weirs.

Riverbed fluctuations around the weirs

Analyses of the riverbed fluctuations around the weirs were conducted using aerial photographs. In the Niyodo River, Kamata weir and Hata weir were the subjects of these analyses. The same analyses were done for the Monobe River.

Figure 19.7 An aerial photo of the Niyodo River in 1947–1948

Riverbed fluctuations around Kamata weir – Figure 19.7 is an aerial photograph of the Niyodo River in 1947–1948. Although Kamata weir was dismantled in 1933, the shape of the weir is indicated with a solid line based on the topography shown in the photograph. Above the weir, the river curved greatly at the mountain of the left bank side, creating a stable sandbar. A stream with a great curve flowed into the right bank side where the intake was above Kamata weir. Considering the characteristics of alternating bars and the flow, pools were formed above the weir.

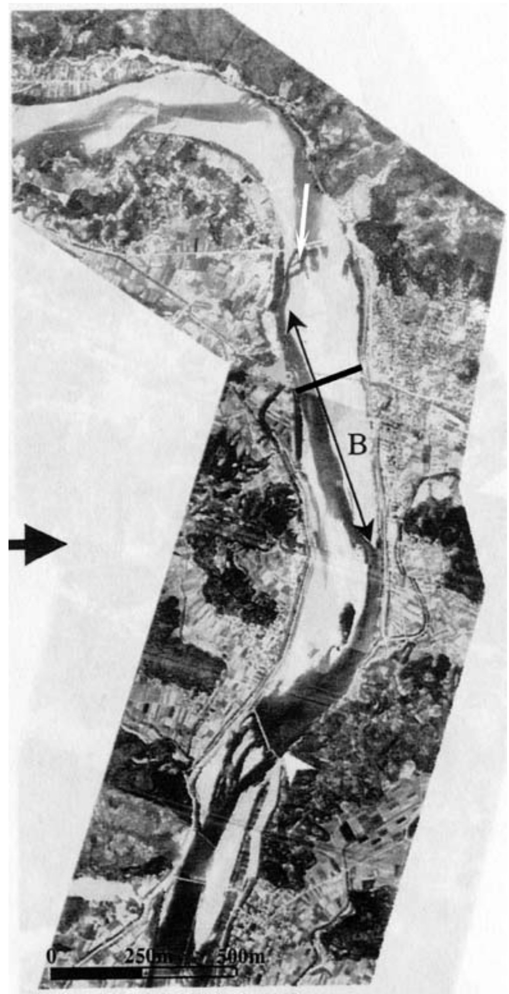

Figure 19.8 An aerial photo of the Niyodo River in 1967

The sandbar around the Kamata weir location became longer (indicated by mark B) as shown in figure 19.8, a photograph taken 20 years later than the photograph in figure 19.7 (in which the length of the sandbar then is indicated by mark A). And in figure 19.9, in a photograph taken 28 years after that in figure 19.8, it is apparent that the length of the sandbar lower than Kamata weir has drastically changed. This occurred because the river course alignment where there were riverbed fluctuations was almost straight, so the riverbed moved with free move-

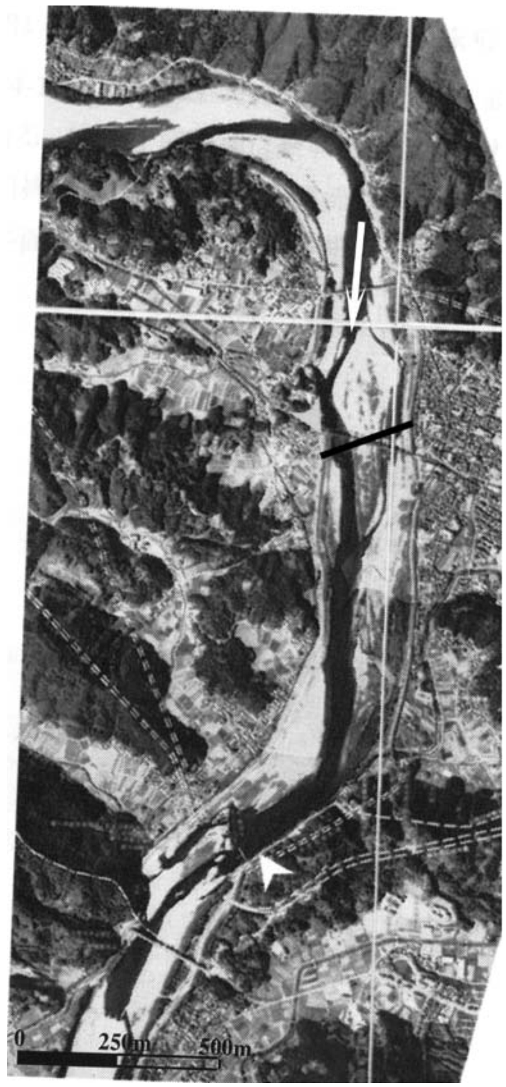

Figure 19.9 An aerial photo of the Niyodo River in 1995

ment of alternating bars, as mentioned previously. It can be seen from these photographs that while the riverbed lower than Kamata weir has moved greatly, the pools and flows above Kamata weir are stable.

Next, through analyses of these aerial photographs, we considered whether construction of Kamata weir complied with the "downstream edge of an alternating bar" theory. Kamata weir was constructed later than Hata weir, and because Hata weir drew water into the plain on the left bank side of the Niyodo River, Kamata weir was planned to take water from the right bank side. The distance from the actual construction point of Kamata weir to the beneficiary area was the longest among the seven weirs covered in this research – as much as 3 km. Considering the weir locations, and assuming that the status in figure 19.9 was closest to the flow before construction of the weir, the weir was located at a point far away from the ideal point in the ''downstream edge of an alternating bar'' theory.

Based on the location of Kamata weir, it is highly likely that a stable pool formed with a largely curved river course above the weir greatly influenced the weir location. In other words, it must be inferred that Kenzan had his own way of thinking regarding the construction of weirs.

Riverbed fluctuations around Hata weir – In contrast to Kamata weir, Hata weir was located immediately after the river's curve, toward the right bank side at the mountain on the left bank side. Also, a pool was formed on the left bank side above the weir. Furthermore, the alternating bar that Hata weir crossed did not move greatly.

Summarization of the investigations and analyses

From the results of investigations and analyses of the seven weirs covered in this research, both the weir locations and weir placements have four patterns. The weir location patterns will be discussed first.

Surrounding topography, river course alignment, beneficiary area and weir locations

The weir locations in relation to the surrounding topography, river course alignment and beneficiary area can be classified into four patterns, as shown in the figure 19.10. The characteristics of each pattern of weir location is as follows:

Pattern A – Above the weirs, there is a mountain that curves the river course. The weirs are located immediately after the curve, and the intakes are placed on the mountain side. By locating a weir at this point, it can be protected from the direct flood flows. Furthermore, to widely distribute water in the lower plain, the higher altitude of the intake starting point is desirable. Also, the riverbed immediately after the curve of river course is fixed, thus stabilizing the flow at low water. Noichi-kami weir (the Monobe River), Hata weir (the Niyodo River), Aso weir (the Ushiro River) and Kohdo weir (the Matsuda River) correspond to this pattern.

Pattern B – There are no mountains above the weir in pattern B, and the weir is located at a point close to where the river course is almost straight. Noichi-shimo weir (the Monobe River) is the only example of

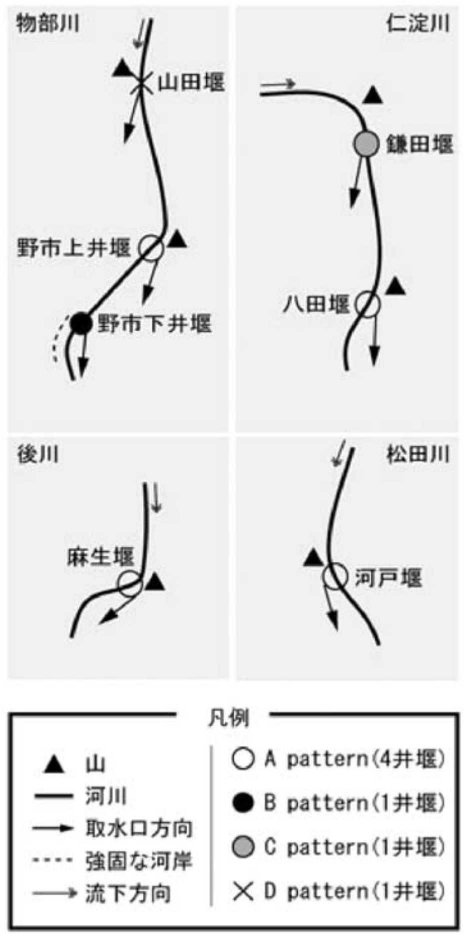

Figure 19.10 Location of curvilinear oblique weirs

this pattern. Regarding the weir location, pattern B is thought to complement the function of the weirs above.

Pattern C – There are mountains above the weir location in pattern C, but the intakes are not on the mountain side. The weir is located immediately after the large curve of the river course; therefore, the sandbar upstream is firmly fixed and a stable pool is formed near the intakes. Kamata weir (the Niyodo River) is the sole example of this pattern. This location was selected for the formed stable pool near the intake.

Pattern D – The weir is located at the vertex of the alluvial fan in pattern D, and the intake is placed on the mountain side. Located at a point with high altitude, the weir has high water-distributing capability.

However, this location is subject to strong flood flows, and earth and sand from above pile up in great amounts, making maintenance and management of the weir quite difficult. Only Yamada weir (the Monobe River) fits into this pattern.

Alternating bars and the weir placements

Next, the characteristics of weir placement are discussed (figure 19.11).

Pattern a – In pattern a, the weirs have intakes above a pool and are placed at an almost right angle to the riverbank, crossing a shallows obliquely. Noichi-kami weir (the Monobe River), Hata weir (the Niyodo River), Aso weir (the Ushiro River) and Kohdo weir (the Matsuda River) fall into this pattern. The profile has a downward curve over the shallows.

Pattern b – The weir is located at the edge of an alternating bar in pattern b, almost parallel to the downstream edge of the alternating bar, and crosses the river obliquely. Intakes are not above pools. Only Noichi-shimo weir (the Monobe River), which distributes water to the area not covered by the upstream Noichi-kami weir, falls into this pattern.

Pattern c – Intakes are above a pool in pattern c, and the weir crosses a downstream edge above the point where pattern a weirs do. Kamata weir (the Niyodo River) is the only example of this pattern.

Pattern d – Since the weir is located at the vertex of an alluvial fan in pattern d, the relation of weir placement to the alternating bar is unclear. Since it is at the apex of an alluvial fan, a large amount of earth and sand piles up, and the weir is thought to have been placed to take advantage of this. The profile of the weir shows many straight segments in the part placed obliquely to the river course, with a part is curved toward downstream. Yamada weir (the Monobe River) fits into this pattern.

The locations and placement of pattern a weirs, with intakes on the mountain side immediately after a curved river course and crossing shallows with an intake above a pool, are special. Of the seven weirs covered in this research, four – Noichi-kami weir (the Monobe river), Hata weir (the Niyodo River), Aso weir (the Ushiro River) and Kohdo weir (the Matsuda River) – fit these locations and placements conditions.

Existing opinions on the characteristics of curvilinear oblique weirs

The ‘‘downstream edge of alternating bar’’ theory

In the ‘‘downstream edge of an alternating bar’’ theory, weirs constructed along the downstream edge are thought to be ideal from the viewpoint of

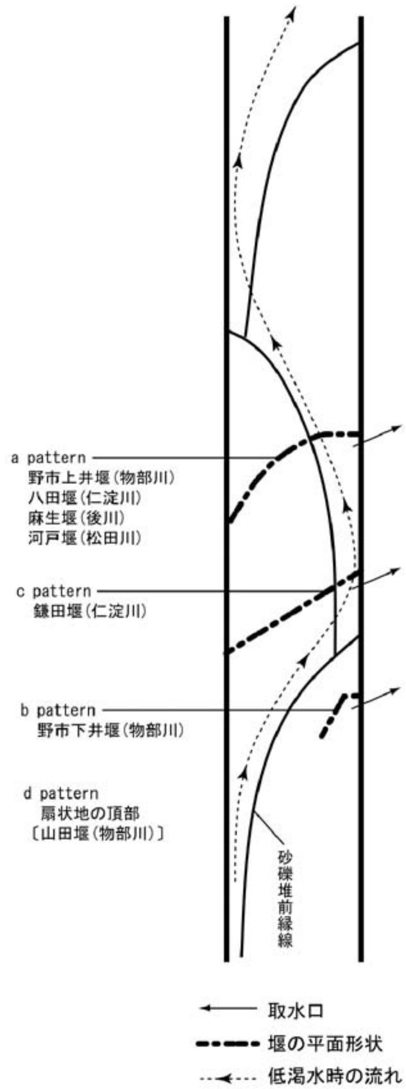

Figure 19.11 Placement of curvilinear oblique weirs

the weirs' safety against floods and their relation to the selected intake points. The farther from the ideal point that the location is, for greater intake facility, the lower the safety of the weir becomes. In other words, in the ''downstream edge of an alternating bar'' theory, importance is put on ''the weir's safety against floods.''

In contrast to the "downstream edge of an alternating bar" theory, the characteristics that curvilinear oblique weirs have in common are that the intakes are located above a pool, which indicates that priority was placed on a pool in choosing the weir's locations. This also means the weir's facility in taking water was valued.

The "ito-nagashi" theory

The "ito-nagashi" theory was a particular principle with regard to a weir's location. With curvilinear oblique weirs, the weir touching the riverbank of the intake and the riverbank cross each other at right angles. The weir crosses the river above a shallows with fine and dense riverbed materials, thus with excellent water-sealing capability. Also, the riverbed has fewer ups and downs, which greatly facilitates the construction.

With this profile, the weirs cross the river almost at a right angle to the current, with a downward curve. There is high probability that the "ito-nagashi" theory was put into practice in the curve design regarding where the shallows are.

Common characteristics found in curvilinear oblique weirs

The common characteristics in the curvilinear oblique weirs that are said to have been built by Kenzan are as follows:

Location – The weirs are located immediately after a curve of the river course caused by mountains upstream. The flow is weakened by touching the mountain right before the weir, thus contributing to the increased safety of the structure. Furthermore, in terms of the altitude of the intake starting point, the weir drains quite easily. Also, this is a point where a stable alternating bar is formed, which facilitates water intake with stable current and construction with a stable riverbed.

Intakes – Intakes are located at points a little bit lower than the pool of the flow. When taking constant intake facility into consideration, intakes are ideally placed close to a pool that is within easy reach of water at low water. Also, selection of a point offering easy construction was a priority among all considerations.

The riverbank and the weir's placement – A weir on the sluice gate side and the riverbed are placed at almost a right angle to each other. The angle was close to 90 degrees, thus preventing the formation of a local current that could cause negative effect on the weir and its intake.

The crossing of shallows – The weir crosses the river obliquely over shallows that are fine and dense riverbed materials. Therefore, it has a high water-sealing capability and construction is easy considering the smooth riverbed, both vertically and horizontally.

Cross-section profile of shallows – The weir crosses shallows with a downward curve. This is the most remarkable characteristic of curvilinear oblique weirs.

Pool-intake and shallow-crossing construction hypothesis

Finally, the hypothesis of the design of curvilinear oblique weirs' locations and the profile is presented as the fruition of this research.

Determination of the intake points

Intakes are determined at the point of a pool formed by the curve of the river by the mountain. It is effective for the improvement of intake constancy at low water and for water distribution to beneficiary areas. Also, the flood pressure is reduced at the mountain upstream (figure 19.12).

Placement of weirs relative to the riverbank

The weir is placed at a right angle to the riverbank at a point with construction advantage which is lower than the intake. Furthermore, the

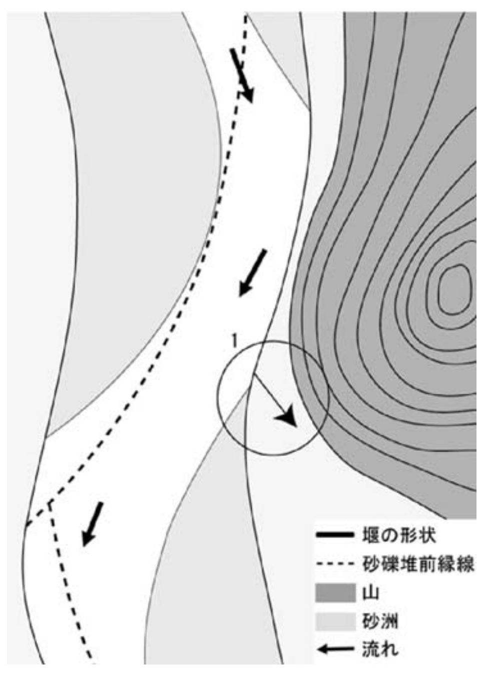

Figure 19.12 The determination of the intake point

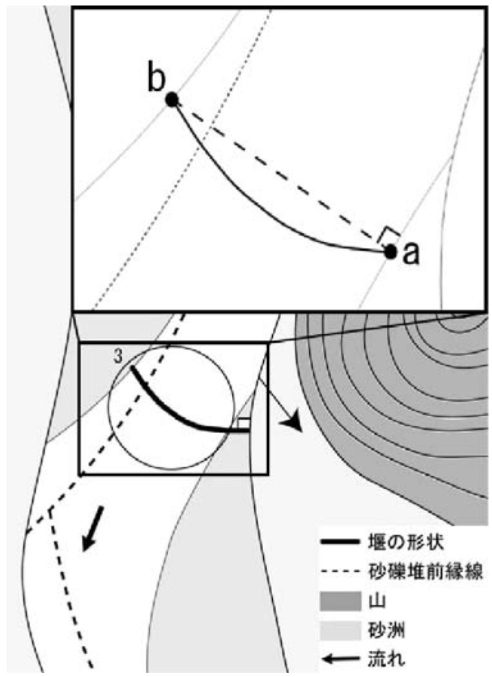

Figure 19.13 The placement of weirs in relation to the riverbank

weir is extended to the current over shallows, straight in the direction crossing the river. By connecting to the bank at a right angle, the localization of the current will be reduced thus improving the safety of the weir (figure 19.13).

Crossing shallows

From the intersection point (a) of extension from the riverbank and the current over shallows, a straight line is drawn directly to the edge of the sandbar on the right bank side, and the intersection point on the left bank side will be (b). The string as α (α is a predetermined constant) times as long as a line segment (ab) is set to the point (a) and (b), and the shape formed by the flow over shallows is determined as the crossing line of the weir.

By taking the shape formed with the flow over the shallows, the strength of the flow is the same at every point of the weir, thus reducing the forces on the weir at low water to ensure the safety of the weir. Also, for the part of the shallows, the riverbed is smooth, which is advantageous in construction. Also, it doesn't contradict with "the downstream

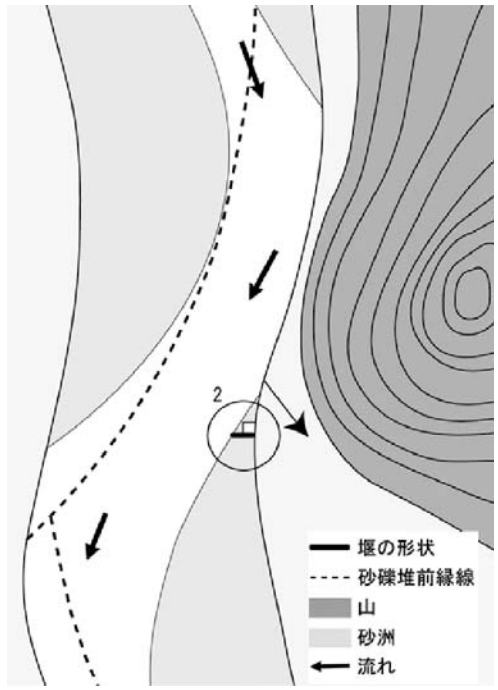

Figure 19.14 Crossing shallows

edge of an alternating bar'' theory, in that the height of the weir itself can be low since it is constructed on the heightened part of the riverbed. Furthermore, the weir has a high water sealing capability due to the fine and dense riverbed materials (figure 19.14).

The line shape over the sandbar on the opposite bank

The line is extended to the opposite bank tangential to the curve crossing the shallows. By smoothing out the connecting point with the curve, the local force of the current is prevented so as to improve the safety of the weir. As mentioned, the weir was designed with the smooth line so that the force on the weir is the same at every point. By so doing, there will be no local weak points made with the concentration of the force at normal time (figure 19.15).

This hypothesis of the curvilinear oblique weirs' form's determination process is called the pool-intake and shallow-crossing construction hypothesis. In this hypothesis, priority is placed on the weir's intake facility.

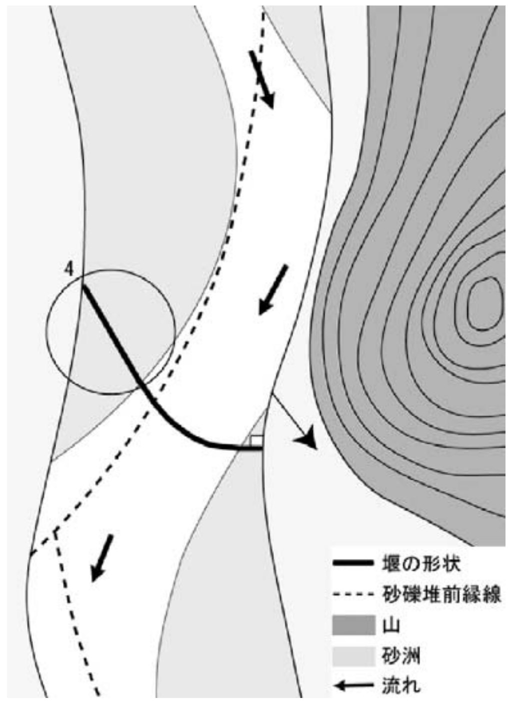

Figure 19.15 The line shape over the sandbar on the opposite bank

The rationality with the intake facility of the weir, the safety against floods and facility in construction can be summarized as follows:

Intake facility – By placing the intake above a pool, water is easily reached even at low water. Furthermore, with the altitude of the water-taking starting point, it has greater water distribution capability at the same time.

Safety against floods – Regarding safety against floods, there are two measures: First, the flood flow is weakened when hitting the mountain upstream. Furthermore, by the smooth line shape of the weir, the force from the flood is dispersed so that the strength becomes the same at every point of the weir to ensure structural safety.

Facility in construction – The weirs cross the shallows with relative smoothness for the longitudinal and cross-section profile and dense riverbed materials. They cross the current at points advantageous in terms of construction, which is reasonable. Also, the shape of the weirs was determined with a line flowing in the river. This is also reasonable in that it disperses the force of the water on the weir evenly. Furthermore, the weir has high water sealing capability from the characteristics of shallows.

Conclusion

In this research, a hypotheses with higher validity is presented as the design principle of curvilinear oblique weirs, based on investigations and analyses with a viewpoint different than those of the two existing design theories. To seek a more concrete design principle, comparisons of the examinations from the viewpoint of more detailed river engineering and technical aspects of the modern period are desirable.

Natural features are created based on the natural conditions at each place. The differences between those natural features are most remarkable in rivers. Before the development of modern materials and technology, products were made according to the specific characteristics of each region. Constructing weirs to be oblique to the river course was a result of taking advantage of the region's characteristics. While the techniques may have been less sophisticated, and the materials weaker, than those of today, our ancestors had shaper eyes and greater wisdom about living in harmony with nature.

With this in mind, for the message projected from the shape of curvilinear oblique weirs, interpretation based on natural science from the viewpoint of the present time is not enough. Our ancestors' knowledge of and techniques for dealing with natural features and local nature are awe-inspiring.

Acknowledgement

The authors would like to express their deepest appreciation to those who cooperated in this research.

Notes

i. Ohtoshi (Kohchi University) has defined oblique weirs in Kohchi prefecture that have a large curvature as "curvilinear oblique weirs" to distinguish them from general oblique weirs.
ii. Miwa's hypothesis about oblique weirs is that they were constructed along the downstream edge of alternating bars, where it's easy to build and there is stability against the stream.

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20

Conclusion

Remi Chandran

When looking back at the history of the earth and the beginnings of life, we are often reminded that we need to understand and consider the laws of nature before undertaking any major steps that could alter the course from the path that it would otherwise have taken. It often happens that, in our rush towards development, we forget about the need to preserve nature's visible grandeurs: towering mountains, forests of immense trees, and grand rivers and waterfalls. Now, in the 21st century, we stand in danger of being deprived of these precious resources – water being one of the most important.

The objective of this book has been to look into the old and ancient methods of water harvesting, and seek to understand how traditional technology represents a classical example of sustainable use of natural resources (rather than our current unsustainable utilization). This book also brings out facts regarding the *common grounds theory*: i.e., how their methods or frameworks influence traditional motivations in natural science, such as ''understanding nature'' or ''searching for final truth.'' This is evident in three classical works: the mining ponds of Banská Štiavnica in Slovakia; the famous Qanat system, which originated in Northern Africa and spread to Asia and other parts of the world; and the remarkable story of Sadd el Kafara, the oldest highest dam of the world.

What is notable about the three case studies is that there had been a thorough understanding of nature in designing the technology. Nevertheless, the understanding of human beings went far beyond, to the unsustainable utilization of nature's resources as we began to focus on concrete infrastructures and over-exploitation of groundwater resources.

On the political side, the Dutch experience is one of the most notable with regard to historical activities in water management and land reclamation. The Netherlands is a prime example of transforming the original, natural landscape into a man-made landscape and the subsequent, never-ending struggle to manage and control water.

Water issues have a history in every country, in varying proportions and formats. The underlying practice of traditional utilization, however, was quite universal even before nations communicated their experiences effectively.

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