COLLABORATIVE RESEARCH TO GET A BETTER UNDERSTANDING OF THE COMPLEX WATER MANAGEMENT SYSTEM IN THE NICKERIE DISTRICT SURINAM

H.P. RITZEMA[1] AND S. NAIPAL[2]

[1] Assistant Professor, Wageningen University, Wageningen University and Research Centre, P.O. Box 47, 6700 AA Wageningen, the Netherlands, Tel: +31 (0)317 48 66 07, Fax: + 31 (0)317 41 90 00, email: henk.ritzema@wur.nl
[2] Anton de Kom University, Paramaribo, Surinam.

ABSTRACT

In the Nickerie District in West Surinam, rice is cultivated in 22 polders (about 15,000 ha). The district has an average rainfall of around 1800 mm; irrigation is needed to grow two rice crops per year. The main source of the irrigation water is the Nanni Swamp; however, in dry periods additional irrigation water is pumped from the Corantijn River and transported through the 67 km long Corantijn Canal. Irrigation is partly by gravity and partly by pumping. Pumping is needed at the intake of the Corantijn Canal, for some polders in the western part of the district and in some polders to pump water to the fields. Drainage is by gravity using the tide in the Nickerie and Corantijn Rivers. The polders were reclaimed over a period of more than hundred years: this has resulted in a complex system without many possibilities to control both the irrigation and drainage flows. A collaborative research programme was initiated to get a better understanding of the functioning of the irrigation and drainage systems and to formulate, in close cooperation with the stakeholders improvement options. The research programme is conducted by staff of the Water Board, in close cooperation with students of Wageningen University. The complex organizational infrastructure was mapped and research was initiated to get a better understanding the water flows: the total volumes of water supplied to the polders, the water management within a polder and the field application efficiency. Results of the research were used to develop a water management module for a train-the-trainers course for local stakeholders. The collaborative research approach proved to be a useful tool to increase the knowledge of the functioning of the water management system. In this paper the preliminary results of the research programme are presented.

Key words: tidal areas; sustainable development; irrigation, drainage, rice cultivation, collaborative research, capacity building.

INTRODUCTION

The Nickerie district, on the border of Guyana in north-west Surinam (5^{o} 56’ N, 57^{o} 01’W), is the rice bowl of Surinam (Figure 1). With a population of about 35,000, rice is cultivated in 22 polders (about 15,000 ha). The majority of the farmers are smallholders with an average plot size of 3.1 ha. The soils are mainly marine clays (clay percentage around 80%) with low hydraulic conductivity (< 5 mm/d) (Wildschut, 1999). The climate is humid with an average annual rainfall of around 1800 mm and two rainy seasons: a long rainy season lasting from April to August and a shorter one from November to February. During both seasons rice is grown. Average yield is around 4.8 t/ha, but in the large-scale commercial polders yields are lower (Graanoogst, 2007).

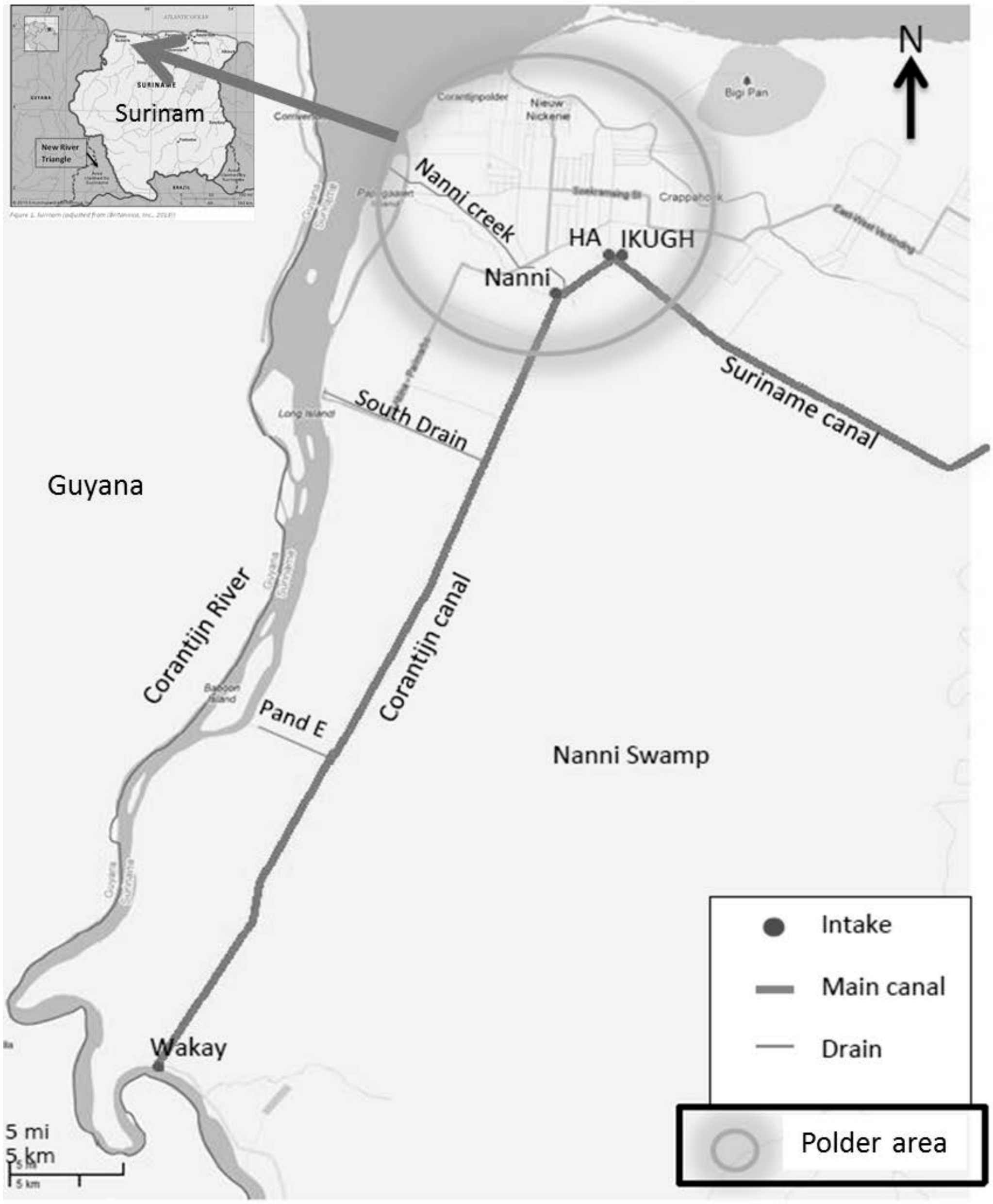

Figure 1 Nickerie district: 22 polders supplied with irrigation water from the Nanni swamp and the Corantijn River through the Corantijn Canal (after Henstra, 2013).

Rainfall is abundant in the long rainy season, the problem is the disposal of the excess rainfall. Disposal is complicated because of the low elevation and because both the Nickerie and Corantijn River are under the influence of the daily tide. Peak irrigation requirements in the short rainy seasons are high, especially in the period October to January when rainfall is not sufficient and irrigation is needed for land preparation and sowing. The design of the irrigation system is based on a peak water requirement of 1.75 l/s/ha, needed for land preparation and sowing in November.

The source of the irrigation water is the Nanni Swamp, a Nature Reserve of about 54,000 ha and famous for its populations of spectacled caiman (*Caiman crocodilus*) and manatees (*Trichechus manatus*) (Baal, 2005). In dry period, when the Nanni swamp cannot provide sufficient water, additional irrigation water is pumped from the Corantijn River at

Wakay and transported through the 67 km long Corantijn Canal (Naipal, 2005). The cost of pumping is high and often no diesel is available to run the pumps.

The polders were reclaimed over a period of more than hundred years and consequently the irrigation and drainage systems were enlarged over time. This has resulted in a complex water management system without much options to control both the irrigation and drainage flows (Mertens, 2008). The improper functioning of the irrigation and drainage infrastructure, resulting from lack of maintenance on canals and civil engineering works, damaged and uncompleted infrastructural works, is one of the main causes of inefficient water use. Not only the physical infrastructure is complex and outdated, but also the institutional set-up is complex. There are many government organizations involved in the operation and maintenance (Grijpstra, 2008a).

The rice sector has become less competitive as the knowledge on recent developments in cultivation practices and land & water management is poor; the infrastructure has been neglected and vocational education facilities in the Nickerie district are lacking. In 2010, the project "*VERRIJST! – Strengthening the rice sector in Suriname*" was initiated. The main objectives of the project were to contribute to the improvement of the Surinam rice sector by supporting the Surinam institutions ADRON (Rice Research Institute), the Water Board "Overliggend Waterschap Multipurpose Corantijn project" (OW-MCP) and the Anton de Kom University (AdeKUS) to enhance of the current level of knowledge; to develop recommendations how to improve the institutional settings; to strengthen the research activities and to introduce new methods for mid-career education. Backstopping was provided by Wageningen University and Research Centre (WUR). In the framework of this project several research activities were initiated, among others, a collaborative research programme to get a better understanding of the functioning of the irrigation and drainage systems. The research programme was conducted by students of Wageningen University under supervision of staff of OW-MCP and guidance of AdeKUS and WU. In this paper some preliminary results are presented.

ORGANIZATION OF THE WATER MANAGEMENT

The first step was to make an inventory of the responsibilities of the organizations involved in the water management in the Nickerie polders, i.e. (Graanoogst, 2007):

- Water Board "Overliggend Waterschap Multipurpose Corantijn project" (OW-MCP)
- Ministry of Public Works (OW)
- Ministry of Agriculture and Fisheries (LVV)
- Ministry of Rural Development (RO)
- Districts Commissioner (DC)
- Internal Water Boards (IWB) of the individual polders, 6 out of 12 still have to be established.

In 2007, OW-MCP was established to coordinate the overall water management in all polders in the Nickerie district. OW-MCP is under the restriction of the Ministry of RO. Most tasks and responsibilities, however, have not yet handed over to OW-MCP (Table 1). To allocate the tasks between OW-MCP and the IWBs a Steering Committee was established under the Chairmanship of the District Commissioner. Till now for only one IWB a charter has drafted in which the rules for operation and maintenance have been formulated. This charter, however, has not yet got legal status (Grijpstra, 2008b). For all other polders, rehabilitation projects are in progress or planned before the responsibilities are handed over to the IWBs.

Table 1 Organizations involved in the water management in the Nickerie district and their responsibilities

Organization	Duties & responsibilities
Water Board OW-MCP	O&M Wakay pumping station, Corantijn Canal and MCP polder
Ministry of Public Works	O&M main irrigation – and drainage canals, including the inlet works at Nanni and HA, Clara pumping station and all drainage sluices
Ministry of Agriculture and Fisheries	Operational management of the Wakay and Clara pumping stations, the distribution of water between the polders and O&M of IKUGH inlet and some main drains
Ministry of Rural Development	O&M of all other works
Districts Commissioner	Water management inside the polders
Internal Water Boards	Chairman of the Steering Committee Water Boards

Interviews with staff members of these organizations were conducted to collect data on the existing water management system, including an assessment of the existing problems and proposed improvement options (Pieters, 2011). Based on these interviews and existing literature a first model schematization of the system was developed (Figure 2). During a presentation to representatives of the above mentioned organizations this first schematization was discussed and an inventory was made of the perceptions of the involved stakeholders of the benefits and limitations of the proposed research activities.

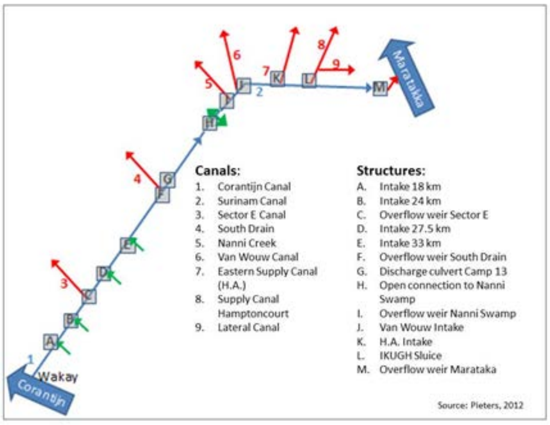

Figure 2 Schematization of the main supply system.

The first schematization was favourably received and it was decided to collect additional information on water levels and discharges with the aim to further develop the existing monitoring programme. This existing monitoring programme was set up by OW-MCP, in cooperation with the Anton de Kom University; automatic water level recorders were installed at strategic locations in the irrigation canal network. Step-by-step the monitoring network is extended by installing staff gauges and more automatic water level recorders. The ultimate aim of this monitoring system is to use it to regulate the required water flows to the individual polders. At present, however, the number of regulation structures is too limited or their operational status is too poor, to manage the system properly. The same applies for the water management infrastructure within the individual polders, including the water management of each plot. In additional to the regular monitoring programme a number of detailed studies were initiated to get a better understanding of the individual components of the water management systems. The results of these studies are presented in the following sections.

OPTIMIZING FUEL CONSUMPTION OF WAKAY PUMPING STATION

Wakay pumping station, 140 km upstream of the river mouth, is used to pump irrigation water from the Corantijn River intake in periods of water shortage. Wakay pumping station has four centrifugal pumps each with a capacity of 7.5 m^3/s. The diesel driven pumps were rehabilitated and overhauled in 2012. Operation of the pumping station is expensive because of the huge diesel consumption. A study was conducted to investigate whether the existing pumping regime can be changed to reduce fuel consumption. The water level in the Corantijn Canal is fairly constant, but the outside water level in the Corantijn River fluctuates considerable depending on the tide and river discharge. The fuel consumption depends on the pumping head and the engine speed. For an engine speed of 600, 655 and 710 rpm (maximum) the fuel consumption was measured and was respectively 62, 79, and 102 l/hr (Donkers, 2013). Flow velocities were measured with an Ott-current meter and the corresponding discharges were calculated with the mid-section method. For the three engine speeds the discharge–head relations were calibrated:

- $Q_{710} = 14.40 \times (1 + H_s)^{-0.415}$ (n = 35 and r^2=0.63)
- $Q_{655} = 17.77 \times (1 + H_s)^{-0.668}$ (n = 12 and r^2=0.95)
- $Q_{600} = 15.69 \times (1 + H_s)^{-0.730}$ (n = 12 and r^2=0.78)

in which

Q_i	discharge in m^3/s
i	engine speed in rpm
H_s	static head in m
n	number of measurements
r	correlation coefficient.

These discharge-head relations were in good agreement with the theoretical relations provided by the supplier of the pumps: the difference varied between -2.8 and 4.3%. As the fuel consumption depends on the static head and the engine speed, several scenarios were developed to illustrate that variation in the number of pumps and variation in engine speed have a considerable influence on the fuel consumption. The scenarios were based on assumed fluctuating outside water level (Figure 3): it was assumed that if the outside water level dropped so much that the head became bigger than 3.5 m pumping was stopped (scenario long) and when the outside water level was so high that the head became smaller than 2 m an extra pump was started.

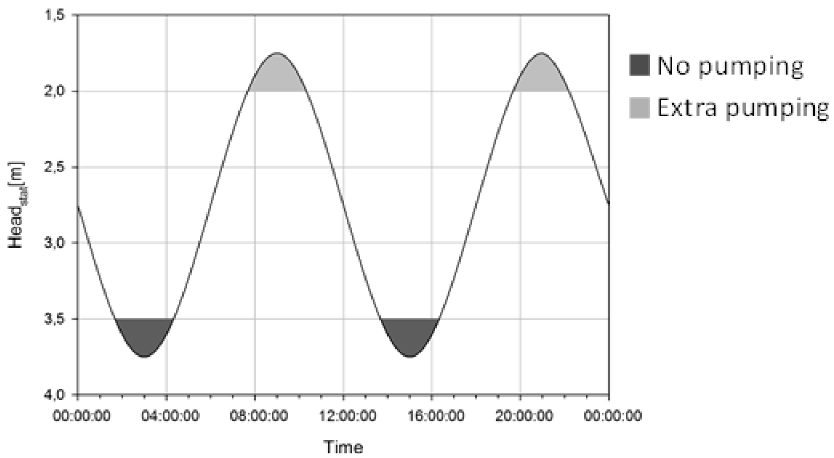

Figure 3 Pumping scenarios: No pumping if Head > 3.5m and extra pumping if Head < 2.0 m

The results show that for a required, pre-set, volume of irrigation water, instead of pumping non-stop with two pumps at 710 rpm for 24 hours (Standard scenario in Table 2), the use of three or four pumps at different speeds and during different periods (Scenario I, II, III & IV in Table 2) can results in considerable savings in the fuel consumption. During the coming dry season these scenarios will be further developed and tested.

Table 2 Fuel consumption and efficiencies for different pumping scenarios.

Scenario	Volume water [m³]	Operating hours [h]	Fuel consumption [L]	Efficiency [%]
Standard: 2 pumps at 710 rpm for 24 hours	1,454,949	48	4,896	100
I: 2 pumps long[a]; 1 short[b] at 710 rpm	1,348,872	43	4,386	104
II: 2 pumps long; 2 short at 710 rpm	1,517,225	48	4,896	104
III: 3 pumps long; 1 short at 655 rpm	1,762,362	62	4,898	121
IV: 3 pumps long; 1 short at 600 rpm	1,444,063	62	3,844	126

[a] Long: pump running as long as head < 3.5 m
[b] Short: only pumping when head < 2.0 m

IN- AND OUTFLOW IN THE CORANTIJN CANAL

In 1985, the Corantijn Canal was constructed (Naipal, 2005). The 67 km long canal is used to transport water from the Wakay pumping station to the Nanni. The canal is so long, because during periods of low river flows in combination with a spring tide, the salt water wedge can reaches 75 km upstream from the river mouth (Mertens, 2008). It is estimated that saline water (chloride % of 300 mg/l or higher) reaches the Wakay pumping station once in 5 years if the pumping station is in full operation. For reasons not known, the last part of the canal was never completed and consequently the water is first disposed into the Nanni Swamp from where it is distributed to the polders through three intakes: Nanni Intake, HA Intake and IKUGH (Figure 1). The Corantijn Canal has a top width of about 60m, a depth of about 3.5m and the maximum design discharge is about 50 m3/s. The canal has banks on both sites: the bank on the right-hand side (looking downstream) separates the canal from the Nanni swamp and the bank on the left-hand side separates the canal from the newly developed MCP polders. There a several inlet- and outlet structures to dispose excess water from the Nanni swamp (the canal forms a barrier between the swamp and the river), to drain excess water to the Corantijn River and to irrigate the MCP polders. Most structures can be regulated, but there are also several ones that cannot be controlled, thus a present the canal is a black-box and it is impossible to monitor the volume of water passing through the canal.

A research was initiated to investigate whether it is useful and feasible to use a simulation model to get a better understanding of the functioning of the canal (Nienhuis, 2013). Duflow, a one-dimensional, non-steady state model for water movement and water quality (Duflow Modelling Studio, 2010), was selected. Duflow was originally developed to simulate the water movement (both quantitatively and qualitatively) in estuaries in the south-west of the Netherlands. A scenario manager allows to calculate various scenarios and to compare the results. One of the reasons for selecting Duflow was that the model was successfully used under similar circumstances, i.e. in a collaborative research study to develop conceptual designs to improve the functioning of the water management system in polders in the Red River Delta in Vietnam (Ritzema et al., 2011). Field trips were made an inventory of the dimensions and operational status of the existing canal structures and to do some additional flow measurements (Figure 4). The data was used to improve the schematization of the Corantijn Canal and to formulate recommendations for further modelling studies and monitoring programmes.

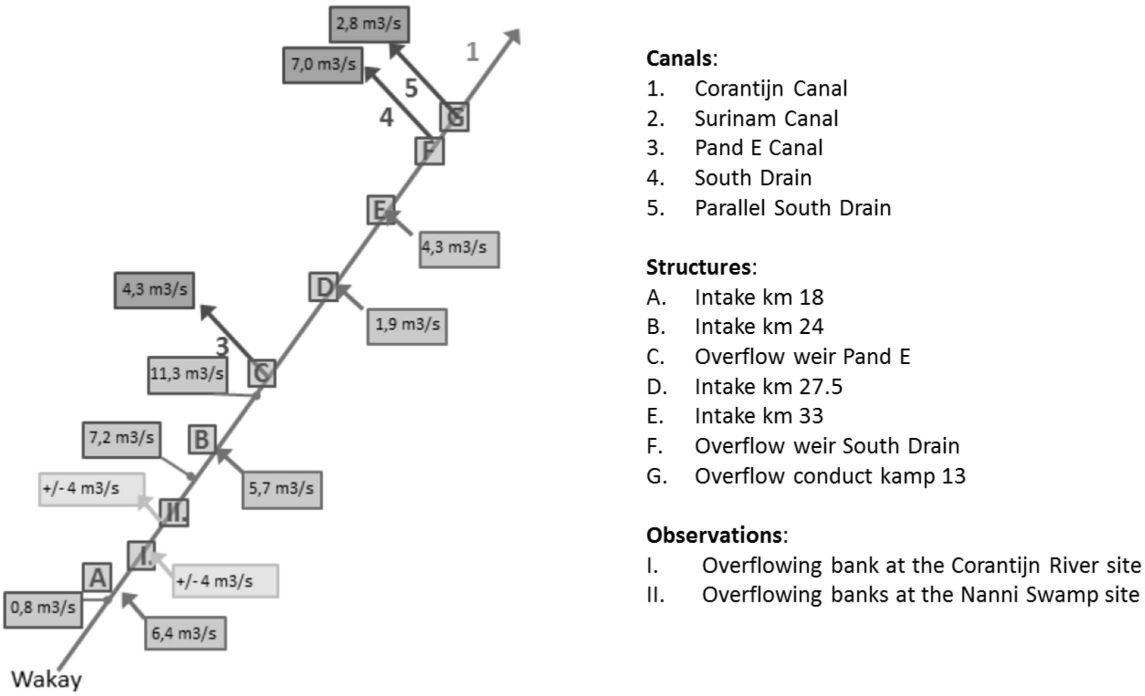

Figure 4 Results of a discharge measuring programme: in- and outflow in the Corantijn Canal on 27-03-2011 (Nienhuis, 2011)

CALIBRATION OF THE NANNI INTAKE

To get a better understanding of the total volume of water supplied to the polders, head-discharge relations will be established for the Nanni, HA and IKUGH intakes. At the end of the 1970's, these intakes were already calibrated, but the calibration of the Nanni Intake was done again because since the last calibration the dimensions of the canals and the structure itself may have changed. For the calibration, velocities were measured with an Ott-current meter and translated into discharges using the mid-section and the mean-section velocity-area methods (Henstra 2013). In total 48 discharge measurements with gate openings of 0.5, 1.0, 1.5, 2.0 and 2.5 m (free water surface) were done. The mean-section method was adjusted as instead of the average velocities in the two adjacent verticals, the velocities measured in only the right vertical were used as input. The discharge coefficient (C_d) obtained with the mid-section method values were in the range 0.65 - 0.84 for 1 gate and 0.66 - 0.77 for 2 gates. The mean-section method resulted in C_d-values that were 0.03 lower, this correspond to a difference in discharge of 4%. The mid-section method discharges are assumed to correspond best to reality, since the cross sectional area used in this calculation covers the real cross-sectional area better than the area used for the mean-section method. The difference between upstream and downstream water levels varied between 0.04 - 0.48m for 1 gate and 0.11 - 0.34m for 2 gates. The found C_d-values are considerable higher than the values found in previous calibrations, but they are probably more reliable as the results of these previous calibrations were doubtful (Kselik, 2013, personal communication) and because more than double the amount of discharge measurements were done: 48 compared to 22 during the previous calibration. In the coming rainy season the same method will be used to calibrate the HA and IKUGH intakes.

For the water division within the polder area, inlets along the Van Wouw canal and HA canal were mapped, canal profiles were established, including canal bed levels and water levels. Additional surveys are needed to map the inlets to the individual polders.

IRRIGATION PRACTICES IN THE VAN DRIMMELEN POLDER

To improve the monitoring network staff gauges are installed in all individual polders. A pilot study was conducted in the Van Drimmelen Polder (850 ha), one of the older polders in the western part of the Nickerie District. The objectives of the study were to determine the best location for the staff gauges and to establish the relation between the water level at the monitoring location(s) and the corresponding part of the polder that can be irrigated by gravity for a given water level in the supply canal(s) (Hidding, 2013). In the two main irrigation canals, i.e. the East and West Van Drimmelen canals, staff gauges were installed, longitudinal profiles were measured and at all field intakes the following data was collected: water level in the canal, invert level and diameter of the intake culvert, ground- and water levels in the field. Based on the results alternative locations for the staff gauges were proposed and for each staff gauge the relation between the water level at the monitoring location and the corresponding part of the polder that can be irrigated by gravity was established (Table 3). The results will be used to optimize the irrigation water management in the individual polders.

Table 3 Percentage of the area that can be irrigation by gravity by a given water level at the Staff Gauge

East Canal (25 intakes)		West Canal (20 intakes)	
Level (m+ NSP)	Irrigated Area (%)	Level (m+ NSP)	Irrigated Area (%)
1.49	100	1.32	100
1.44	99	1.27	92
1.39	95	1.22	85
1.34	87	1.17	66
1.29	72	1.12	46
1.24	51	1.07	32
1.19	34		

EFFECT OF LAND LEVELLING ON THE WATER BALANCE IN RICE FIELDS

To facilitate mechanical land preparation and harvest, the rice fields are large: in the older polders 50 to 100 m wide and 500 to 700 m long and in the more recently reclaimed polders the width can be as much as 300 m. The fields are poorly levelled resulting in pests and diseases, especially the occurrence of red/weedy rice in the higher parts of the plots and poor germination in the lower, wetter, parts. Research done by ADRON shows 1% red rice results in a yield reduction of 6% (ADRON, 2008). A study was conducted to established the water balance in rice fields and to study the effect of land levelling (Witmer, 2012). Rice fields in four representative polders were selected, i.e. in:

- Hamptoncourt polder, with an average plot size of 2.3 ha this polder is representative for the small-holder polders in the eastern part of the Nickerie district. These low-lying polders are irrigated by gravity irrigation from the Nanni inlet.

- Clara polder, with an average plot size of 3.4 ha this polder is representative for a small-holder polder in the western part of the district. These polders are relatively high, thus irrigation water is supplied through the Clara pumping station.
- Euro-noord polder, also in the western part of the district, but cultivated by medium-size farmers (average plot size 6.5 ha) and irrigated by gravity.
- Nanni-oost polder (formerly Cooperation West Surinam), representative for the large commercial polders mostly cultivated by entrepreneurs (average plot size 11 ha) and pumped irrigation.

In one polder, the Nanni-oost polder, a field was levelled with a laser-controlled scraper on 16 November 2010. All selected fields were surveyed and automatic water level recorders (WLR) and staff gauges were installed. Furthermore the farmers were asked to record their operation land & water management practices. The fields were visited twice per week to interview the farmers and to check the WLRs. At the end of the season, the farmers were asked to fill in the ADRON questionnaire. Since 2002, this standardized questionnaire is used to collect information on rice production of smallholders by means of random sample of about 5% of the rice fields (Grijpstra and Soerdjan, 2008).

The topographic surveys were used to make detailed maps of the micro-relief of the rice fields that were not levelled (Figure 5). Differences in elevation up to 0.35 m were observed, resulting in considerable variation in the depth of the standing water layer. To quantify this variation a cumulative distribution of the depth related to the lowest point in the fields was made (Figure 6). If we assumed an optimum depth of the water layer is in the range 0.075 - 0.225 m, we can concluded that in the levelled field in the Nanni-oost polder (Batali) almost 87% of the field was within this range. In other words, only 13% of the field was too wet or too dry. In the non-levelled fields the variation was much larger: more than 25% of the fields were either too wet or too dry. These sub-optimum water layers resulted in poor yields: in the parts that were too high yield reduction was caused by the occurrence of red rice and in the parts that are too low poor germination occurred.

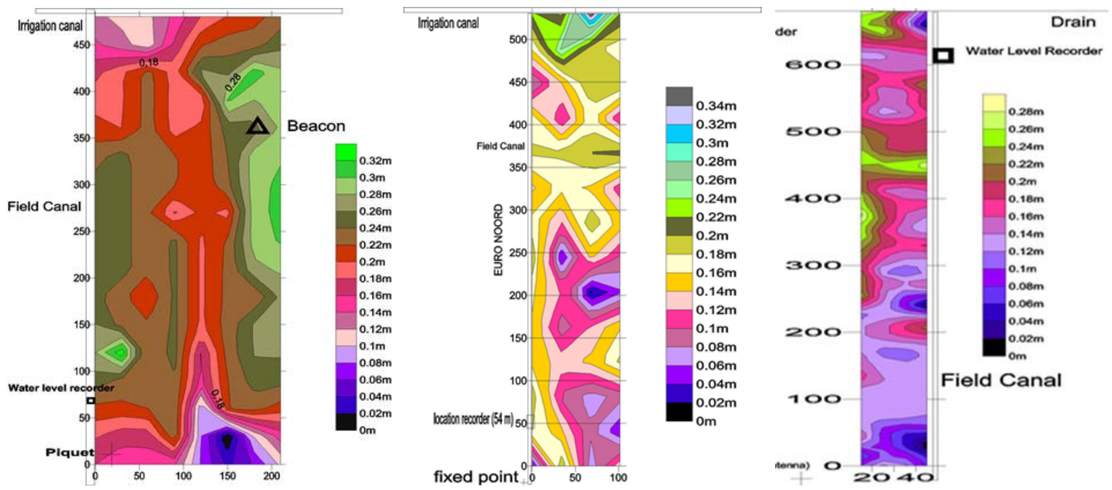

Figure 5 *Micro-relief of the un-levelled rice fields in the Nanni-oost ploder (left), Euro-noord polder (centre) and Clara polder (right) (Witmer, 2012).*

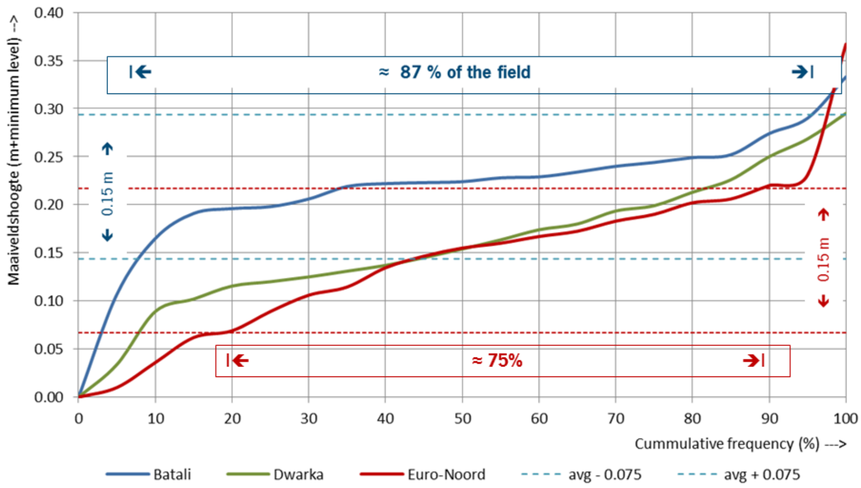

Figure 6 *Cumulative distribution of the depth of the standing water layer in the three selected fields.*

The depth of the actual water layer varied because of the combination of rainfall, irrigation, crop evaporation and drainage (Figure 7). Rainfall data from ADRON meteorological station was used: the rainfall during the observed period (November-March 2010/2011) was average, but the distribution over the growing season was not: December and January were well below average and February and March well above average (Figure 8). Crop evapotanspiration was calculated with CROPWAT (FAO, 2010). Analysis the data indicates that large amounts of irrigation water were applied in the first three months and much excess rainfall had to be drained off in the second part of the growing season. Consequently, water efficiencies were low. Based on the variation of the depth of the standing water the water balance in the rice fields was estimated. Preliminary results indicate that the levelled field (Batali) did not result in water savings but, because of the more uniform layer of standing water, higher yields were observed: and increase from 1.8 to 2.6 t/ha. These yields are still well below average, a reason can be that the large commercial enterprises, like Batali, do not tailor-made their water management and agronomic practices to a specific field but they treat all their fields in the same way to reduce operational costs.

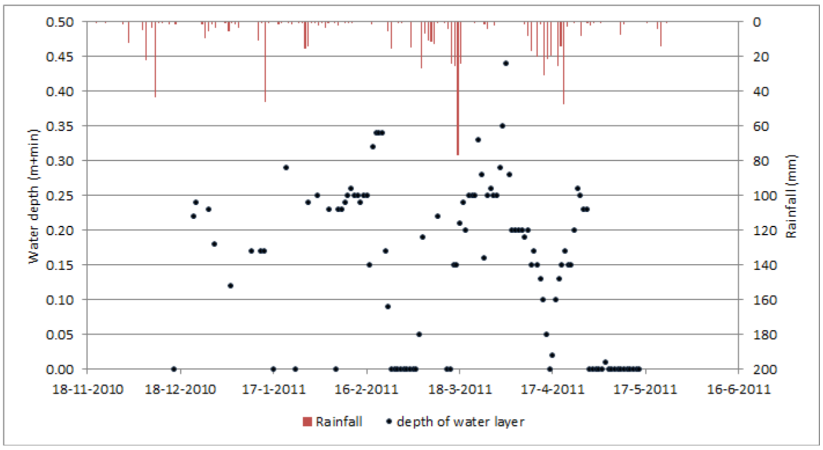

Figure 7 *The depth of the water layer fluctuates under the influence of irrigation, rainfall, crop evaporation and drainage: example from a rice field in the Nanni-oost polder (Witmer, 2012).*

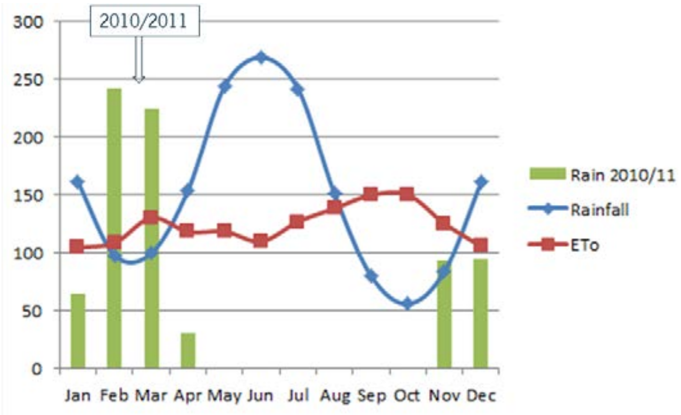

Figure 8 Rainfall during the short rainy period in 2010/2011 (November-March) was well above average.

To reduce the variation of the depth of the standing water two methods are used: (i) construction of compartments and (ii) levelling. Compartments are used in fields were the elevation changes gradually from one side to the other. An example is the field in the Clara polder (Figure 9). Compartments makes water management more complicated because the compartments do not have direct access to the irrigation canal (at the top end of the field) or the drain (at the bottom end of the field) and consequently the water has to let in/out from compartment to compartment.

Levelling is either done by scrapers or hydraulic excavators followed by puddling with a beam (Figure 10). Land preparation by puddling requires large volumes of water. The cost of levelling in Nickerie is estimated to be in the range € 450 - 575 per hectare, depending on the method (personal communication Bert Vermeulen, 2012).

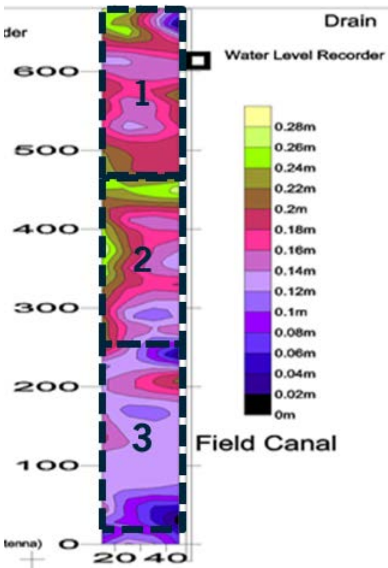

Figure 9 Compartments are used to separate the higher and lower parts of a field: example of a field in the Clara polder.

Figure 10 Levelling by scraper (left), hydraulic excavator (centre) both followed by puddling (right).

TRAIN-THE-TRAINERS COURSE

The results of these studies were used to develop a water management module for a train-the-trainers course for mid-career professionals working in the rice sector, i.e. trainers, extension workers, foremen of the large commercial enterprises, etc. The objective of the course is to give these professionals the tools and capabilities to disseminate their knowledge to other (small-holder) rice producers and production workers. The subjects cover the complete rice production cycle, i.e. seed production, land preparation, crop and water management, mechanization, organization and marketing. The course is based on the following didactic principles (Verrijst, 2011):

- Constructive learning: starting point is the knowledge and experiences of the participants.
- Social learning: leaning from each other, i.e. participants learn from each other as well as from teachers and vice versa.
- Practical oriented learning: the starting point is the actual situation in the rice sector in Nickerie.
- Participatory learning: learning by doing, both in the classroom and in the field.
- Competence-oriented learning: an integrated approach focussing on all aspects of rice production and the capability to disseminate the obtained knowledge.

In November 2012, a one-week training was conducted for 18 professional working in the rice sector in Surinam.

CONCLUSIONS

The water management in the rice polders in the Nickerie District, north-west Surinam, is complicated because the water management infrastructure is fragmented, has been extended over time and lacks appropriate regulating structures. On top of this the organizational set-up is also fragmented and complex. A collaborative research programme was initiated to get a better understanding of the functioning of the water management system.

At system level, the main components, i.e. the Wakay pumping station, the Corantijn Canal and the Nanni intake were investigated. At the Wakay pumping station, discharge – head relations were established and simulations were done to optimize the operation of the pumps. Considerable savings in fuel consumption can be achieved if the pumping regime is matched to the tidal fluctuation in the Corantijn River: more pumping during high tide and less or no pumping during low tide. The Corantijn Canal was mapped and an inventory was made of all inlet and outlets along the canal. Water levels and discharges were measured and a simulation model was used to assess its performance. Operation seems to be problematic because at many places there is (un-)controlled in- and outflow of water. The Nanni intake was also calibrated and the discharge coefficient was calculated for various gate openings. A start was made to map the in- and outflow to the van der Wouw Canal, the main supply canal to the polders in the western part of the district.

At polder level, staff gauges were installed in the main irrigation canals to assess the required water levels needed to irrigate the fields by gravity.

At field level, the effect of land levelling was studied in farmers' fields in four representative polders. The results show that variation in micro-relief in the paddy fields is quite pronounced resulting in a variation in the depth of the standing water up to 0.35m. Subsequently more than 25% of an average field is either too wet or too dry resulting in yield reduction. In a levelled field, water savings were negligible but, due to a more uniform layer of standing water, a yield increase from 1.8 to 2.6 t/ha was observed.

The results were used to develop a water management module for a train-the trainers course. In November 2012, a one-week course was organised for 18 professional working in the rice sector in Surinam. Although, the VERRIJST-project has formally ended, research and monitoring activities are continuing on an ad hoc basis with students from Wageningen University doing their Bachelor or Master research. This type of collaborative research is slow and rather difficult to plan but low-cost and the results are encouraging.

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