Dutch Engineering Overseas: The Creation of a Modern Irrigation System in Colonial Java

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This article describes and analyses the development of modern irrigation in Java within the context of the establishment and transformation of the colonial state in the Dutch East Indies / Indonesia. In order to make this relationship comprehensible the concept "large technical system" has been adopted. The colonial socio-technical irrigation system was built between 1830 and 1942. Engineers, civil servants and agricultural experts were the main system builders and they formed specific coalitions practising specific irrigation approaches. After Indonesia gained its independence, the colonial irrigation system remained in existence and, consequently, irrigation engineering remained top-down, large-scale and focused on agricultural-technical management.

Introduction

Not very far from the Indonesian capital of Jakarta in West Java an air traveller is able to see, in the Cisadane river, a giant weir with ten sluices. This massive sample of engineering work serves to ensure that irrigation water goes to thousands of hectares of land, so helping the local population to attain high rice yields. The weir forms part of an extensive network of government-constructed and managed irrigation canals, dams and other waterworks throughout Java aimed at facilitating wet-rice farming. This network is of vital importance. Java, the main island within the Indonesian

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archipelago is now inhabited—at the beginning of the 21st century—by some 100 million people, all living in close proximity to each other. Rice is the staple diet and about half the population is employed in agriculture. The weir in the Cisadane is a monument to Dutch colonial irrigation technology. Irrigation has a long history in Java but the Dutch, themselves inhabitants of a country in which water control is crucial, laid the foundations for the present irrigation network when they colonised the Indonesian archipelago (known collectively as the Dutch East Indies). The referred to foundations were particularly laid between 1830 and 1945. By the end of the colonial period, 1.3 of the 3.3 million hectares of wet-rice fields were being irrigated with the help of"technical watering systems"(40%).

This article, based on long-term research into civil engineering in the Netherlands and the Dutch East Indies (see e.g. Bosch et al., 1998 and Ravesteijn, 1997, forthcoming), shows how and why modern irrigation technology was introduced and expanded in colonial Java. Special attention is given to the conditions which enabled the development of modern irrigation and particularly to the link between this development and the creation and transformation of the Dutch East Indian colonial state. In addition, postcolonial developments are briefly considered. In describing and analysing modern irrigation development in relation to colonial state formation, the concept"large technical system"is used. The argument focuses on (1) the way in which Java's modern irrigation system has developed and notably the phases which can be distinguished and the sorts of system builders that characterised each phase, (2) what the development conditions were and particularly the (critical) problems that occurred from time to time and (3) how the irrigation system evolved in conjunction with the social context and what the various influencing factors at each phase of development were.

The data and insight presented here contribute to the historiography of technical development, particularly in terms of the colonial context. Theoretically, the aim is to contribute to theory formation in relation to the (social) development of technology, chiefly by applying the large technical system concept to a new research field, by linking it up to other technical development concepts, including the "technical regime" concept, and by suggesting these concepts could be connected through a sociological ("structuration") perspective. From a policy standpoint, it is shown that the large technical system concept helps to explain why postcolonial Indonesian politicians and engineers had, and still do have, limited manoeuvring capabilities when it comes to changing fundamental aspects of Java's irrigation system.[1]

Theoretical backgrounds

Technical (or technological) development is not only related to empirical research but also to theory formation; the objective being to thus, on the one hand, gain a better understanding of technical development while, on the other hand, providing a structural research line. This kind of theory formation has evolved—together with technology research—within the interdisciplinary field of Science, Technology and Society (Science and Technology Studies) that has developed since the Second World War and especially in one of the integrating disciplines, that of the History of Technology (Spiegel-Rösing and De Solla Price, 1977; Jasanoff et al., 1995). In that connection a two-pronged basic hypothesis has been developed which is that (1) science and technology do not develop in isolation of each other and the social context or in reaction to the social environment but precisely (2) in conjunction and in interaction with each other and with society. The technology researchers involved subsequently reject one-sided technical development approaches, especially the technology push model, the market pull innovation model and the "technology as applied science" model while striving to establish an interactive science, technology and society approach. To date this noble aim has led to nothing other than the emergence of a variety of concepts and approaches for the describing and analysing of technical developments, the only striking characteristic of all this being the awareness that "everything is connected to everything" (see e.g. Bijker, 1995) though it should be mentioned that the social-constructivist approach, according to which technical development is a process of variation and selection influenced by social processes, has been an important impetus (see e.g. Bijker et al., 1987 and Winner, 1993). The time seems ripe for endeavouring to identify fruitful concepts and elements in theory formation in the field of technical development and to integrate these concepts and elements, the ultimate goal being to achieve a comprehensive approach to technical development in social and scientific respects.

Science and society are clearly recognizable "contextualizing" factors in the rise of modern hydraulic engineering in (colonial) Java. As far as the social context goes the most important forming power of East Indian society was the colonial state which comprised the East Indian government and the administrative machinery. When the United East Indian Company went bankrupt in 1798 the Dutch State took over its possessions. In the East Indies a satellite state was established which subsequently underwent a process of transformation. When it came to the formation of the East Indian state there were, broadly speaking, three phases that could be distinguished (Van den Doel, 1994, pp. 21 and 445-446; Locher-Scholten, 1994, pp. 5ff.):

1. 1816-1870/90: the early colonial state. In line with the orders of the authorities in the mother country the colonial government followed a policy that was directed at exploitation and at maintaining "peace and order." A simple administrative organisation evolved.
2. 1870/90-1920: a transition period when a process of political modernisation began and the East Indies as a whole became more independent from the Netherlands. Trade and production fell into the hands of private enterprise. The government supported such entrepreneurs by providing infrastructural systems while at the same time developing a policy directed at improving public welfare and the population became involved in the job of governing. Within the administrative organisation there was expansion and diversification.

3. 1920-1945/49: the modern colonial state. The state was relatively autonomous. Public involvement in government was reinforced but, in response to growing nationalistic tendencies, the authorities endeavoured to consolidate colonial relationships.

The development of modern irrigation in Java was also made possible by all the discoveries that were being made in the fields of mathematics and physics (Van Maanen, 1924; Schoemaker, 1997), notably in the area of geometry (land or soil surveying) and hydraulics (the study of water flow) and, partly in relation to that, in the field of (Indian) hydraulic engineering. As far as hydraulics was concerned it was Simon Stevin who, around 1600, substantially contributed to Archimedes' Law by resolving what was known as the "hydrostatic paradox." In the eighteenth century it was the Law of Cornelis van Velsen which asserted that "flowing speed is proportionate to the root of the drop" that constituted a milestone. From this various formulae were derived which were useful for the designing of irrigation canals (including the Strickler formula).

In 1842 an engineering college was established in Delft where, just as in other respected European technical colleges, engineers were given a good grounding in mathematics. In 1903 a chair was established in Delft for East Indian Hydraulic Engineering and in 1921 a similar chair was created at the newly established Polytechnic in Bandung. What was important for irrigation intervention was the matter of calculating the rate at which rivers can transport water volumes on the bases of rainfall levels and topographical details. It was the engineer A.P. Melchior who, in 1895, developed a method for dealing with this hydrological question.

In the 20th century attention was given to the measuring and regulating of water that flowed to the paddy fields. This was to culminate in the development of the Romijn gate, an inlet sluice that controlled the amount of water let through while simultaneously measuring it. To this end extensive experimentation was being carried out in various laboratories which, in the twentieth century, was a new phenomenon. In that century developments being made in the mathematical branch of statistics were to be applied to hydrology. The main concern was that of finding ways of determining the risk of water works being overtaxed on the basis of rainfall figures. During the course of the nineteenth century engineers were also confronted with substantial irrigation works maintenance problems because of the highly changeable water volumes and the gigantic erosion and sedimentation processes. These problems were finally resolved in the twentieth century. What was important when it came to the designing of irrigation canals was the matter of establishing flowing speeds that would be great enough to prevent silting up but small enough to prevent erosion. The empirical design conditions laid down by the engineer R.G. Kennedy in the British East Indies in 1895 could not be applied in the Dutch East Indies and, in 1925, it was the engineer H.C.P. Vos who came up with a theoretically based solution. Another twentieth century phenomenon was the rise of ground mechanics or geo-technology which focused on the earth moving mechanisms employed.

A promising concept in understanding the interaction of science, technology and society is that of the"large technical (or technological) system" or ""socio-technical system." Such a system is understood to comprise a complex network of technical artefacts and all the related social structures, characterised by internal integration and external adaptation and aiming at fulfilling social needs. Hughes (1983, 1987; see also his 1998 publication; compare e.g. Summerton, 1994) gives content and shape to this concept in his study on electrification in Western society. He distinguishes a number of phases in the building of a large technical system, notably the phases of invention, development, innovation and expansion, and identifies corresponding types of system builders: inventors, inventor-entrepreneurs, manager-entrepreneurs and financier-entrepreneurs. He also formulates certain development mechanisms, one of which relates to critical problems or"reverse salients"—a term derived from warfare—of a technical or other nature which have to be solved before a socio-technical system can grow.

Another notion is the impact of momentum or the technical and organisational components of a system that give it"mass"or substance so that it generates its own direction and rate of growth. The momentum mechanism says something about the relationship between a large technical system and its environment. Hughes suggests that in the initial period of system building the effect that the environment has on the system and its technical core is more substantial than the reverse, while later on the opposite holds true. A system characterised by momentum seems to be autonomous, but Hughes believes that, ultimately, a socio-technical system is maintained and made to grow because of the social entities involved. Hughes (1987, pp. 76-77) expresses this as follows:

> Technological systems, even after prolonged growth and consolidation, do not become autonomous; they acquire momentum. They have a mass of technical and organizational components; they possess direction, or goals; and they display a rate of growth suggesting velocity. A high level of momentum often causes observers to assume that a technological system has become autonomous. Mature systems have a quality that is analogous, therefore, to inertia of motion. The large mass of a technological system arises especially from the organisations and people committed by various interests to the system.

The large technical system concept has been applied in many technical fields, including state controlled activities (see e.g. Schot et al., 1998 and A Campo, 1992), but large water-based systems have been neglected. In Java the Dutch constructed weirs, canals, aqueducts, reservoirs and other structural works to support rice and sugar cultivation. A variety of institutions and organisations were connected to these irrigation works, such as water regulation facilities and regional irrigation departments, the East Indian Public Works Department and the provincial Public Works services, laboratories, related companies (such as the Hollandse Beton Groep, i.e. the Dutch Concrete Group), technical training centres (such as the Polytechnic in Bandung) etc. This complexity of technical and non-technical elements might be considered a "large technical system": the large modern irrigation system.[2]

The large technical system concept forms part of what is known as social-constructivism. Other concepts figuring in this technical development approach are: "artefacts" (artificial objects being seen as the basic units of technical development analysis, in this case: irrigation works and systems, including the necessary management), "actors" (social entities acting in relation to technology; in this connection we will especially encounter engineers, civil servants and agricultural experts) and—in combination with the actor concept—some kind of ""attachment of meaning" (the way in which an actor perceives an artefact and its eventual problems, e.g. modern irrigation as a necessity or luxury). Recently another interesting concept has been conceived that links technical development to the social context, namely the "technical regime" (or "technological regime") concept which is a set of rules for engineering including guiding principles, promises and expectations, functional requirements and design tools as well as concepts (Van de Poel, 1998; see also Rip and Kemp, 1998 and Ravesteijn, 2002). Technological regimes guide technical development in such a way that patterns arise and they contextualise such development through rules that besides having a rational-technical character have a social character and a "locus": the engineers and other actors that are involved. The question is how all these technical development concepts relate to one another.

I shall return to the system concept, its relation to other technology development concepts and its policy significance in the final sections. First, though, I shall give the necessary details on modern irrigation development in Java, including the postcolonial period, and the circumstances in which this development took place and its connection to the process of Dutch East Indian state formation.

Irrigation development

Historical overview

It was during the first half of the nineteenth century that Dutch engineers first started constructing irrigation works, notably by creating barrages in rivers which already had irrigation networks. Often these works replaced Javanese structures or those constructed by the local colonial administrators[3] with the help of forced labour. The local people used to make their dams from wood and stone and their structures were therefore temporary. Each year, when the rainy season came, these dams would either be washed away or seriously damaged. The works constructed by the colonial authorities, though bigger than the traditional structures, were just as vulnerable and so they also had to be perpetually renovated and reconstructed. The engineers erected "permanent" works. At first they also used wood but gradually they introduced more durable materials such as brick and concrete. This is because, in the west monsoon season, the rivers had to cope with suddenly increasing vast volumes of water and therefore often burst their banks and thus they were not easy to control.

The building of a dam in the Sampean river in East Java well illustrated this point. Construction work commenced there in 1832 under the supervision of the engineer C. van Thiel. The dam, which was made of wood and stone, was the first specimen of irrigation engineering work in Java. However, it was not until the turn of the century that the dam in the Sampean irrigation area which covered some 9500 ha finally took shape. Nevertheless the engineer Rietveld commemorated the Sampean weir's hundred year existence with "respect and praise for the Sampean delta pioneers who, under difficult circumstances, had managed to engineer much" (1932, p. 287). He recognized all failures of the pioneers and the extremely high costs of the dam, but stressed the advantages of increased knowledge:

> invaluable experience had been gained. Often the premium for knowledge is high but here one may definitely question whether the knowledge gained was so expensive. Let us focus on two issues: the large part played by Sampean observations in Melchior's study on maximum river transport capacities and furthermore the scepticism that has grown surrounding the *padas* "soil type", a collective name used to describe a number of more or less good or unfavourable notions. Who could estimate the monetary value of the two aspects? (Rietveld, 1932, p. 286).

The construction of the Sampean dam and other similar types of works was a direct result of colonial development policy. In the 1830-1870 period the Culture System, which dictated that the Javanese should cultivate certain cash crops, was in force. One of the chief crops was sugar cane. This was grown in sections of the paddy fields in designated areas also including the Sampean delta. In the 1840s it was this Culture System, together with all the other obligations that had been imposed on the Javanese, that led to famines in Central Java. Irrigation works were therefore set up that would help to improve the population's agriculture. The crises also led to the foundation, in 1854, of the Dutch East Indian Public Works authority in the form of the Public Works Bureau. Where previously the maximum number of engineers taken on had been ten, the new service provided work for 35 engineers. In 1866 its name was changed to the Department of Civil Public Works.

The Public Works authority was unable to innovate much change: Public Works was simply answerable to the Civil Service. The Civil Service was responsible for water control and a key figure was always the resident in charge of a region (or residency). It was he who made most decisions as far as irrigation was concerned. Only occasionally, when faced with complicated tasks, did he call upon engineers for their help. Public Works was furthermore short of finance and personnel which meant that it was not always able to meet requests for technical support. Moreover, the engineers, who in the first place had been militarily educated and who had later received training in civil engineering, had little relevant knowledge.

They were highly critical of the irrigation works that had been constructed by the people and by civil servants but, despite their "scientific" knowledge, their works were at first little better than what had gone before.

The engineers aspired to improve their position and thus became entangled in a competitive struggle with the representatives of the Civil Service. It was notably the engineer H. de Bruyn who in the 1861-1877 period was twice director of the Public Works authority who made himself heard. De Bruyn was educated at the Royal Military Academy in Breda. He linked the creation of modern irrigation works to profit but also to affluence, progress and civilisation; for the civil servants modern irrigation was a luxury! Under his regime the number of engineers within the Public Works Department rose to seventy-five. Modern irrigation works remained scarce but qualitatively they did improve and, partly because of this, the engineers' quest for emancipation finally brought success.

The turning point came in 1885 when, with the introduction of new regulations, the Public Works Department virtually became an independent service. At the same time, however, personnel numbers were reduced and the number of engineers dropped to thirty-nine. Public Works was divided into two departments: the General Division and the Regional Division. The residents only had authority over the engineers in the insignificant Regional Division. The General Division included two already well-known components: the Technical Section and a number of regional Public Works Departments (set up in 1855). The Technical Section was later broken down into five separate sections for each of the various types of public works. The new verve was apparent from the installation of a third component: the Irrigation Brigade. The Brigade's task was to pave the way for modern irrigation systems for all rice fields by collecting information. The 1885 regulations produced the following overview of the data to be collected:

> The brigade collects and orders ... the data produced by rainfall observations in *Java* which are of interest to irrigation. With all the chief rivers it determines what are the basins and the water levels, it calculates the water flow rates and, with the help of maps based on topographic and statistic details, it draws up irrigation maps clearly indicating the river basins and the existing water channels and irrigated fields which also show exactly how the relevant fields are irrigated as well as indicating what are the degrees of irrigation in relation to the volume of water required for entire irrigation.
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> Through experimentation it determines how much flowing water is required for the full irrigation of various fields and it becomes familiar with the construction and effectiveness of the structures created by both Europeans and Inlanders in the Dutch East Indies for the purposes of irrigation (East Indian Statute Book, 1885).[4]

Construction activities increased and, in 1890, were given definite form when the General Irrigation Plan for the island of Java covering nineteen projects was introduced; another seven projects were added to the plan later. It was also decided that water control should be made "technical." As of 1888, the regional Irrigation Departments that were set up were designed to chiefly deal with the operation and maintenance of works. At the same time, water distribution methods were devised. A good example of the new approach was the activities developed in the Pemali river area in Central Java. The engineer A.G. Lamminga gave this region an entire irrigation system while at the same time providing 32,500 ha of land with water. An operational plan was also worked out that was headed by a water manager who was able to function independently of village administrators. The Pemali works and the management form that grew with the project became a model for later works. Lamminga, who made his reputation as the founding father of modern irrigation technology in the Dutch East Indies, was associate professor at the Polytechnic in Delft from 1910 to 1911 and his subject was East Indian hydraulic engineering.

Little attention was given to the economic side of all the irrigation projects but that changed in 1897 when the Rentability Commission, which was made responsible for examining the economic feasibility of projects, was established. This period also marked the beginning of the end of relative autonomy as far as the Public Works Department was concerned. Not only the engineers were represented in that commission but also civil servants who, because of this, again managed to have a big say in matters. The rentability criterion was refined when, in 1901, the Ethical Policy was introduced.

The Ethical Policy emanated from the population's situation of "diminished prosperity" that became evident towards the end of the nineteenth century. The new policy aimed at improving people's welfare, not least by improving irrigation. It was connected to a "modernisation mission" in which modern technology was central. In spite of this, engineers were once again required to scale-down. Irrigation endeavours were incorporated into the activities aimed at stimulating small farmers and this permeated through to rentability considerations. A new group of experts then appeared on the irrigation stage: the agricultural experts and, after 1905, they were accommodated within the Department of Agriculture. They, too, had a representative in the Rentability Commission.

The question of the rentability of irrigation works became a hot issue at the time of the Solo Valley works project in East Java. This project was a programme concerning the irrigation of no less than 156,000 ha of land as well as a major river diversion plan to protect the navigational routes of Surabaya from silting up. After five years the project was suspended because budget limits had been exceeded. Because the engineers were unable to agree on the economic aspects of the plan and technical aspects were giving rise to questions (the large works were, in part, impossible to execute or would, at least, have brought with them great risks) and because the agricultural and control aspects were problematic (would the fertile silt perhaps accumulate in the long canals? how could agricultural activities be co-ordinated in such a large area?) work on the project was later halted altogether. The main opponents were the agricultural experts; at that time the engineers found that the civil servants were more or less on their side. In his reflections the engineer Vlugter stressed the importance of the agricultural dimension in the debate on the Solo valley works when he remarked that what had been learnt from these works was that "before any irrigation works project could be embarked on it was imperative to obtain agricultural-economic advice" (1949, p. I. 101).

After 1900, because of the Solo fiasco and because of the Ethical Policy, a preference developed for smaller irrigation works, though the execution of the 1890 irrigation plan continued.[5] More attention was also paid to irrigation control. In practice three-cornered discussions started to take place between engineers, civil servants and agricultural experts. Another effect of both these things was that Public Works affairs became decentralised.

In the end the engineers learned how to work effectively, control and yield-wise. In the second decade of the twentieth century construction activities increased. By about 1920 most of the General Irrigation Plan projects had reached completion and the cost of the mostly new projects had reached an all-time high of around ten million guilders a year. At that time more than 200 engineers were working for the Public Works Department. Engineers were able to concentrate on perfecting management and specific works. What was important was the matter of developing laboratory facilities. The economic problems of the 'twenties and 'thirties inevitably led to expenditure cutbacks and also to growing numbers of people being involved in rice cultivation which intensified the perfectionist tendencies. Much the same went for the political problems that were arising from increasing nationalism. A new generation of big irrigation projects started to take shape, including large reservoirs. These projects came about as a result of extensive technical and agricultural research, were worked out in minute detail, and were largely executed in a routine fashion. In addition, a refined management structure was designed and set up. In the final decades of the colonial era whole series of such projects were embarked on, like for instance the 52,000 ha Tangerang works in West Java of which the above-mentioned weir in the Cisadane river was a part. In the wake of the political-administrative reforms that had been set in motion after the turn of the century, three provinces were formed in Java. Each of these provinces had its own Public Works service.

Development conditions

The development of modern irrigation in colonial Java traced its origins from a small number of unconnected headworks (1830-1885), through to the execution of the earliest projects for entire areas accompanied by managerial directives (1885-1920) and finally to the realisation of entire series of systems of irrigation and control (1920-1945). Modern irrigation evolved thanks to a clear colonial need for up-to-date irrigation systems and a situation that gradually offered increasingly favourable conditions in terms of policy, administration and ideology. The rising number of engineers, respect for engineers and knowledge of engineers were further contributory factors. We can specify this in more detail by examining the three periods of irrigation engineering.

In the nineteenth century there was a demand for modern irrigation works, both for rice crops and for sugar cane cultivation. The ever-growing population periodically suffered from famines, also because of the Culture System which forced people to grow certain cash crops, including sugar cane. The East Indian government reacted by introducing an ad hoc policy to provide occasional irrigation works and by employing contingency measures. There were other conditions that also made the construction of modern irrigation facilities possible, though to a limited degree. The government created an impressive administrative apparatus but the irrigation service that was established left little space for manoeuvre. Civil servants were in control of the residencies into which Java was divided. When constructing waterworks they made use of traditional methods. Engineers were unable to change matters either by what they said or did. They were present in the public service sector but in small numbers. The engineers strongly believed in sticking to their "scientific" approach but they were neither specialised enough nor knowledgeable enough to guarantee the desired results. In such circumstances engineers could only set up a few headworks.

Slowly but steadily the government developed a policy that favoured expanding modern irrigation. The population's interests were becoming more important, though the sugar cane industry remained powerful enough to encourage the government to act to its advantage. The colonial government converted the irrigation service into an independent organisation and so introduced technocratic rule. Adopting the engineers' ideology and associating modern irrigation technology with welfare and modernisation helped to reinforce the technocratic rule linked to the Ethical Policy initiated at the turn of the century. Engineers were given the opportunity to build complete irrigation systems. In other words, the government created a situation in which irrigation modernisation was given much more scope but after 1900 this slowed down. Since the beginning of the last century engineers have also been supported by professional organisations. The unfavourable factors at play during the second period were the haphazard knowledge of irrigation technology and management, lack of specialisation among engineers and an overall shortage of personnel. It was a time when certain great men laid down foundations while others made big mistakes. Cost-benefit analyses took on great significance and, in conjunction with events taking place in the Solo Valley and the introduction of the Ethical Policy, agricultural experts appeared on the scene.

Eventually engineers gained insight from their experience and got specialised training. Personnel problems were alleviated by employing foreign engineers as well as emerging East Indian engineering graduates. Consequently, the conditions for irrigation modernisation during this last period were favourable, a fact which led to the implementation of a whole series of projects.

Irrigation and the colonial state

Modern irrigation development corresponded to the state formation process continuing in the East Indies, in which exploitation and the maintenance of order aided by a simple administrative system made way for entrepreneurial and welfare support that was helped by a diversified and specialised government bureaucracy. Headworks were built in the early colonial state period, the first irrigation (control) systems were realised during the transition period from traditional to modern administration and all the remaining systems were realised in the modern colonial state era.

The developments on irrigation-technical and political-administrative fronts were interrelated through the groups (or institutes) that were involved in both these facets (i.e. the actors), which were: engineers (the Dutch East Indian Department of Civil Public Works)[6], civil servants (the Civil Service) and later, also, agricultural experts (the Agricultural Department). Another essential actor in both development processes was the colonial government which steered the state formation process and also determined the parameters for irrigation activities; over the course of time, the Dutch government's intervention in this gradually diminished. The engineers, agricultural experts and civil servants became embroiled in a debate on the authority and the nature of irrigation intervention. It was a struggle that finally gave way to co-operation. All three set out to bring colonial policy in general and irrigation policy in particular as much as possible in line with their particular views on irrigation intervention and with their specific interests. In that respect the engineers formed an up-and-coming group, just as did the agricultural experts, while the civil servants slowly lost power and influence. The power and competition struggle that raged between engineers, civil servants and later also agricultural experts had its effects on the irrigation efforts.

In the early colonial state period the government of the day allowed a limited number of modern irrigation works to be constructed and it was only here and there that headworks were installed. At that stage civil servants dominated and the room for manoeuvre given to engineers was minimal. Irrigation improvement was given new impetus in the transition period and the nature of the activities also changed. At first the government gave the engineers plenty of freedom and so they embarked on installing entire irrigation systems and on regulating the relevant management. Later the government broadened its scope by involving civil servants, once again, more prominently in the process and by calling in agricultural experts. Under the policies of the day the construction of smaller-scale works and the establishment of technical control facilities were given relatively more weight. After a while all of that changed and once again large new works projects were undertaken. In the modern colonial state period, political and other circumstances were favourable for the realisation of irrigation (control) systems. At the time irrigation involvement was a co-operative enterprise between experts and civil servants. Economic and political problems did, however, precipitate certain adjustments.

Conversely the disagreements about irrigation involvement did have consequences for the state. In the early phases of the state formation process the engineers who were new on the scene did enter into conflict with the powerful civil servants. It was only slowly that the engineers saw results, notably when their technical innovations became more successful. The opposition they provided did, however, manage to contribute to the dismantling of the Civil Service. During the transition phase the engineers at first enjoyed a certain degree of autonomy but the Solo Valley fiasco, together with the Ethical Policy, changed the position of the engineers and the constitution of the state. The engineers, by then a more or less established group, found themselves competing with the new agricultural experts. The civil servants were also once again given a clear role in irrigation involvement. In addition, responsibility for public works was decentralised which weakened the position of the centralised Public Works Department. Nevertheless, the authorities adopted the ideology of the engineers which was that modern technology was essential to prosperity and progress and they made that the basis for their new policy. The irrigation development that had manifested itself in previous years suddenly became a model for developments being aimed at throughout society as a whole. In the final state formation stage rivalry subsided and public works engineers, civil servants and agricultural experts banded together with the government to refine and tighten up water control.

Postcolonial development

The independent Indonesian state that developed in the 1940s was the end-result of a process of colonial state formation; it was the next step following that process. In spite of this political transformation and all the changes made in conjunction with perpetual technical development, including the construction of large multipurpose reservoirs, the linking up of irrigation systems, the introduction of new management structures such as water users associations and river basin management and the consideration of environmental problems (e.g. deforestation), irrigation development showed a great measure of continuity in the postcolonial period.

Continuity is evident in the colonial irrigation works still in operation, in the extensive programme of rehabilitation and in the expansion of modern irrigation facilities where, to a certain extent, the "wheel of irrigation" has been "reinvented" from the point of view that engineers embarked on larger works of irrigation systems and thought was only given to smaller irrigation system works, management and to the participation of farmers when problems arose. There is still competition between engineers and civil servants, although engineers have consolidated the dominant position they once acquired. Recent discussions in Indonesia about large-scale versus small-scale irrigation engineering, about water management ("absolute" based on crop needs versus "proportional" based on the available water quantity), about the management of river basins and about environmental problems remind one of similar discussions that took place in the colonial period and the outcomes usually do not imply a completely different policy. Continuity was also reflected in the Solo Valley problems, still an area blighted because of what remained largely uncontrolled water conditions.

The main problem in the field of irrigation in Indonesia remains the relationship between the government's irrigation service activities and local farming. Striking the right balance between the state and the locality, modern technology and wet-rice agriculture and between engineers and farmers is the main challenge facing the present society, just as it was the main challenge in colonial and pre-colonial times. Consequently, knowledge about colonial irrigation technology is relevant, not just to the present but also to the future as far as Indonesia's entire irrigation network is concerned.

Discussion

The large technical system concept

Analyzing the development of modern irrigation in colonial Java in terms of the large technical system concept (see note 2), we can say that the basis for the island-wide modern irrigation system was laid in the 19th century; however, it did not really get going until the 20th century. With all its various aspects this social-technical complexity had then become thoroughly interwoven into the social context and numerous interest groups—engineers, entrepreneurs, user groups etc—ensured that it remained intact and developed further.[7]

Three phases in the making of the modern irrigation system in colonial Java and three types of engineers can be distinguished: the era when"pioneers" constructed headworks (1830-1885); the time when "trend-setting builders" completed the first entire projects (1885-1920) and the period when series of refined irrigation systems were constructed and managed by"perfectionist professionals" (1920-1945). However, other system builders were also involved, notably civil servants and agricultural experts. Consequently, types of coalitions rather than types of engineers controlled irrigation engineering in the subsequent system phases. This conclusion contradicts—or supplements—Hughes' limited view of actors as individual people but it supports his idea of central control exercised by engineers, civil servants and agriculturists who—in whatever coalition—were agents of the central colonial state. However, the influence of the engineers should not be underestimated. It would seem that as far as its cohesion and uniformity is concerned the modern irrigation system constructed in colonial Java must especially thank, on the one hand, the great role played by state influence in the creation and management of the system (though the nature of this influence differed from phase to phase) and, on the other hand, the tremendous contribution made on balance by engineers.

Each phase in the making of the modern irrigation system was characterised by certain problems which had to be solved in order to allow further developments in the establishment and growth of this system to take place. In the earliest period the marginal interest shown in irrigation works and the fact that the engineers were subservient to the civil servants were problems, as well as the small numbers of engineers and their lack of technical knowledge. These problems were solved through experience, a growing awareness among colonial administrators of the significance of the Javanese population's welfare as well as the powerful sugar lobby, and an improvement in the position and numbers of engineers. The second period was characterised by problems resulting from a lack of knowledge in several areas, including irrigation management and agricultural aspects, as well as problems related to rentability and to the training and availability of engineers. As a result the Rentability Commission was installed, engineers experimented with various types of management, agricultural experts were involved, engineering education was expanded and improved, and foreign engineers were attracted. The last period's problems revolved around the details and efficiency of works, also because of a lack of means, rice-farming expansion and political turmoil. The solutions were especially to be found in laboratory experiments and in perfecting management. All these problems were not only solved through technical but also through "political-administration" means and in this way the system that developed obtained and maintained a mixed character. These factors more or less match Hughes' notion of reverse salients as matters ("fronts") that lag behind in terms of development and which thus also hold back the progress of things as a whole, that is, with the possible exception of obstacles in the first phase when the system was still being set up. The Solo Valley works project, for instance, had to contend with the rentability question and with unresolved problems in the field of agriculture, management and technical matters.

Through the construction of this socio-technical modern irrigation system and through the actors involved the development of modern irrigation in Java became related to the formation of a modern colonial state in the Dutch East Indies. In the combined modernisation process of irrigation and the state the influence of irrigation and agricultural experts increased at the expense of that of civil servants. Consequently, in the course of its development, the modern irrigation system became less influenced by the political-administration environment. Conversely the emergence of technical irrigation experts and of the modern irrigation system made the unfolding of a technocratic colonial management situation possible. Irrigation engineering met the Ethical Policy modernisation mission which was to make progress by applying modern technology. Irrigation management structures related to works and areas became essential aspects of colonial state bureaucracy. To sum up, my data seems to support Hughes' suggestion that during the course of the creation of a large technical system the influence of the social environment on the system diminishes, while the influence of the system on the environment increases: in the beginning the modern irrigation system was mainly shaped by the colonial state, later on the system became an important modeller of politics. In other words: the "technical construction" of the Dutch East Indian state, i.e. colonial state construction based on modern irrigation technology or the modern irrigation system, became relatively more important over the course of time, while conversely the political construction of irrigation technology became relatively less significant.

An analysis in terms of the large technical system concept proves its strength in the case of the Solo Valley works. When progress on these works was halted the engineers feared serious consequences in terms of budget cuts and reorganisations but that did not happen. Even the preference for small works turned out to be temporary. The momentum mechanism can explain this. Around 1900 intervention in irrigation had led to the development of an island-wide irrigation network of structural works and institutions to which, apart from the public works engineers and their organisations (including the engineering college at Delft and the Royal Institute of Engineers) other actors had been commissioned, including civil servants and agricultural experts. This complexity had become firmly integrated into the social context and was substantial enough to perpetuate itself and had thus sufficient momentum to further develop. The Solo fiasco had little effect on all of this, though there were long-term effects (see below).

The system concept also helps us to understand better all the developments in postcolonial Indonesia. After the country had gained its independence, irrigation engineering remained top-down, large-scale and focussed on agricultural-technical management. The results of experiments carried out with small-scale irrigation facilities made and managed together with the local farmers were good but had little impact. Indonesian engineers, who from 1921 onwards, were being educated at the Polytechnic in Bandung, continued colonial style activities and their approach only changed slowly. Of course new developments also took place, like the creating of multipurpose works and the introducing of water users' associations but, nevertheless, the colonial socio-technical irrigation system just seemed to continue, also because the Indonesian state that grew from the colonial state did not in fact make a big difference. Here we can thus immediately draw conclusions as far as policy is concerned: socio-technical systems place clear limitations on dealings so that consequently, the manoeuvring capabilities of actors with regard to certain technology come to depend on the measure of "systemness" of the development of such technology and on their insight into the properties of such "systemness."[8]

Towards a sociological theory of technical development

In the development of modern irrigation in colonial Java three irrigation regimes could be distinguished: the semi-technical, the technical and the agricultural-technical irrigation regimes which were respectively responsible for the building of headworks, irrigation systems and agriculturally-based irrigation systems; these technological regimes developed beside the Javanese irrigation regime (see Ravesteijn, 2002). The three Dutch irrigation regimes fit in with the three phases in the building of the modern irrigation system in colonial Java and these regimes and system phases fit in with the three periods of colonial state formation in the Dutch East Indies. In fact, the different types of coalition that were identified within the system phases were the locus of a specific regime.

This analysis also throws new light on the transition from one system phase to another. According to Hughes this process is more or less steered by means of internal logic but through regime shifts social transformation is also involved. Elsewhere (2002) I demonstrate that the failed Solo Valley works, though the immediate consequences were not serious, did contribute, alongside of other changes in irrigation and political fields, to the shift from the technical to the technical-agricultural irrigation regime. Through this regime shift the Solo works also became involved—as one of the relevant factors—in the transition from the building to the perfecting phase in the development of the modern irrigation system in Java, thus influencing the way in which the system grew.

Important terms for helping one to come to grips with the development of modern irrigation in Java and technical development in general are: artefact, socio-technical system, actor, technological regime and ascribing significance. These terms could possibly be used in a conceptual and theoretical framework to describe and analyse technical development in general. First of all, though, a certain cohesion has to be created between these concepts. That could be done through a sociological perspective. To start off with, the terms referred to (except "artefact") correlate with differentiations that are familiar in the social sciences, such as the actor versus the factor or system aspects of social life and the objective/structural versus the subjective / cultural aspects of society. In the second place, within the social sciences a theory is being formed which is directed at reconciling the mentioned and other opposing notions in which the opposing actor-system is seen as the most fundamental one. Here it is the structuration theory of Giddens that is particularly promising. Giddens believes that actors structure their actions on the basis of rules and resources which lie embedded in the social systems (interaction patterns, institutions included) and that through acting thus these systems are also perpetuated (Giddens, 1984; see also Jacobs, 1993). This view can help to, for instance, enlighten our vision of the momentum mechanism within a large technical system. Despite the fact that Hughes emphasises here the involvement of actors, momentum appears to be seen, in his work, as operating as an independent developing force. Giddens helps us to understand how such a mechanism works. On the one hand, actors continually reproduce in their dealings the conditions that will ensure that the socio-technical system is perpetuated while, on the other hand, the behaviour is conditioned by this same system. We might thus see momentum in terms of actors which, as it were, hold each other prisoner. The same may be applied to technological regimes: actors abide by rules, in these cases design rules and in so doing they reproduce those same rules. It would seem that consolidating such insight in the light of theory formation in relation to technical development will be a particularly worthwhile exercise.

Conclusion

The large technical system concept would appear to be a useful analysis instrument in connection with the development of modern irrigation in colonial Java, both for scientific and policy reasons. Not all aspects of Hughes' concept could, however, be applied as has been demonstrated in conjunction with his actor concept. Coalitions of engineers, civil servants and, later on, agriculturalists dominated the irrigation system development. The introduction of the technological regime concept took us still further away from Hughes' individual actor concept, in the sense that with the development of modern irrigation the system was governed—through the relevant coalitions of actors—by a series of subsequent technological regimes. It has been suggested that the large technical system concept goes together well with other technical development concepts and also that a sociological perspective, especially Giddens' structuration theory, might help in linking them, thus stimulating the formation of a coherent conceptual and theoretical framework with regard to the (social) development of technology.

Notes

1. This article is based on a paper presented at the 5th International Conference on Technology, Policy and Innovation (Ravesteijn, 2001). I thank the participants of the workshop on Water Management Infrastructures for their stimulating comments.
2. The large technical system concept is used as an analytical instrument to help us understand reality. I do not consider a large technical system or in this case the large modern irrigation system in colonial Java, to be phenomena that really exist or existed.
3. Local colonial administration was in the hands of the Civil Service. Local colonial administrators will thus be referred to as "civil servants."
4. Some years later, the Brigade was integrated into the Technical Section.
5. The alternative programme for the Solo Valley focused on reinforcing dykes and excavating small reservoirs; later some large reservoirs were also built.
6. This article focuses on engineers who were occupied with irrigation: irrigation engineers. Other types of engineers, such as harbour and railway engineers, also played a part in the colonial state formation process. The research I am currently conducting into the history and the achievements of the Public Works Department in the Dutch East Indies will clarify this part.
7. The modern irrigation system in colonial Java was something that developed alongside of Javanese irrigation and which gradually superseded it, at least in part. Borne by local farmers and their communities and enriched with elements of the modern system (like, for instance, permanent works) the traditional facilities have managed to hold their own even up to the present day! I shall not discuss the viability of Javanese irrigation, nor shall I go into the interesting matter of the interaction between modern and Javanese irrigation engineering.
8. Follow-up research into the development of modern irrigation in colonial Java at Delft University of technology concentrates on the Dutch irrigation tradition in comparison with other colonial irrigation traditions, e.g. in British India. This research might produce data that could be relevant for discussion in terms of "technological style," another of Hughes' notions related to his system concept.

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