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Adaptive Water Resource Management in the South Indian Lower Bhavani Project Command Area

Mats Lannerstad and David Molden

International Water Management Institute

Linköping University

Comprehensive Assessment of water management in agriculture

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Adaptive Water Resource Management in the South Indian Lower Bhavani Project Command Area

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Cover photographs (clockwise from bottom left):
(a) LBP/Bhavanisagar Reservoir
(b) Flow measure, LBP canal
(c) Groundnut cultivation, LBP
(d) Paddy transplanting, LBP
(e) Paddy harvest, LBP
(f) LBP canal
Photo credits: Mats Lannerstad (all photographs).

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Contents

Summary

This study explores the theory and practice of Adaptive Management (AM) based on a detailed field study. To what extent farmers and water resource managers already practice AM; and whether it is practiced in an optimal manner or could there be areas for improvement based on recent advancements in the theory of AM; are some of the questions that are particularly appropriate in the light of rapid changes in river basin water use and also in relation to basin closure.

This paper draws on the development and use of water resources in the Lower Bhavani Project (LBP), with the LBP reservoir and the 84,000 hectare (ha) LBP command area. The project diverts water from the Bhavani River, a tributary of the Cauvery River, in the South Indian state of Tamil Nadu. The LBP was the first major irrigation project initiated in India after independence in 1947 and was in full operation by 1956. The LBP has had a major impact on the socioeconomic development of the area, and continues to be a productive irrigated area.

However, behind the story of a productive irrigation system lie more complex stories of societal change, conflicts and negotiation in response to water scarcity and several drivers of change. In fact, there were problems from the start, as the original design concept for the project was not accepted by farmers who opted for more water-intensive crops rather than the suggested ‘dry crops’. In addition, a highly fluctuating climate and the transfer of water to urban areas have all been a challenge for agricultural producers. Farmers, system managers and others have responded to these challenges by trying out different management systems, and have continued to adjust their practices in the face of change.

This paper presents a five-step framework of analysis based on recent theories of AM to understand the extent to which it is practiced and how it could be improved. The Adaptive Water Management (AWM) analysis shows that the LBP system has increasingly fulfilled the criteria of a complex adaptive system over the years. Social learning takes place at system and farmer level. The main uncertainty factor, rainfall variability, has been considered in a stepwise way during the system change cycles and has been included in the system design. The system has, to some extent, fulfilled the requirement of an adaptive regime and has built a substantial amount of social capital. This has been a rather ad hoc process, which could have been much faster had attention been paid to institutional setups and infrastructure designs that support AM.

However, the future will not be easier. The basin is closed with water resources already over-allocated to various uses. Yet, cities and industries, and users outside the basin, will demand more and agriculture itself is becoming less important to the economy. To meet these future challenges, it is essential that policymakers recognize and build on the existing social capital and the negotiation and learning systems that have been developed.

Finally, the LBP case study gives us some hope. In spite of contending with an imperfect irrigation system design and intense competition for water resources, water resource managers and farmers are able to adapt and continue to reap benefits from a productive agricultural system.

Adaptive Water Resource Management in the South Indian Lower Bhavani Project Command Area

Mats Lannerstad and David Molden

Introduction: Rapid Change and Increased Complexity

It has now been accepted that natural resource management has to be viewed in a context of constant change. Neither the environment nor the society is static, and we all have to live with change and have to adapt to new demands and realities. One of those changes is the pressure on food production systems, with global population increases, increasing GDP and purchasing power, which in many countries increases the demand for food and other agricultural commodities (Bruinsma 2003; Alexandratos et al. 2006). Water, the bloodstream of the biosphere (Falkenmark 2003), will be one of the most decisive factors restraining, or enhancing, agricultural production in many countries (Falkenmark and Rockström 2004; Comprehensive Assessment of Water Management in Agriculture 2007). World population is estimated to increase to 8.3 billion by 2030 and to 9.2 billion by 2050, an increase of more than 40% in the coming decades (UN 2008, medium projection 2006 revision). Consequently, food demands, with rising average diet levels, are expected to rise by another 50%, at least, in the coming decades (Alexandratos et al. 2006), and unless changes are made, this may also require 50% more water (Rockström et al. 2007; Comprehensive Assessment of Water Management in Agriculture 2007). Water for biofuel production (e.g., Berndes 2008) and the implications of climate change on water resources (Bates et al. 2008) further increase this complexity. This development draws attention to the concept of adaptive water resources management that aims to handle change in an increasingly complex and unpredictable human-environmental-technology system (NeWater 2005) - an ability that will be of critical importance for the future.

It is easy to discuss the general issue on a global level. The question is how people can or could react to these drivers of rapid change on a local scale. Will agricultural systems collapse as a result of environmental failure? Will they stagnate because people cannot cope with rapid changes? Or will they be able to positively respond by making changes themselves? Within agricultural water management, irrigation systems, in particular, have developed a reputation of having low resilience, and are thus vulnerable to change. The idea that they are subject to collapse is perhaps most well-known from the popular book *Pillar of Sand* (Postel 1999). Postel questions whether the "irrigation miracle" can last and analyzes whether the rise and fall of historic irrigation-based civilizations can offer some lessons for our globally irrigated society. Given the importance of irrigation in food production, a downfall of today´s irrigation systems would be devastating to both individual farmers and also to the global food system. But is it really likely or are irrigation system users capable of adapting to the changing environmental and societal drivers?

This study explores this area and other theoretical and practical questions related to AM in irrigation using a detailed case study of the LBP in Tamil Nadu, Southern India. In the LBP system, there is both a large livelihood dependence on agriculture and intense pressure from within and without on the system's water resources. In order to try and answer these questions, the paper describes how people act, cope and adapt locally to deal with environmental preconditions and changing human demands, taking into account a century-long perspective, and then considering the last 50 years in more detail. The study will concentrate on a real and complex case where farmers' federations and single farmers, irrigation engineers and other authorities have adapted in various ways to urgent societal needs, farmers' desires, changes in water availability, and seasonal and inter-annual climate variability. The paper will examine whether or not AM is practiced, and shed light on whether the system can cope with future demands.

Adaptive Water Management: Concepts and Analysis Framework

The concept of AM "can more generally be defined as a systematic process for improving management policies and practices by learning from the outcomes of management strategies that have already been implemented" (Pahl-Wostl et al. 2007: 4). "Adaptive management is learning to manage by managing to learn" (NeWater 2005: 7). The starting point for AM originates from the field of industrial operation theory developed during the 1950s (Johnson 1999). In the 1970s, it was applied to resource issues and developed into the concept of "Adaptive Resource Management", sometimes called "Adaptive Ecosystem Management" (Holling and Marshall 2002).

AM stands in contrast to coping (Table 1). Ad hoc and reactive responses, during a time of emergency or rapid change, aimed at short-term survival are examples of coping strategies. Adaptive strategies are instead proactive adjustments aimed at promoting, for example, long-term ecosystem integrity and human well-being. Whether actors choose coping or adaptive strategies is often the result of existing or missing capacity of factors like social learning and institutional change based on shared experiences, often over long periods of time and transferred over several generations (Fabricius et al. 2007).

In AM cycles, policies and practices are adapted as circumstances change and people learn. Identification of problems and goals are followed by the development and implementation of policies and practices to meet these goals. Monitoring of the results provides the basis for re-formulation of problems and goals, and the cycle (Figure 1) begins again in an iterative way. An important part of the process, already mentioned above, is stakeholder participation and social learning (Stringer et al. 2006). According to this thinking, management decisions should be based upon site-specific information gained through

TABLE 1. The characteristics of coping and adaptive strategies in communities (*Source:* Fabricius et al. 2007).

	Coping strategies	Adaptive strategies
Aims	Survival	Both survival and sustainable management of social-ecological systems
Time frames	Short-term, immediate	Long-term, evolving over several generations
Response types	Reactive, opportunistic	Proactive, planned
Learning	Limited, through individual experience and innovation	Extensive, through knowledge exchange, inter-generational transfer and institutional development

experimentation with management (Blumenthal and Jannink 2000). The AM approach acknowledges that time and resources are too limited to delay actions until ‘enough’ information is known. This is of particular relevance to addressing urgent problems such as “human poverty and declines in the abundance of valued biota. ... Adaptive management is about urgency, acting without knowing enough, and learning” (Lee 1999: 5).

The adaptive capacity of a system is a “measure of the thresholds within which systems are able to deal with change: systems with high adaptive capacities can thus retain their integrity under a broader range of conditions than systems with low adaptive capacities. ... In social systems, adaptive capacity refers to the ability to learn from mistakes and to generate experience of dealing with change, which in turn largely depends on the ability of individuals and their social networks to innovate” (Fabricius et al. 2007: 1-2).

Adaptive Water Management (AWM)

A significant body of work has moved the adaptive resource management concept to the specific field of water and advocated adaptive water management (AWM), or adaptive water resource management (AWRM), approaches (e.g., Holling and Marshall 2002; NeWater 2007; Pahl-Wostl et al. 2007; Lankford et al. 2007). For example, Pahl-Wostl et al. (2007) favor an AWM approach in line with the steps of the general AM approach. Their definition of AWM is, however, somewhat broader than the original definition of AM (as defined above) and is more to be viewed as a guiding paradigm to design adaptive policy processes (NeWater 2007). In particular, they discuss how AWM can improve the conceptual and methodological basis for achieving sustainable and integrated water management in an uncertain and complex world, and consider four parameters: uncertainty; the AWM process; AWM regimes; and social learning.

Uncertainty

Three kinds of uncertainty must be taken into account in AWM: (1) Lack of knowledge related to availability and variability of data, (2) Uncertainty in our understanding of water systems, and (3) Uncertainty related to potential shocks such as climate variability.

The AWM process

To manage the possible impacts of these uncertainties and sustain capacity to react to their outcomes requires the development, implementation and reflection of a policy process as shown in Figure 1. By following this process, it is theorized, the adaptive capacity of the water system is increased by introducing learning processes and establishing the necessary conditions for these processes to take place. During the process management strategies, and even goals, might themselves be adapted as new information surfaces and uncertainties become realities.

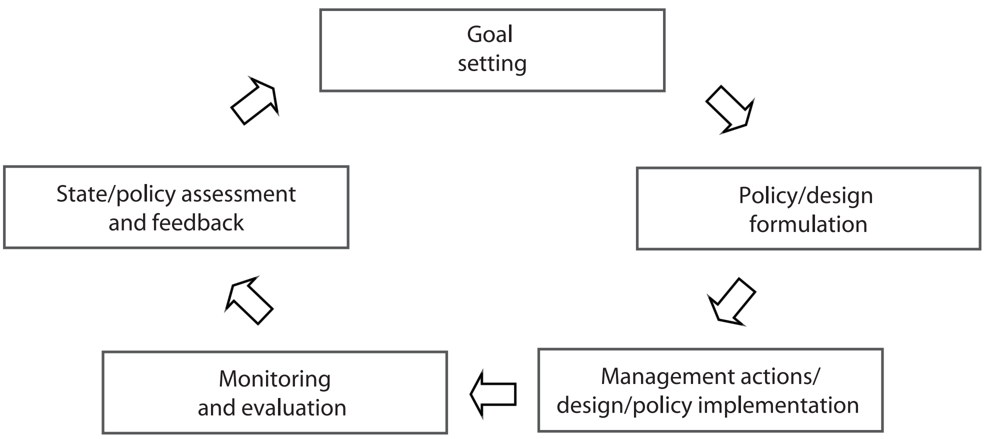


FIGURE 1. Iterative cycle of policy development and implementation in adaptive management (*Source*: modified from Pahl-Wostl et al. 2007; and NeWater 2007).

AWM regimes

A management regime refers to the entire "complex of technologies, institutions, environmental factors, and paradigms that are highly interconnected and essential to the functioning of the management system that is targeted to fulfil a societal function such as water supply or flood protection" (Pahl-Wostl et al. 2007: 8). In Table 2, two contrasting regimes are compared, "prediction-and-control" and "integrated adaptive". The first regime is based upon the assumption that human-environmental-technology systems are predictable and controllable. The latter instead recognises and is organized to handle the complexity and unpredictability characterising such systems. The structural requirements that according to Pahl-Wostl et al. (2007) are likely to typify an integrated adaptive regime are presented for five characteristics.

A regime has the capacity to be adaptive if its performance can meet three requirements. First, information such as performance must be collected and monitored, formally or informally, over a sufficient time period. Second, actors in the management system must be able to understand the information and draw meaningful conclusions. Third, those actors must be able and willing to implement change to the management system, and actors must thus be informed in a way that make them understand the reasons behind suggested changes (Pahl-Wostl et al. 2007).

Social learning

As discussed, social learning is considered an important part of AWM. From a perspective of river basin management, social learning develops and sustains the capacity of authorities, experts, interest groups and the public to experiment, learn, discuss and manage their water effectively as conditions change. The social learning and interaction helps people recognize inter-dependence and differences, and can thus enable collective action and resolution of conflicts. In a water resource system, technical infrastructure, the behavior and habits of users, and engineering rules of good practice are often mutually dependent and stabilize each other. This might block changes towards the improvement of water resource management schemes. According to the theory, with social learning such barriers can be overcome and open up possibilities for sustaining AM practices, with new innovative technologies and practices (Pahl-Wostl et al. 2007).

AWM Analysis

Based on the general ideas outlined above and explicitly discussed in the work by Claudia Pahl-Wostl and her colleagues within the EU-financed research project "New Approaches to Adaptive Water Management under Uncertainty" and articles published in the journal "Ecology and Science",

TABLE 2. Ideal-typical characterizations of a prediction-and-control and an integrated adaptive water management regime (*Source*: modified from Pahl-Wostl et al. 2007).

Characteristic	Prediction-and-control regime	Integrated adaptive regime
Governance structure	Centralized and hierarchical, with narrow stakeholder participation.	Polycentric and horizontal, with broad stakeholder participation.
Sectoral integration	Sectors are separately analyzed, resulting in policy conflicts and the emergence of chronic problems.	Cross-sectoral analysis identifies emergent problems and integrates policy implementation.
Scale of analysis and operation	Transboundary problems arise when river sub-basins are the exclusive scale of analysis and management.	Transboundary issues are addressed by multiple scales of analysis and management.
Information management	Understanding is fragmented by gaps and the failure to integrate information sources that are proprietary.	Comprehensive understanding is achieved by open, shared information sources that fill gaps and facilitate integration.
Infrastructure	A massive, centralized infrastructure has single sources of design, power, and delivery.	A decentralized infrastructure on an appropriate scale has diverse sources of design, power, and delivery.

this paper examines how AM has or has not occurred over a 50-year time span in the LBP. The analysis, thus, aims to see how well the LBP has adapted without being guided by any theory. The framework for analysis focuses on five questions:

1) Is the LBP system adapting to changes or only coping with changes?
2) What levels of uncertainty exist in the LBP system? What determines or impacts the level of uncertainty?
3) Is it possible to distinguish cycles of AWM in the LBP system during the last 50 years, i.e., goal setting, and policy formulation, implementation, monitoring, and assessment and feedback?
4) Can the LBP system be described as an "integrated adaptive regime"? Which 'characteristic' requirements exist in the LBP system and do they change over time? Does the system prove to have an 'adaptive capacity'?
5) Is there social learning within the LBP system? Is it short-term or long-term? Does the knowledge stay with the actors in the system, or is it lost over time?

Within these questions, issues of actors (e.g., farmers, water managers, politicians, society), time scale (e.g., cropping season, years) and spatial scale (e.g., farm, irrigation system, river basin, boundaries of the AWM system) will also be addressed.

We use these questions to analyze whether or not AM has taken place. To answer these questions, a variety of approaches were used including analysis of existing literature and maps; secondary water flow and allocation data, and other statistics; interviews with key actors; and extensive field trips in the area to gain an understanding of scale and context.

The Case Study: Water Scarcity and the Lower Bhavani Project

The Lower Bhavani Project (LBP) is located in the Southern Indian state of Tamil Nadu. Most parts of Tamil Nadu lie in the rain shadow area of the Western Ghats and, unlike other parts of India, do not benefit from the relatively reliable Southwest monsoon from June to September. Instead, the state has to rely mainly on the unpredictable and erratic Northeastern monsoon from October to December, which is characterised by cyclones and short and heavy downpours. The high variability in annual and seasonal rainfall and the hot climate pose a challenge to agriculture.

Food shortage has, thus, often been a problem in Tamil Nadu. For example, in the eighteenth century, major famines occurred in 1709-1711, 1728, 1731-1734, 1737, 1782 and 1792. '*Mari*' means rain, and the importance of rainfall and water being the limiting factor for a sustained livelihood is illustrated by the worshipping of the Goddess "*Mariamma*" in almost every village (Mohanakrishnan 2001: 1). Construction of tanks to capture local runoff, bullock bailing from wells, and temporary or permanent weirs to divert water from the rivers have long been a tradition to overcome highly variable climatic conditions and also to enable irrigation (Rathnavel and Gomathinayagam 2006).

The Cauvery Basin (81,000 square kilometers (km^2)) is the largest basin in Southern India and the most important source of water in Tamil Nadu. In the second century A.D., the Grand Weir (Grand Anicut) was constructed across the Cauvery River to distribute the river flow across the delta area, which is still the largest command area in the basin (Figure 2). The Bhavani Basin is the fourth largest sub-basin of the Cauvery and covers an area of 6,200 km^2. Weirs, some tanks and a large number of open wells were constructed during historic times as methods of adapting to natural water limits. The Kalingarayan Weir, just before the confluence with the Cauvery River, was built in the thirteenth century, and the Kodiveri Weir, further upstream, was constructed in the seventeenth century (Figure 2) (PWD n.d. (a)). The Kalingarayan (named after a local ruler) and Kodiveri weirs were the first major local attempts to adapt to water scarcity in the basin. The construction of the Kodiveri Weir, upstream of Kalingarayan, also created the first direct link between two irrigated systems in the basin and was the first step towards today's complex situation where the basin river flows are controlled by people.

The Coimbatore and Erode districts (Figure 2), covering part of the Bhavani Basin and the entire LBP command area, are described as areas "of exceptional dryness" with "not less than two-thirds of the seasons" as "unfavorable" (Madras Presidency 1902). The years 1804-1805, 1806, 1808, 1812, 1813, 1823, 1831, 1832, 1834, 1836, 1861, 1866, 1876-1878, 1891-1892, 1892-1893, 1894-1895, 1904-1905 and 1905-1906 were all years with serious water scarcity and many of these years are described with words such as "scarcity, desolation and disease" or "famine, sickness and death". In 1808, the failure of both monsoons caused a famine "that carried off half the population", while the "The Great Famine" between 1876 and 1878 is described as being "more disastrous in effect than any of its predecessors" (Madras Presidency 1902; Baliga 1966: 17).

The situation in the Coimbatore District called for improvements and an extension of existing irrigation structures, or the construction of new schemes. As early as 1834, the British engineer Sir Arthur Cotton thought of building a reservoir in the Bhavani Basin. Several proposals followed. By the end of the nineteenth century, the main goal, however, was to create a reservoir across the Bhavani or Cauvery River to protect the faraway Cauvery Delta. The upstream dam would even out the monsoon variability and moderate the re-occurring floods that caused damage to people and property in the delta, and ensure a steady flow during drought conditions (GoM 1965: 8; Barber 1940: 3).

In 1901, a potential scheme across the Bhavani River was compared with a proposal for a reservoir across the Cauvery River at Mettur, upstream of the confluence of the Bhavani and Cauvery rivers. The final decision favored a reservoir across the Cauvery, and triggered a renewal of earlier 'Madras-Mysore disputes' between the Madras (Tamil Nadu) and the Mysore (Karnataka) governments over the flow of the Cauvery River. As a result, the project was delayed 15 years and was eventually sanctioned after the interstate agreement in 1924. The largest reservoir in Tamil Nadu, the Mettur Dam, is 2,650 million cubic meters (Mm^3), was completed in 1934 (Barber 1940: 14), and it introduced a water storage to balance the river flow reaching the Grand Weir (Figure 2).

It was only after the sanctioning of the Mettur Dam that plans for a reservoir in the Bhavani Basin were considered again. In 1928, the government concluded that a reservoir should be located at the confluence of Moyar and Bhavani rivers. This "The Lower Bhavani Project" (LBP) would be more remunerative than the competing alternative with two reservoirs further upstream, "The Upper Bhavani Project". Design and development for a command area in the Coimbatore District continued until 1938. The LBP, like many other irrigation projects investigated by the British, was, however, not sanctioned since the investment did not meet the British requirements for economic return (Baliga 1966: 259; GoM 1965: 4; Mohanakrishnan 2001: 58).

After Burma was separated from India in 1937 and Japan entered World War II, the annual grain import of 1.5-2 million tonnes (total Indian production was 46 million tonnes) from Burma to India was stopped, and imports from alternative sources like the USA, Canada and Australia were impossible. With the Bengal Famine in 1943, food problems became acute on a national scale.

Several factors added to the difficulty in matching food supply with food demand: Food consumption per capita was already below the minimum standards of nutrition; the Indian population increased 100 million (or 37%) to 370 million from 1931 to 1951 (GoI 2005); and agricultural production stayed static. In addition, the partitioning of India into Pakistan and the Indian Union reduced grain supplies further by 0.7-0.8 million tonnes per year, as a proportionately larger part of the cereal production and irrigated lands went to Pakistan (GoI 1952).

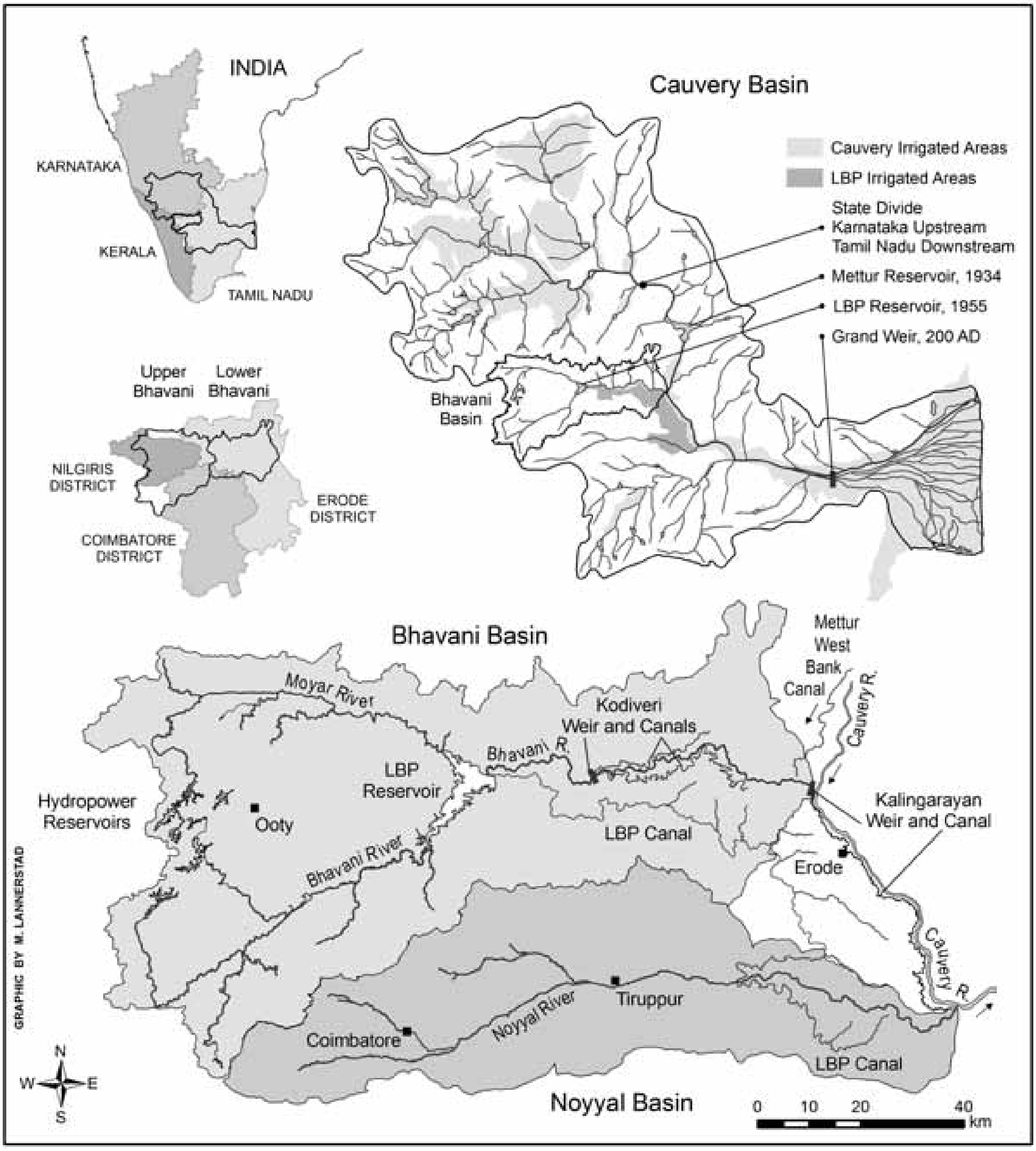


FIGURE 2. LBP, Bhavani Basin and Cauvery Basin in a hydrological, irrigation and administrative context (*Source:* areas of the Cauvery Basin were modified from GoI (2007), not to scale).

In April 1942, after the separation from Burma, a "Conference of Representatives of the Provinces and the Indian States" met to discuss increasing food production. The recommendations formed the basis for the "Grow More Food" Campaign that strongly influenced agriculture in the coming decades. The measures to increase food production focused on: (a) switching from cash crops like cotton to grain, (b) intensifying cultivation with irrigation, better seeds and farming practices, and (c) cultivating all fallow and other cultivable land. The "Minor Irrigation Programme" focused on work that could be implemented quickly and did not demand large funds. The programme aimed at both private work, such as the building of wells, tanks and water lifting appliances, and public measures, such as channels, embankments, tube wells and public tanks (GoI 1952).

"Medium" and "Major" irrigation projects demanded more planning and funds. The LBP, with the LBP Reservoir and the LBP Canal, was, however, already set for implementation and could thus be the first "Major" project initiated in India after independence in August 1947. The "motto for the government was to eradicate poverty in the country and bring prosperity to the people". The criterion for minimum economic return was disregarded and the project was approved by the National Government as a "Post-War Development Scheme". The project was formally sanctioned by the Cabinet of the Madras State on September 19, 1947 (GoM 1966: 14). The work commenced, according to modified British plans, in 1948. Water was released into the LBP canal for the head region in 1952/53 and the full command area was in operation by September 1956 (ibid p.16).

Local, regional and national food concerns, thus, finally granted the famine-prone Bhavani Basin area with the LBP in 1956. Total reservoir storage is 929 Mm^3 (PWD n.d. (a)). Together with the hydropower reservoirs from the 1960s and a smaller drinking water reservoir from 1984 in the elevated upper part of the Bhavani Basin, the total large-scale storage, today, reaches almost 1,500 Mm^3 (Figure 2). This quantity equals the average yearly inflow to the LBP Reservoir during the last few decades. The reservoir was the first major local adaptation to the climate preconditions in the area, and also a major step towards a basin where all river flows, except for extreme floods or droughts, could be largely controlled by people.

LBP Command Level Adaptations

In the half century since the LBP was completed, dramatic societal development has taken place in India and Tamil Nadu. The Indian population has increased almost threefold since 1950 to more than 1,100 million in 2007. In Coimbatore and Erode districts (Figure 2), the combined population increased even more dramatically from 1.8 million in 1901 to 3.2 million in 1951, and to 6.9 million in 2001 (Economist 2007; GoI 2005).

As late as the mid-1960s, India continued to witness serious drought and near-famine conditions with food shortages only partly made up by food aid imports, mainly from the United States under Public Law 480 (P.L. 480). In response came a major shift in the Indian food policy, with public investments in agriculture, both domestic and international, eventually resulting in the take off of the Green Revolution at the end of the 1960s. In 1976, food production self-sufficiency targets were met for the first time (del Ninno et al. 2005). Despite the dramatic population growth, food shortage on a national level is not a problem anymore. Due to the lack of purchasing power, however, more than 200 million people are still undernourished (FAO 2006).

India as a nation has moved from an agricultural economy with famines towards a society where, in 2006, agriculture only stood for 19% of GDP, while services (54%) and industry (27%), dominate. The export of agricultural goods reaches US$10 billion, representing about 10% of all exports (Economist 2007). In Tamil Nadu, agriculture only represents 11% of the 2004/2005 Net State Domestic Product, but 47% of the 28 million large workforce are either 'cultivators' or 'agricultural laborers'. Agriculture is, thus, still of great importance for the livelihoods of many people, but more and more of marginal importance to the state economy (Department of Economics and Statistics 2006). So, while agriculture plays a diminishing role in the economy, the large number of farmers still constitutes an important political power in the Indian democracy.

The post-LBP completion period has been, in other words, a time of dramatic agrarian change in India. During that period, a number of alterations in water allocations and water use have taken place within the LBP command area, both at system and farm levels. The changes in the LBP system are, to a large extent, linked to, and must be understood within, the general Indian agricultural and social development context. As will be explained later on in the report, the changes since the inauguration of the LBP can be viewed as adaptations to climatic conditions, demands of farmers, acute national food demands, and a shift from the cultivation of coarse grains towards meeting the rising demands for paddy, and following the general rapid societal development.

Estimates of British Time Engineers for the LBP

The first quantification of the average amount of water resources available in the Bhavani Basin that could be allocated for a new command area was done during the first decades of the twentieth century. In the 1940s, a few years before the end of British rule, the average amount of water resources available for the LBP command area was estimated at 650 Mm^3 annually. This figure takes into account riparian water rights to downstream historic Kalingarayan and Kodiveri canals and the potential need to supplement Mettur Dam releases for the Cauvery Delta. The water quantity was estimated to be sufficient for a command area of 69,000 hectares with irrigated ‘dry crops’, such as cotton, millets and groundnut. This was an amount and a cropping pattern designed not to optimize food production but rather to optimize the economic return and produce cotton for the local industry or for export. The water demand design of 650 Mm^3 per year was based on a river flow analysis carried out during 27 years from 1916 to 1942. The water quantities estimated to be available for the LBP was decided in the perspective of a high inter-annual variability of precipitation in the catchment area of the LBP Reservoir. The recorded river flow data showed that the entire project area could only be fully irrigated during 16 years, part of the area in 7 years, and none in 4 years (Gopalaswami 1959: 9; GoI 1964: 4; GoM 1965: 28). The initial design of the LBP, which both had a smaller command area and a more modest water demand compared to later proposals, thus builds upon known facts that full use of the LBP could only take place during 60% of the years, and partial or no use would be the outcome during the remaining years.

1946 Plan – Design of the Engineers – All Dry

Despite the estimates on river flow indicating insufficient water availability during 40% of the years, the final plan included an increase in the command area of about 22% to 84,000 ha, and a 40% extension of the canal length. Originally, the entire command area was supposed to be located only north of the Noyyal River (Figure 2), but after pressure from a local “influential gentleman” by the name of Hejaman, and with a motivation to let the LBP also benefit the famine-prone Dharapuram sub-district, the canal was extended 55 kilometers (km) further south of Noyyal River to a total length of 200 km (GoM 1966: 14; Blomqvist 1996: 100). The additional command area in the Dharapuram sub-district covers 10,000 ha. To maintain the LBP at 84,000 ha and avoid a total increase in the command area to 94,000 hectares, the increase in the command area was balanced by an evenly spread 12.5% reduction (known as “the Dharapuram cut”) of the already planned command area. The extension canal, sanctioned financially by the government as a famine relief measure to create jobs in the region (GoM 1966: 14-15), further increased seepage and evaporation losses, which were not included in the original estimates (GoI 1964). The main idea at the time was to share the water supply, even though limited, to as many people as possible.

The LBP was aimed for irrigated ‘dry crops’, with cotton planned to cover half the area, and other irrigated dry crops, like millets and groundnuts, to cover the other half. Only seepage-prone areas of about 4,000 ha would come under paddy (Figure 3 and 4, 1946 Plan). Water was to be supplied from September to March, with a cut in supply for one and a half months during the Northeast monsoon, from middle October to the end of November, to save water and utilize local rainfall. Since the supply to the dry crops should be intermittent, water was to be released and provided according to a ‘set turn’ system. All sluices along the main canal, the major distributaries and branches were to be opened and closed in alternate miles. Two equal zones were created by naming all sluices from mile 1 to 2, 3 to 4, 5 to 6, etc., as ‘odd mile reaches’ and all sluices from 2 to 3, 4 to 5, 6 to 7, etc., as ‘even mile reaches’. The two zones in the LBP command area are thus geographically mixed, and a farmer in the ‘odd mile reach’ often has his field next to a farmer within an ‘even mile reach’. With this system, sluices were to be open during alternate five and a quarter days and water was to be provided for a particular field with an interval of ten and a half days (GoM 1966: 173).

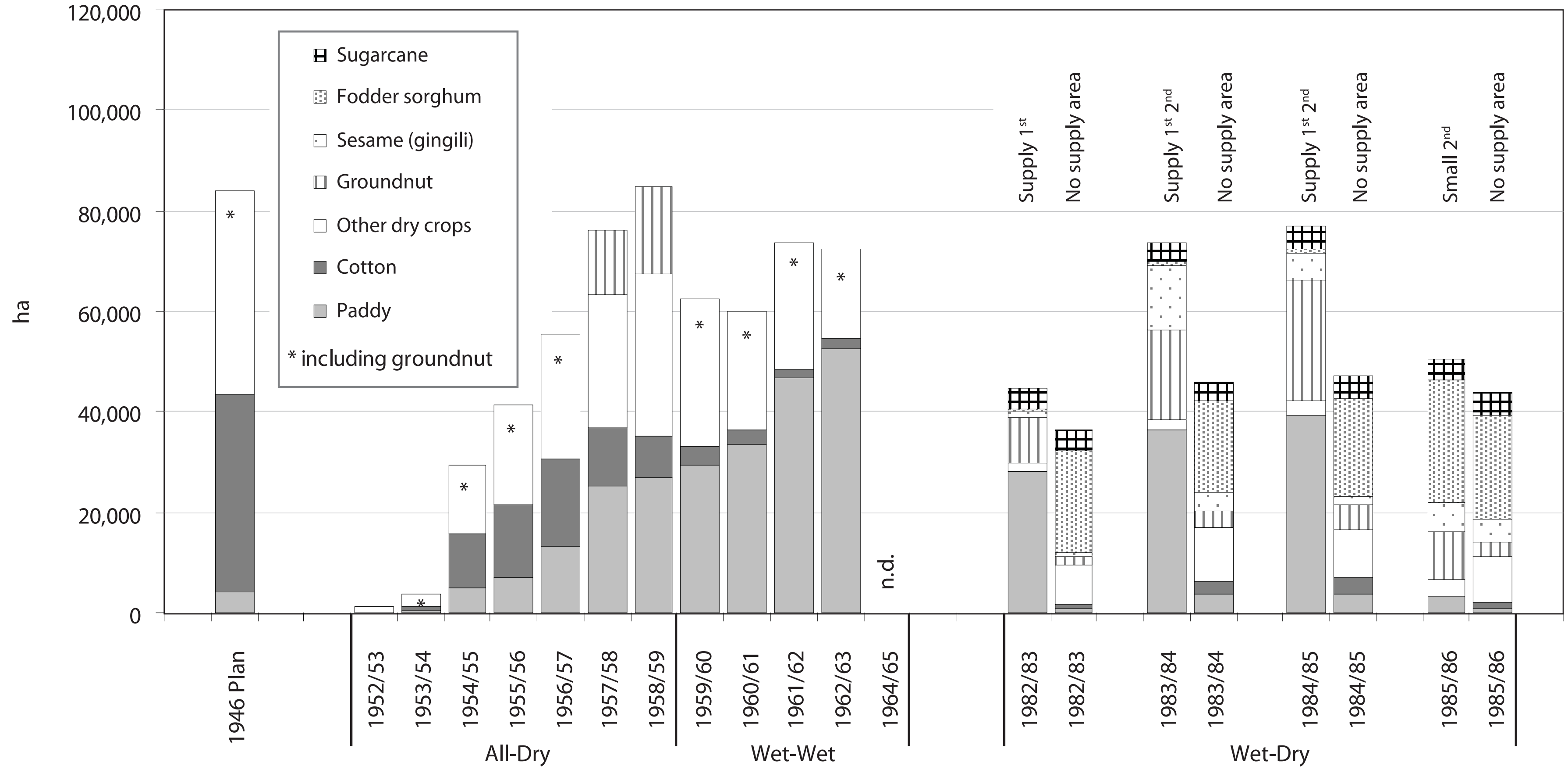
The expansion of the command area and extension of canal length show how the planners adjusted to the general demand for more cropping land and pressure from strong local demands. It shows how the design was changed in contradiction to available hydrological knowledge for political reasons. The question is whether these well-intentioned plans could be implemented, and how the outcome from the changed plans turned out.

1959 System – Choice of the Farmers – Wet/Wet

After the opening of the LBP canal, the paddy area increased beyond the stipulated 4,000 ha (Figure 3). Crop restrictions were imposed by local authorities, but the farmers opposed the restrictions and paddy cultivation escalated further. The farmers complained to the State Government, who made it clear that “they were very anxious that the farmers should have no cause for complaint” (Gopalaswami 1959: 15). Accordingly, engineers from the Public Works Department (PWD) in charge of the Lower Bhavani Reservoir had no option but to keep the canal flowing as long as there was water available in the dam (Gopalaswami 1959; Planning Commission 1965).

The farmers preferred paddy as they regarded this crop as being more profitable, and they also claimed it was not possible to cultivate cotton as planned, because there was too much soil moisture from seepage. The farmers also argued that cotton demanded too much manure and preferred to grow groundnut on the more elevated areas (Planning Commission 1965). During the five and a quarter days of sluice opening, the farmers under each sluice tried to acquire as much water as possible to make up for the next five and a quarter days of sluice closure. This behavior, of farmers primarily at the head-end, and weaknesses in canal management started a negative trend in the use of water (Sivanappan n.d.). As a result, more water had to be released (Figure 5, 1956/1957, 1957/1958 and 1958/1959) and the initial seepage problems increased, thereby stopping the cultivation of dry crops and increasing further the suitability to grow paddy.

In 1959, the Commissioner of Land Revenue and Food Production, a Mr Gopalaswami, consulted different experts, authorities and farmers in the LBP area regarding a new allocation system for the LBP. At an open meeting of farmers in the LBP area it was decided to change the system. With the ‘Wet-Wet’ system the cropping year was divided into two seasons, August to November and December to March. Half the command area would get continuous supply during the first season and the other half during the second season.



FIIGURE 3. Cropping patterns in the LBP command area. Plan from 1946, and trend in irrigated areas for 1952/53 to 1962/63, and for 1982/83 to 1985/86 cropping patterns for both half the command area with canal supply and the other half relying entirely on rainfall and wells (no supply area) (*Data sources:* Gopalaswami 1959; GoI 1964; Sivanappan and Associates 1989).

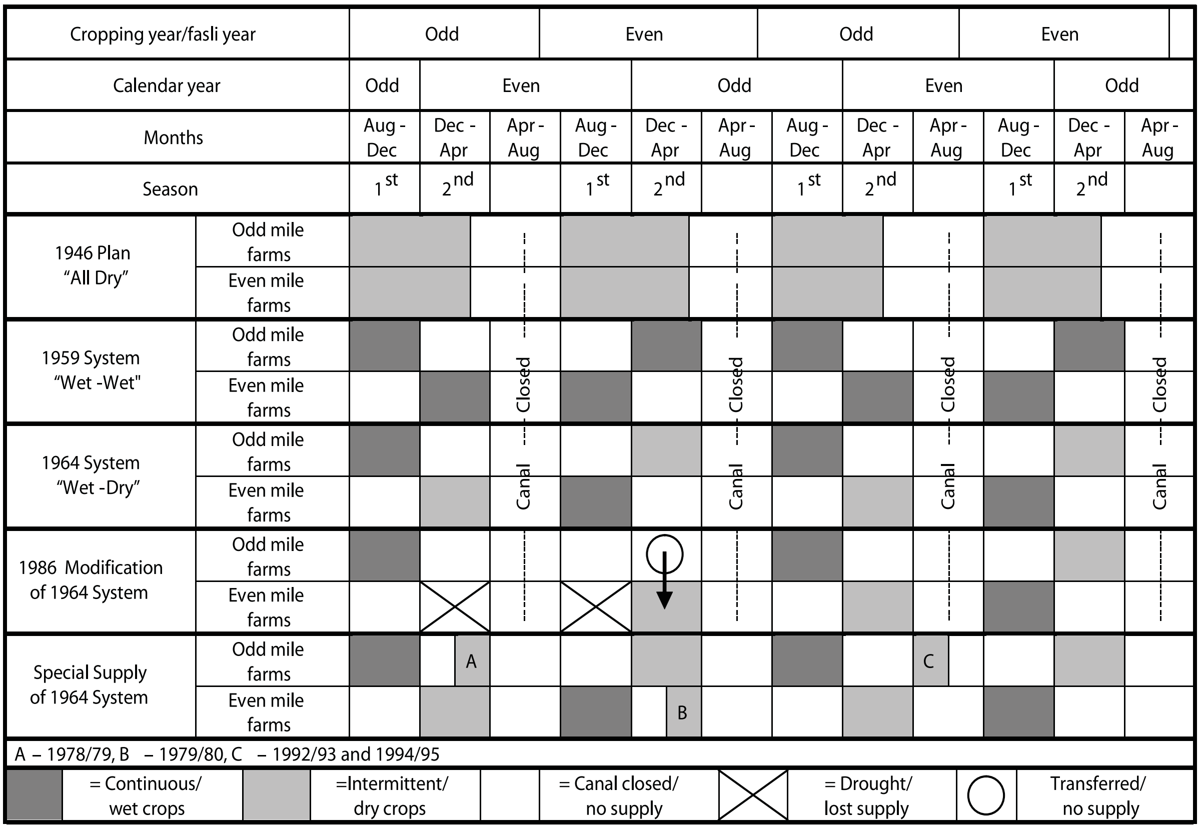


FIGURE 4. Changes in the LBP canal water allocation system.

Fields belonging to "odd mile reaches" would get supply in both the second and first season during an odd calendar year, and land under "even mile reaches" would get the same supply during even years (Figure 4). The odd and even reach methods that were originally designed to be used for the ten and a half day supply interval in the "All Dry" system was reassigned to be used on a seasonal basis. All cropping restrictions were removed allowing two wet crops (Gopalaswami 1959; GoI 1964: 8).

The LBP canal is designed mainly for dry crops with intermittent supply and can only discharge 6 Mm^3 of water per day. To irrigate wet crops over the entire LBP command area about double the discharged capacity, i.e., 12 Mm^3 per day, would be necessary. It is thus not possible to irrigate the entire command area with wet crops during one season. By using the 'odd' and 'even' allocation system to create two seasonal zones the entire canal discharge could be used on half the area and doubling the water allowance per hectare will enable paddy cultivation. If the discharge capacity of the canal had been higher paddy cultivation over the entire command area during the first season would otherwise have been a better alternative, utilizing the northeast monsoon and avoiding the hot weather during the second season. The state government introduced the 'Wet-Wet' system in 1959 as an experimental measure to be extended from year to year (GoI 1964: 8).

During the 'Wet-Wet' system an average of 1,300 Mm^3 of water was released per year, which is more than double the planned 650 Mm^3 (Figure 5). In reality, water was released continuously for 120-140 days every season, from July or August until the end of April (PWD records). Paddy cultivation increased, and during 1962/63 it covered more than 50,000 ha, which is 73% of the irrigated area (Figure 3). A period with extremely high precipitation in the Upper Bhavani catchment with peak inflows into the LBP Reservoir made it possible to extend the Wet-Wet system over four years. During the cropping year 1963/64 the inflow

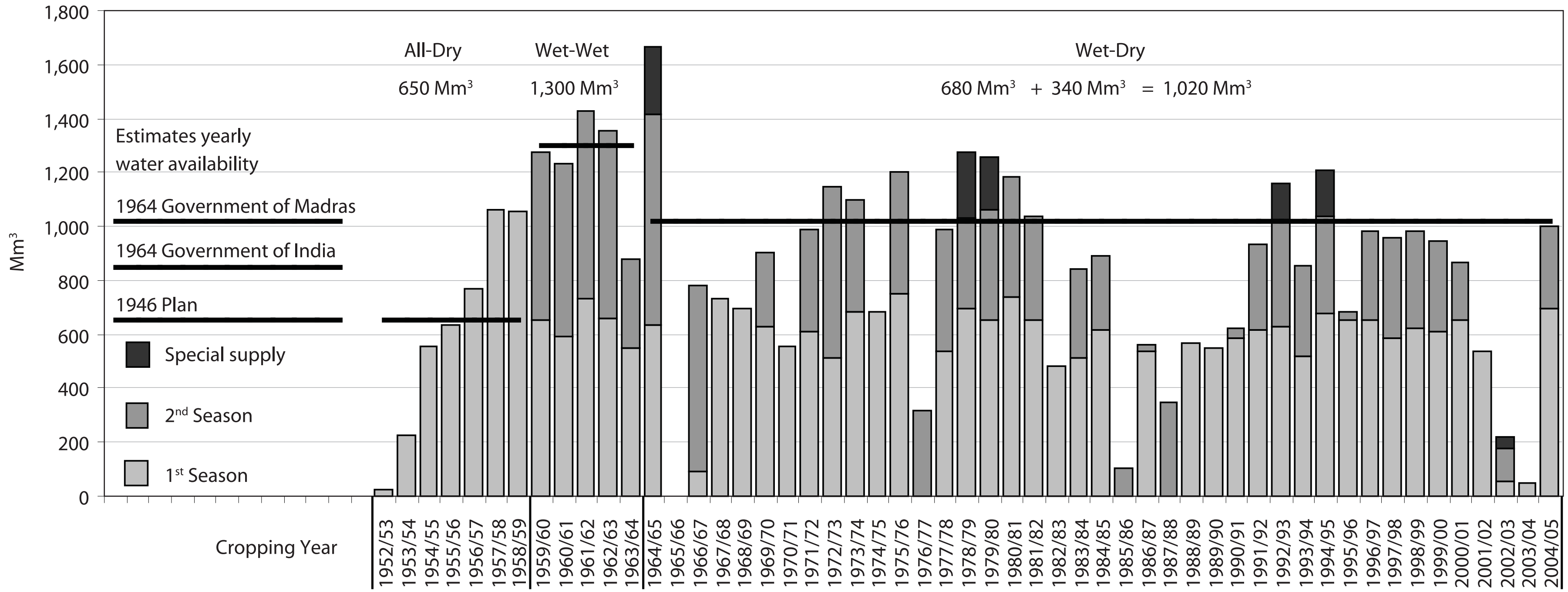


FIGURE 5. Releases into the LBP Canal 1952/53 to 2004/05 (*Data sources:* PWD records, Sivanappan and Associates 1989; GoM 1965; GoI 1964).

to the LBP Reservoir only allowed 550 Mm^3 to be released into LBP Canal during the first season. During the second season only 320 Mm^3 could be released and the entire command area belonging to the last half of the canal were denied irrigation water (GoI 1964: 9).

The escalation of paddy cultivation shows how the farmers refused to adopt the prescribed canal irrigated dry crop pattern stipulated in the 1946 Plan. This method of canal irrigation was an entirely new practice to the entire State of Tamil Nadu (GoM 1965: 171). Farmers in the Coimbatore area are known to be hard working and quick in adapting new techniques. Unfortunately, there were no research and demonstration farms in the command area where the farmers could have learnt the practices and advantages of canal-irrigated dry crop cultivation. It was also difficult for the farmers to vision the proposed large-scale canal-irrigated dry crop cultivation (GoI 1964: 17). Before completion of the entire LBP canal system, farmers at the head-end of the canal took advantage of the available surplus water quantities to intensify cultivation. This development led to a ‘cropping anarchy’ with more and more land under paddy. The authorities underestimated the strength of local tradition. The only example of local canal irrigation to learn from was the cropping pattern of the historic Kodiveri and Kalingarayan canals where riparian rights assure a continuous canal supply with two to three paddy crops every year (GoI 1964: 15). The growing paddy cultivation shows the negotiation strength and political power of the farmers, being capable of convincing the irrigation engineers to deliver a continuous supply instead of intermittent supply, and to get support from the state government for a changed system.

With the Wet-Wet system the existing division of zones with sluices belonging to ‘odd’ and ‘even’ reaches was cleverly used to introduce a seasonal partition of the command area. The Wet-Wet system, agreed upon at the open meeting with the Commissioner of Land Revenue and Food Production, was a decision against known hydrological facts. Of course, single farmers do not have a perspective of the system, but instead they focus on their own situation. From a “system water use perspective” it was, however, clear that ‘dry crops’ would have been more profitable, e.g., cotton would generate six times more profit per water quantity supplied to the fields (GoI 1964: 15; Gopalaswami 1959). The Wet-Wet system demanded twice the estimated average yearly water availability. The state government, nevertheless, agreed to adapt to the demands of farmers and try the Wet-Wet system. The decision by the government to lift the crop restrictions and jeopardize the long-term sustainability of the entire LBP system must be viewed in the context of the general famine affecting the entire nation. The ‘Grow More Food’ Campaign favored the cultivation of rice and not cotton. India, as late as at the end of the 1960s, was dependent on the import of cereals and struggled to reach food self-sufficiency.

The exceptional water releases were possible only because of very high inflows into the LBP Reservoir during 1959/60-1962/63. The Wet-Wet system had an ‘over optimistic’ design and it could not continue during normal years.

1964 System – Compromise and Adjustment to Seasonality – Wet/Dry

In 1963, the Madras Government intended to restrict the cultivation of paddy “in order to conserve and economically distribute the available supply of water in the project (LBP) to the best public advantage”. The government ordered a zoning of the command area with “wet”, “garden” (land with wells) and “dry” zones, and put a ceiling on paddy cultivation of 24,000 ha (an increase compared to the earlier planned 4,000 ha). Based on pilot studies and experience of the field staff, it was concluded that a reasonable limit for paddy cultivation could “hardly be successfully carried out”. The main reasons were seepage problems and resistance from the farmers opposing “interference with their own judgement of the crop to be raised” (PWD 1984: 152).

In 1964, the Madras Government ordered that a revised proposal for a new system should be implemented, the “Wet-Dry” system. Even though it was decided in 1964, because of “too much” and “too little” inflow into the LBP Reservoir in the years that followed, 1969/70 was the first year that releases were made for one wet and one dry season (Figure 5). In the "Rules for Water Regulation" it is stated that the total water quantity for both seasons should be 1,020 Mm^3. During the first season, August 15 to December 15, 680 Mm^3 of water was to be released as a continuous canal supply and without any crop restrictions. During the second season, December 15 to March 15, half the quantity, 340 Mm^3, was to be released intermittently and only irrigated dry crops were allowed. Any wet crops were to be completely prohibited and heavily penalized. If there was any "extra" water available in the reservoir, the Chief Engineer at the PWD, after special order from the government, was entitled to release "a special supply" to farmers who did not get water during the second season that year (GoM 1964: 22; PWD 1984: 152-153). As shown in figure 4 this "special supply" in 1978/79 and 1979/80 was released during the second season parallel to the normal intermittent supply, and in 1992/93 and 1994/95 the "special supply" was provided during May and June for a "third crop period" (PWD records).

The current "Wet-Dry" system is an adaptation to the demands of farmers to grow paddy and opposed the government plans to limit paddy cultivation. Compared to the Wet-Wet system, it is a much better adaptation to the seasonal climatic variations. During the northeast monsoon the heavy rainfall makes it more suitable to grow wet crops, while the sparse rainfall and hot climate during the second season makes it favorable for dry crops, with a minimum of seepage problems. The design of the current system demands less water than the "Wet-Wet" system, but still more than the average availability, and also makes it difficult during most years to leave a carry-over capacity from good to bad years in the LBP Reservoir, as intended in the original design of the 1946 plan (GoM 1965: 31). The possibility for the Chief Engineer to utilize excess water and release a "special supply" is an embedded adaptation to the rules to have the possibility to utilize the extra water available during years with higher inflow than normal (compare figures 5 and 7), but without including the quantity in the regular allocation expectations.

1986 Modification – Equity between Farmers and Adjustment to Annual Variation

Originally, the sustainable reservoir yield to be allocated during majority of years was estimated at 650 Mm^3 per year (23,000 million cubic feet (Mcft)) (GoM 1965: 31). An analysis of the viability of the entire project in 1964, based on data from 29 years (1934/35-1962/63), stated that "the project anticipation may, at best, be based upon not more than 850 Mm^3 (30,000 Mcft) utilizable storage" (GoI 1964: 12, 21). In the Madras Government order from 1964 introducing the still existing "Wet-Dry" allocation system, it is declared that "the total commitments which the project can sustain is 1,020 Mm^3 (36,000 Mcft) of water" (PWD 1984: 152). During the last 44 years with the Wet-Dry system in force, the supply for the LBP canal only reached the anticipated 1,020 Mm^3 during 10 years (Figure 5). For 22 years there was a supply equal to, at least, 850 Mm^3 (the estimate from 1964). This quantity is enough to give a sub-optimal supply for both the first and second seasons. The often used 75% dependability only equals to 550 Mm^3 per year.

As shown in Figure 5, there have been both seasons and entire years without any water released to the LBP command area. According to the 1964 system, water is delivered to a fixed schedule (Figure 4). If water supply is missed in a particular season, it will be permanently lost and the farmers scheduled to get water during one season will not be compensated the next season (Palanisami 1984: 26). This was the case during the 1980s. By some twist of fate, almost all the seasons without available water quantities in the LBP Reservoir coincided with the turns for farmers in the "even mile reach" area (compare Figure 4). In the six years from 1982/83 to 1988/89, the farmers in the "even mile reach" area should have received canal supply during three dry and three wet seasons, but only got canal supply for one dry season and one wet season.

Therefore, the Chief Engineer at the PWD suggested to the government (with the sanction of farmers in the LBP area) to make an exception to the rules and give the available water during January to April 1988, which was to be allocated for farmers in the "odd mile reach" area, to farmers in the "even mile reach" area (GoTN 1987). During the drought of 2002-2004 this new praxis to make the water supply more equitable was tested again. After two seasons of water loss for farmers in the "odd mile reach" area, the Lower Bhavani Farmers' Federation held a public meeting on October 26, 2002 and the majority decided that the water supply in the coming dry crop season which was meant for farmers in the "even mile reach" area should be released for farmers in the "odd mile reach" area. Some farmers objected and the decision was brought to the High Court of Judicature at Madras that ruled in favor of the Federation (District Collector 2003).

The current 1964 allocation system has an 'inbuilt' water scarcity relative to the designed command area, and years without full adequate supply are, therefore, unavoidable. Thanks to the strong and vibrant Lower Bhavani Farmers Association, the farmers have, thus, found a solution to cope with the inequity that might take place. The shift in allocation order from farmers in "odd" to "even" mile reach sluice areas in 1988, and the shift from "even" to "odd" in 2003 show how the farmers, with the support from the authorities, have adapted to the annual supply variability on a system level, and tried to share the water in a fair way.

Adaptation of Engineers to the Cropping Season Preferences of Farmers

The District Collector decides the opening and closure of the canal in consultation with the PWD authorities and the people's representations (Shanmugham 1991: 13). The "Rules of Regulation" state that the first season should last from August 15 until December 15 (120 days) and the second season from December 15 until March 15 (90 days) (PWD 1984: 152). The real outcome from the 36 Wet seasons and the 23 Dry seasons since 1964/65 with canal supply shows a different pattern. About 75% of the second seasons end during the last two weeks of April or the first two weeks of May, and there is no record of a closure in March at all. Today, farmers and others normally refer to April 15 as the end date for the second season, even though regulations still state that it is March 15. On average, the first season is extended to 133 days and the second season to 114 days.

This shows how the PWD engineers and the District Collector have adapted to the practiced canal management and succumbed to the desires of farmers in the LBP area and extended both the Wet and Dry seasons.

Farm Level Adaptations to Unpredictable Canal Supply in the LBP Area

During the initial years after the opening of the canal in the 1950s, the farmers in the LBP area demanded enough water to be able to grow paddy. After experimentation with the Wet-Wet system the final outcome turned out to be the current Wet-Dry system from 1964. With the present system there are both scheduled seasons without canal supply for every farmer, every second year, and unplanned seasons without supply, during years with inflow to the LBP Reservoir below the level of demand.

As expected, many farmers often, but unpredictably, experience an untimely and inadequate water supply. The middle and tail end distributaries of the main LBP Canal are, to a larger extent, progressively deprived of their allocations (Shanmugham 1991). It is also clear that farmers with large landholdings (or other power) within each distributary are able to influence, and ensure, their own water supply. In contrast, the marginal farmers are more affected by untimely and insufficient water allocations (e.g., according to a survey, 43% during initial growth stages) (Centre for Water Resources 2003).

Farmers have adapted to problems of water scarcity in various ways. One way is to find additional water resources, mainly from groundwater sources. Another option is to adjust the cropping pattern to suit the water availability.

Additional Water Resources

The wells that already existed in the command area before the construction of the LBP Canal were quickly recharged by the ample seepage water, and many farmers saw the benefits of increasing the supplemental irrigation from groundwater (Palanisami 1984: 36). In the 1950s, farmers in the LBP area expressed a desire for full freedom to "sink wells", and demanded increased access to electricity (Gopalaswami 1959). The authorities, on the other hand, tried to restrict the number of wells in the command area and limit their use only during the off-season and for dry crops. Apart from some remaining restrictions, the ban against new wells within the command area was lifted in 1965. In 1956, besides wells with bullocks, there were about 400 diesel pumps and 200 electrical pumps (Saravanan 2001). In 1989, there were about 30,000 wells in the 162 revenue villages in the LBP command area, 50% with electricity, 30% with diesel and 20% with bullocks (Shanmugham 1991: 17). Following the trend of the number of wells in the Erode District (Lannerstad 2008), the number of wells in the LBP command area has increased to about 35,000 and all bullocks have been replaced by electricity pumps.

Wells are recharged both during the monsoon and when there is canal water released in the command area. During the monsoon season, the water table ranges from 1 to 9 meters (m) and during the dry months it drops to 7 to 24 m below ground level (Shanmugham 1991: 17). More than 30 years of observation well data inside the LBP area show a rather stable recharge over the years (PWD data).

During the 1960s the irrigation authorities set up 34 schemes, "Harnessing Schemes", to capture seepage and drainage from the LBP command area, and this increased the command area by 7,000 ha (PWD n.d. (b)). Today, less than half are working due to reduced drainage water reaching these "tail end" schemes (pers. comm. PWD 2004-2007). This illustrates the effectiveness of water use in the field and groundwater utilization in the LBP command area. According to the 1946 Plan, one-fourth of the water let into the LBP canal was regarded as being "lost" to evaporation and seepage. However, "experience shows that the greater part of the water which was expected to be lost is not really lost" (Gopalaswami 1959: 6), and the water reappears as seepage in low-lying fields or raises the groundwater level and is available in the wells. So, thanks to the wells of the farmers, part of the water released into the command area can be applied to the fields more than once.

Well water is not always sufficient and some farmers have individually turned towards water resources outside the command area. They abstract water directly from the Bhavani River, the southern Kodiveri Canal or the Kalingarayan Canal which all delineate the LBP command area. Both the canals and the river have a continuous supply during almost the entire year. Most of these arrangements are unauthorized. Thanks to improvement of pump and pipe technology, water can be transferred long distances. Single farmers can finance smaller arrangements, while groups together share the costs of larger endeavors. One scheme is pumping water from the Kalingarayan Canal more than 7 km into the LBP command area (PWD pers. comm. 2004-2007).

The current LBP canal supply system has an inbuilt water scarcity, and the porous soils cause large amounts of seepage. The farmers in the LBP area understood the potential of supplemental irrigation. The authorities initially tried to stop this development, but later had to accept this quite successful adaptation. Today, most of the wells also have electricity connections. The groundwater data also indicates that the practice is sustainable. The more recent trend to pump water from other irrigation canals and the Bhavani River is, compared to the wells, an adaptation that the authorities cannot formally agree to. The continuation of these unauthorized arrangements, however, point to some kind of passive acceptance, or political inability to terminate this behavior.

The strong and vibrant farmer's organization in the command area, the Lower Bhavani Farmers' Federation, also try to convince the government to change the "Rules for Water Regulation" (PWD 1984) to reduce the quantity of water released for the Kodiveri and Kalingarayan canals and give a larger proportion of the yearly inflow to the LBP Reservoir to the LBP Canal. The Federation, thus, questions the historic water rights in the basin, but has so far not gained support for their claims.

Flexibility in Cropping Pattern

The changes in cropping pattern following alternating canal supply during four years, 1982/83 to 1985/86, are illustrated in Figure 3 (compare figure 5 and 6). The left column visualizes the crops on half of the command area that is supposed to receive canal supply during both the first and the second seasons. The right column, “No Supply Area” shows the crops on the half that has to rely entirely upon precipitation and, for those who have wells, groundwater. Supply was given for both seasons in 1983/84 and 1984/85. During such normal years about 40,000 ha of paddy and 20,000 ha of groundnut dominate the cropping pattern. In 1982/83 supply was only given during the first season and the irrigated dry crops normally belonging to the second season are missing. In 1985/86 water was given as three “wettings” to raise irrigated dry crops like sesame during one season. The limited water given during this year makes it look very similar to the cropping pattern of the normal “No Supply Area”, with a large area with rainfed fodder sorghum, and other well-irrigated or rainfed dry crops.

The cropping patterns in figures 3 and 6 clearly show how the farmers cope with the variable canal supply by growing well-irrigated or rainfed crops. A long-term adaptation has been accomplished by the farmers that have a well, or those who get water from a source outside the command area. Nevertheless, not all farmers have wells and the uncertainty in water supply under the current allocation system leaves many farmers without real cropping opportunities during many seasons. It is, therefore, common that farmers also seek work options on other farms, or outside agriculture. To have one family member working outside agriculture is in a way, on a family income level, an adaptation to bridge the erratic incomes within the LBP farming system. The current trend of industrial development in the area and the commuting possibilities that have dramatically improved recently, have made it feasible for many members of farmer families to find new complementary livelihood options outside the LBP command area.

Season		Farms with and without canal supply	Crop Combinations		
			Farms **without** wells	Farms **with** wells	
First season (Aug-Dec)	Continuous canal flow Heavy rainfall Northeast monsoon	Farms during year with canal supply	Paddy	Paddy	Sugarcane, turmeric, coconut
		Farms during year without canal supply	Rainfed sorghum, pearl millet	Groundnut, pearl millet, sorghum, cotton	
Second Season (Jan-Apr)	Intermittent canal flow Very limited rainfall Summer	Farms during year with canal supply	Groundnut, sesame, vegetables, fodder sorghum	Groundnut, sesame, vegetables	
		Farms during year without canal supply	Fallow	Pulses, sesame, vegetables	
Intermediate Season (May-Aug)	Canal closed Some rain Southwest monsoon	No supply	Fallow	Fallow or pulses, sesame, vegetables	

FIGURE 6. Cropping patterns during normal conditions for farms with and without canal supply, and with and without wells for supplemental irrigation (*Source:* modified from: Shanmugam 1991: 14).

Future challenges

There will be increased competition over water resources in the closed Bhavani Basin. As shown in Figure 7, the inflow to the LBP Reservoir is falling. Upstream of the dam, increased water demands such as irrigation of vegetables, river pumping, changed rainfed vegetation cover with a higher consumptive water use, evaporation from hydropower reservoirs, and drinking water out of basin transfers, have all contributed to a reduced inflow to the LBP Reservoir (Lannerstad 2008). Climate change (Bates et al. 2008) or long-term cycles of climate variation might also contribute to the trend. The different factors causing the reduction of river flow from the Upper Bhavani have not all been studied and quantified so far.

Present drinking water withdrawals are, however, likely to increase from the present 160 Mm^3 to more than 210 Mm^3 per year in the near future. The major part is out-of-basin transfers from Upper Bhavani to the rapidly growing Coimbatore and Tiruppur cities along the ephemeral Noyyal River (Figure 2). At the time of construction of the LBP Reservoir, annual drinking water withdrawals only measured 4 Mm^3. The LBP Canal has the lowest priority in Bhavani Basin because of historic riparian rights (Lannerstad 2008). The drinking water withdrawals are, thus, a direct competing demand. Withdrawals above the reservoir equal 17% of the designated annual demand for the LBP area, or 50% of the water supply during the second season. Together with other factors that increase the consumptive water uses upstream of the reservoir, the drinking water out-of-basin transfers can mean more seasons without canal supply for farmers in the LBP area.

The competition for water is also tightening for the entire Cauvery Basin. The LBP Reservoir is regarded by many as a "Surplus Project" intended to only impound and use water excess of the riparian rights of farmers in the Cauvery Delta and those in the historic command areas in the Bhavani Basin. The large number of farmers in the delta represents a strong political influence. When the competition for water increases in other parts of the closed Cauvery Basin, there is a risk that water will be requested from the LBP Reservoir. This happened during the extreme drought of 2003/04 when water was released for the Cauvery Delta, while no water was given at all to any of the command areas in Bhavani basin (PWD records). In January 2007, the Indian National Court of Arbitration delivered the "The Report of the Cauvery Water Disputes Tribunal with the Decision" to resolve the last Cauvery Dispute between the states of Karnataka and Tamil. The Decision provides a settlement on the amount of water that each of the Cauvery Basin states can utilize (GoI 2007). Some of the present diversions into the historic canals are not included in the estimates because they are not part of earlier interstate agreements (GoI 2007, IV: 141). In the perspective of a closed Cauvery Basin, this means that these water quantities are not accounted for to be used within the Bhavani Basin. The LBP will, thus, have to be considered in both the context of the Bhavani Basin and, again after almost 100 years, in the context of the Cauvery Basin.

As agriculture becomes integrated into the global economy, farmers in the LBP area are facing transformation challenges. Already, many farmers experience rising input costs. Competition with the flourishing nearby urban areas has increased the labor costs. Many workers leave the unreliable and seasonal agricultural jobs and seek employment in the textile and other industries. As a consequence, mechanization is a recent trend in the area. Some farmers also chose less labor-intensive crops, like coconut plantations. Many farmers invest in their children's education as they see no future in agriculture. Changing demands for agricultural products because of changes in food preferences and a demand for industrial crops, with a trend towards contract farming, like sugarcane, will also drive agricultural development in the LBP Command area.

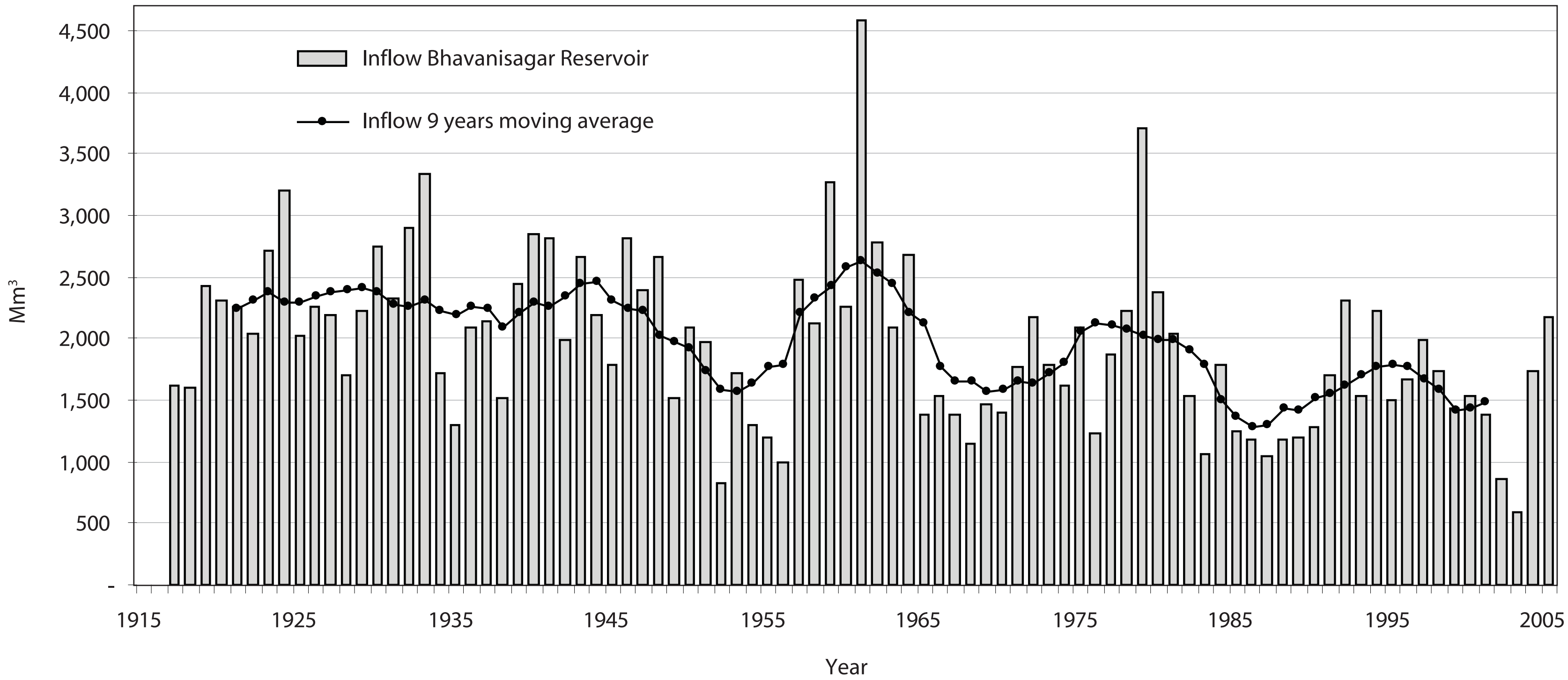


FIGURE 7. Flow at (1917-1956), and inflow to (1957-2005), the LBP Reservoir (*Data Sources:* PWD records; GoM 1965; NWDA 1993)

AWM Analysis and Discussion

The LBP trajectory presents a number of changes and adaptations during the last 50 years. By using the framework presented it is possible to see how well the LBP experience matches the theories of AWM. To reiterate, the five main questions to be considered relate to 1. adapting or coping; 2. uncertainty; 3. the AM process; 4. Social learning; and 5. Adaptive regimes and adaptability.

Adapt to what, and at what scale

Within a cross-disciplinary research collaboration, Dewulf et al. (2007) have analyzed the perception of the AM idea and describe how different persons frame the concept. Central questions for participants in the study were: “Who or what is adapting, changing and learning?”; “What is it that they adapt, change or learn?”, and “In response to what do they adapt, change, or learn?”. This highlights the difficulty of defining the boundaries of an AM system, and where to place the actors participating in the process. There is a difference between discussing aspects inside a system, that are adapting or being adapted, and aspects that are outside the system, that the system adapts to (ibid).

The LBP system is a complex human-environmental-technology system and is, thus, difficult to delineate. The spatial boundaries appear to be easy to define by stating that it only includes the LBP command area. The LBP Reservoir is, however, also a part of the system - at least, the management of how water is released into LBP Canal. In addition, the LBP area is part of Bhavani Basin and, in a larger context, is also part of the Cauvery Basin. The human component, with irrigation engineers and politicians in charge of the policy development and management, is not like the farming community only found within the command area, but is spread over the Erode and Coimbatore districts, in other parts of Tamil Nadu, and, perhaps, even in India as a whole.

The drivers behind the establishment and changes of LBP originate at different scales. Initially, construction of the reservoir was a water storage project for farmers in the delta in the Cauvery Basin. It was only after the decision to build the Mettur Reservoir that the LBP project was considered again. This time, the project should benefit the people in the famine-prone Coimbatore District. The construction was, however, inhibited because the project did not fulfil the economic return of the British Empire. After Independence in 1947, the project was sanctioned with a national Indian interest. Since the completion of the LBP, all the changes in water allocations and cropping pattern have been an internal question within the Bhavani Basin. After the introduction of the “Wet-Dry” system in 1964, it is more or less an internal issue within the LBP command area.

In the analysis of the LBP system, it is necessary to look upon “the system” as generally confined within the limits of the LBP command area, but also allow the definition to, with a certain degree of “plasticity”, occasionally stretch out. Some actors will also have both a role as an external force, and an internal actor within the system.

Adapting or coping

The LBP case study clearly displays a pattern of adaptive strategies. Over the years farmers and authorities together have adapted to each other, to available water resources relative to the size of the command area, and the environmental conditions in the LBP command area. The increased food production from the fields in the LBP area has been of immense importance for the survival and rising standard of living for people in the area. Considering the fact that groundwater levels in the command area remain quite stable, with only insignificant salt accumulation problems, the system appears to be environmentally sustainable from a water perspective. The water allocation design has been adapted to meet the demands of farmers and climatic realities over more than 50 years.

An example of a proactive response is the establishment of wells in the command area for conjunctive use to increase the reliability in timing of water supply to the field, and to balance the seasonal and yearly water scarcity experienced in the system. This development was held back by the authorities in the beginning, but later the idea was accepted and supported by the removal of hampering policies and an expansion of electricity connections in the area.

The 1964 water allocation and cropping system is an adaptive strategy to embrace human demands and adjust to the limits and seasonality of nature. With continuous water supply during the first season all farmers could continue to cultivate paddy, even though this was possible only every second year, and the system gained acceptance from the farmer community and met the food production demands from society. With paddy during the first season, and intermittent water supply and only irrigated "dry crops" during the second season, the system matches the rainfall seasonality and reduces water demand closer to the sustainable yield. The option in the "Rules of Regulation" to release excess water for a third crop is an additional step in an adaptive strategy to maximize water use over seasons and years with high variability.

Another example is the capacity built up in the system to "cope" with the great variability in canal supply. Farmers in the LBP area have acquired the competence to cultivate a range of crops depending on the water allocation during a specific season. During the drought of 2003/2004 there was no water to be allocated for any of the canals in Bhavani Basin. For the first time, the historic canals under Kalingarayan and Kodiveri weirs experienced seasons without canal diversions. Stable supply of 10 to 11 months had made many of these farmers rely on paddy cultivation. Few wells and no practice of growing rainfed crops left them without any options. In the LBP area, farmers could cope to a much higher degree thanks to social learning and adaptive strategies.

Uncertainty

The LBP is an adaptation to overcome the great seasonal and annual variability of precipitation in the area. This is the imperative factor creating uncertainty in how to manage the LBP system. During the last 50 years the inflow to the reservoir has varied from more than 4,500 Mm^3 per year to as little as only about 500 Mm^3 per year (Figure 7). In some years there is no water to be allocated for the LBP Canal at all, and in some years the rich reservoir inflow is enough for both surplus releases into the Bhavani River, and is sufficient for a wet crop, a dry crop and may even supply water for a short third crop in the LBP Command area (Figure 5). River flow data and rainfall estimates have been available since the beginning of the twentieth century. Even with data, the high variability makes it difficult to predict the future. The "average year" almost never occurs and the statistics can consequently only be used to get an understanding of the maximum and minimum water availability.

In the original plan, research results proposed an ideal outcome based on engineering and agronomic knowledge. The human factor and the true environmental realities could only be understood after the implementation. The lessons learnt over the years from the outcome of canal supply, groundwater use, rainfall over the command area, seepage effects, crop choice and cultivation practices have all contributed to an increased understanding of how the water supply, the environment, and the farmers work together within the system. Today, there is quite an extensive knowledge of how the system works, but this still poses a management uncertainty.

An important factor for the functioning of the system, and the livelihoods of the farmers, is the demand and prices offered for different agricultural produce. In the 1950s, 1960s and 1970s paddy cultivation was an attractive and remunerative crop. Today, small farmers still appreciate paddy as it can be sold according to stable government procurement prices and can be stored and consumed within the household. During interviews in 2007, many farmers expressed concerns about how paddy cultivation had become uneconomical. Labor costs and agricultural inputs had increased, but at the same time that the market price had fallen even below the state procurement price. The farmers discussed opportunities to change the entire water allocation design for the LBP to cultivate other crops. They would prefer sugarcane. With the surge in the global price of cereals during the first half of 2008, the situation has probably changed. The price volatility is an example of how the global economy increases uncertainty at a local level.

The present system with two zones during a cropping year in a three step mode can utilize as much water as the amount that was consumed during the years of the Wet-Wet system (compare 1959/60-62/63 with, for example, 1978/79 and 1994/95 in Figure 5). During the first season, the same water quantity that was the total annual demand in the 1946 plan, can be used for one paddy crop on half of the command area. In the second season, an additional volume, equivalent to about half the quantity in the 1946 plan, can be used for the dry crops on the other zone. The third step is the possibility to utilize an available surplus quantity for a third short crop on the non-supply zone during the second season, or during the third season when the canal is usually closed (Figures 4 and 5, 1977/78-79/80 and 1992/93 and 1994/95). From a societal perspective, this management system optimally utilizes the inflow to the LBP Reservoir up to the limit of the discharge capacity of the LBP Canal. From the individual farmer's perspective, it is a system with a high uncertainty and an unpredictable livelihood set up. In a way, the present system puts farmers in the LBP command area in a permanent state of "stand by" since full water supply for both seasons occur during less than 50% of the years. The fact that two lost seasons in a row means no canal water for three years (Figure 4) makes it complicated for the single farmer to base the household economy on canal-irrigated crops. This system has consequently forced the farmers, individually and collectively, to adapt, improve and optimize the suboptimal set up.

AM Process

The changes in the design, water allocation scheme, cropping pattern, and water use in the LBP illustrates how the initiative moves back and forth from different actors, like the engineers, the local authorities, national demands, LBP Farmers' Federation, and the individual choice of farmers. The implementation of the original plan and every system change that have followed can be viewed as AM cycles (Figure 1). It shows how the original plan has been adjusted step-by-step to become the present complex human-nature-technology system.

With the cycles of system change over the years, the knowledge about the system has increased and the three types of uncertainty stated in the section, *Adaptive Water Management: Concepts and Analysis Framework*, above, have either been reduced or considered in the rules. More and more data is collected over the years and the knowledge of the outcomes on a system level, in relation to, for example, seepage and the reactions of farmers, have increased the understanding of the system and this knowledge has been used for planning the next goal and design formulation. The major uncertainty, variability in water availability, has been considered and included in the management rules. Two zones and up to three potential crops makes it possible to adjust the system to any water availability: no crop; one wet; one dry; one wet and one dry; one wet, one dry and one short third crop; or only one short crop during the entire year (Figure 5, 1986).

The original goal was to build a reservoir across Bhavani River and use the perennial flow to increase and intensify the cultivation in the region. Before the original LBP plan, designed by engineers and agronomists, reached the implementation phase it faced opposition from other parts of society. The original design of the command area and the cropping pattern and crop composition - that would be in balance with average water availability and give all farmers a reliable and stable annual income during most years - were disrupted by increasing the command area and extending the canal. The 1946 plan, “All Dry” became a first step towards a higher probability of non-supply years for the individual farmer. The plan could never be implemented since farmers in action refused to cultivate canal-irrigated “dry crops” and with the support of the Madras State Government chose to cultivate paddy.

The “Wet-Wet” system, that increased the water demand by 100%, is the first water allocation design that was fully implemented. After a couple of fortunate water rich years, the design was evaluated as unrealistic. In 1963, the government investigated the possibilities to put a ceiling on paddy cultivation and bring back the LBP system closer to the original level of water demand. Once again, the farmers refused to adjust and the goal to formulate a design with zones with different irrigation intensity was rejected. The present “Wet-Dry” system of water allocation and cropping pattern from 1964 is a compromise between precipitation seasonality, average water availability considered by the engineers, and the demands for paddy cultivation from farmers and society. It was implemented and it was not until the mid-1980s that it proved to be unsatisfactory and the modification made to the system in 1986 was formulated and implemented. Consequently, farmers and the authorities have adapted to each other over the years.

It might appear remarkable that the original design, based on river flow availability, was rejected by both politicians and farmers. The initial canal extension and expansion of the command area must be viewed from a perspective of a local famine and poverty. A reservoir was being built and why should not, as many as possible, benefit from the project? A larger command area also made it possible to utilize all the water during peak years. The changes towards paddy cultivation must be viewed in the context of the general national food deficiency situation with food aid programs like the P.L. 480, the “Grow More Food” Campaign and a with the close memory of famines. Food shortage problems and a general trend of dietary preferences towards rice, away from coarse grains, made both authorities and farmers favor remunerative paddy cultivation instead of cotton and millets.

The outcome from every version of the system is monitored with records of releases into the LBP canal (Figure 5) and agricultural statistics with crop areas and yields (Figure 3). For a number of years other data has also been in existence, e.g., records with changes in the groundwater level and the chemical status of groundwater in the area. The statistics and reactions from farmers, such as the violation of rules of the system, give a clear feedback to the planners for the next cycle of design formulation.

Every development of a change in the LBP system is similar to the cycles described by the AWM theory. The cycle does not always complete the full circle. Often farmers or other actors have intervened at an early stage, and as a result a new goal has to be set, and a new design has to be formulated. It is interesting to note that the “Wet-Wet” design, however unrealistic, was a real test implementation in line with today´s idea of AWM. The ‘voice’ of the farmers is very strong in the LBP system and only the “Wet-Wet”, “Wet-Dry” and the “1986 modification” have been fully implemented without interruption. The farmers have participated in the policy formulation of all these three systems. It shows that without participatory policy formulation, implementation has been difficult.

Adaptive Regimes and Adaptability

Since the inauguration of the LBP system it has moved, partly, from a “predict-and-control-regime” towards an “integrated adaptive regime”. The governance structure, today, is much more polycentric. The system change in 1986, confirmed by a public meeting of farmers in 2002 and a court order in 2003, visualizes the broad stakeholder participation on a system level. This can be compared with the original design that was only decided by experts. The transition has to be viewed in the general societal development that has made farmers more knowledgeable. An example is the literacy rate for Tamil Nadu. In 1951, the literacy rate was only 21% (even lower in the countryside) and by 2001 it had reached 74% (Department of Economics and Statistics 2006).

In 1955, the infrastructure could be characterized as massive, centralized and a single source of design, power and delivery. The extensive groundwater development in the LBP area, and some river and canal pumping, has resulted in a kind of decentralized water supply infrastructure for many farmers, where the single farmer - thanks to a more reliable water availability - can invest in high value crops or change to perennial cultivation.

Sector integration and scale of analysis and operation are only slowly moving towards the description of an "adaptive regime". The LBP command area is affected more and more by the changes and the increased complexity in Bhavani Basin. During the last decades, the inflow to the LBP Reservoir has been decreasing (Figure 7). There is, however, no complete structured analysis that put the LBP system in the context of an increasingly complex and multiple sector basin perspective. River flows and authorized allocations of surface water are all documented by the PWD or other authorities. This information is not widely accessible. Even if the basic information is shared openly, the public would probably not understand the complexity of the information. One major reason is that the great variability is hiding the long-term trends.

Considering the definition of adaptive capacity given by Pahl-Wostl et al. (2007), the LBP system partly fulfils the requirements. Performance indicators with canal releases and crop outputs have been recorded since the inauguration. Daily flow readings along the LBP canal and for all major side canals exist. Unfortunately, detailed data is not being kept over the years and only monthly or seasonal records are available at the engineers' offices. These are the records available with the LBP Farmers' Federation, researchers and some authorities. Based on the monthly, seasonal or yearly data, the actors in the LBP system can draw basic conclusions. Changes in the system that have taken place also show that actors, on a system level, accept and understand why the changes are taking place. This is especially true for the Wet-Dry system from 1964 and the system modification in 1986.

Social learning

The origin of today's Tamil Nadu Agricultural University, TNAU, was founded by the British in 1868 in Madras (The Agricultural School at Saidapet) and relocated to Coimbatore in 1906. It became a university in 1971. In 1955, the Bhavanisagar Agricultural Research Station (today part of the TNAU) was established next to the LBP Reservoir. The location of the TNAU and the TNAU research station means that the center for all agricultural research and knowledge in the state is situated very close to the Bhavani Basin and some partly even inside the LBP Command area. About 100 years of rainfall data is available with the statistical department in Chennai, and the PWD in charge of irrigation water distribution have measures for river and canal flow for the same period. All kinds of knowledge and expertize are, thus, available in the area. Despite this, many decisions regarding the LBP and the water allocation for the command area have been taken in opposition to known facts. The perception and demands of farmers and other parts of the society have strongly influenced the system design and clearly illustrate the importance to include the human component early in natural resource management, and the hazard when not.

The original "All Dry" plan from 1946 was a novelty in the LBP area. The designed cropping pattern with irrigated dry crops was tested in the area. The refusal of farmers in the LBP area to cultivate dry crops, can, however, clearly be a sign of 'social learning' in the area. The farmers learned the cultivation of paddy from the historic canals. Farmers found it difficult to imagine a large-scale irrigation of "dry crops" and claimed that seepage would make it impossible. The authorities underestimated the need to support the farmers in learning the new practice. With the introduction of the "Wet-Dry" system in 1964 the old idea with "dry crops" was introduced a second time. The planners had learned from the arguments of farmers and moved the practice to the dry season. The farmers accepted the arrangement and all the farmers can now cultivate canal-irrigated dry crops.

The entire chain of system changes shows that social learning is taking place within the LBP system. The initial over-optimism resulted in a design with an over-dimensioned water demand and cropping area. The different actors have together learned how to optimize the system within the limits of the technical infrastructure, the reservoir capacity and the canal discharge capacity, and the variability in available supply decided the by the erratic precipitation.

The way farmers have learned and been inspired by each other, like the benefits from conjunctive groundwater use and the acceptance of irrigated dry crops, are examples of social learning between actors at short timescales. On a long-term perspective, all the actors in the LBP system have learned from the environmental responses and each other's behavior. Together they have contributed to the alteration of governance structures and have developed new innovative practices without being bound and limited by the original use of the existing technical infrastructure.

The historic knowledge about how the current situation emerged does, however, not seem to be part of the average understanding of engineers, researchers or farmers in the area. During years of water scarcity, many complain about the situation, but few appear to be aware that it is the farmers that forced the government to introduce the present system. After the failure of the Wet-Wet system, a less water demanding system was proposed in 1963, but again, it was rejected by the farmers. The present Wet-Dry system does not allow any "carry over" storage from wet to dry years, and, thus, increased the uncertainty for the single farmer. All actors, thus, live with change, but few appear to remember what caused the change in the system and why it changed.

Conclusion and Messages for Policymakers

The LBP is an example of an irrigation system that has proved to adapt over time. Several changes have taken place and earlier mistakes or failures have been addressed in a stepwise way to reach the present complex human-environment-technological system. In general, the system performs well and has served the farmers and the region well for more than 50 years despite massive changes in agrarian and social structure.

What adaptations have taken place in the LBP?

Over time the interplay between farmers and water authorities have resulted in a flexible irrigation system that has adjusted to the natural seasonal variability in rainfall and annual water availability, the demands of society, at large, and water users - the farmers. Compared to the original project plan, adjusted according to the estimate of assured annual water availability in the basin, the present system has a 20% larger command area and a 60% increase in yearly water demand. This has created a system with inbuilt water scarcity and high unpredictability, leaving the farmers to endure and adapt to frequent seasons without canal supply. The farmers in the LBP area have proved to be able to adapt over the years. The large-scale development of wells in the area shows how the farmers have successfully managed to increase water availability to balance water scarcity during seasons without supply. The farmers have also acquired a capacity to swiftly adjust the cropping pattern to the highly unpredictable variability of seasonal canal water supply, and also to entirely rainfed conditions.

How well does the LBP match the ideas of AWM?

The AWM analysis shows that the LBP system has, over the years, fulfilled the criteria of a complex adaptive system more and more. The system proves to have an adaptive capacity and farmers not only cope in an ad hoc manner but have developed different adaptive strategies. To a large degree, the system fulfils the requirement of an adaptive regime. Social learning takes place at both system level and at the individual farmer's level. The uncertainty factors have been considered in a stepwise way during the system change cycles and have been included in the system design. The system has moved from a top-down project to a management system with multiple actors. Both farmers and the authorities have learned over the years and now have better possibilities to interact.

When compared to the current theories regarding AM and adaptive regimes, the LBP system behaves in many ways as the theories suggest. Even though the development over the years has not been carried out with the AWM theories as the road map, the LBP system has over time proved to follow many of the ideas brought forward within this field of research. The LBP case study thus shows that AM already takes place in real life. This is a surprising conclusion, because it is often held that irrigation systems do not adapt well.

What policy suggestions can be drawn from the LBP?

Some key lessons can be drawn for policymakers. Policymakers need to tap into a rich skill set available in the agricultural community that includes the local knowledge of farmers and resource managers in order to promote AM. Policies should foster collaboration between different knowledge holders, and experimentation as done in the LBP. To allow for upcoming modifications, the design of large infrastructure should take into consideration a range of possible changes that may occur. This also includes recognizing that it is impossible to get everything right because of future uncertainties.

The failed implementation of the original LBP plan shows the importance of nourishing social learning before or during implementation of complex systems and new practices. The LBP design was based on the introduction of large-scale irrigation of "dry crops", like groundnut and cotton. The authorities underestimated the need for widespread training to introduce this novelty. Social learning is necessary to get the acceptance and cooperation of the users. If the engineers had invested more energy in this aspect, the LBP system would have experienced less turbulence before reaching equilibrium where nature, technology and humans agree.

The closure of the Bhavani Basin will progress and the complexity and interconnectedness between basin water users will increase. The LBP command area has the weakest riparian rights and additional water demands from other users in the Bhavani Basin might create a new threshold to which the system will have to adapt. It will probably be necessary to find compromises in the future and will, in line with integrated adaptive regime theories, be of great importance that the information on how water is allocated and aspects of performance from a basin perspective are shared openly.

Finally, the LBP case study gives us hope. In spite of contending with an imperfect irrigation system design and intense competition for water resources, water resource managers and farmers are able to adapt and continue to reap benefits from a productive agriculture system. Users of the LBP system have proved to be capable of dynamically tackling new situations arising in a changing environmental and societal context. The LBP, thus, shows that the fear of collapse of today's irrigation systems is overestimated.

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