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Irrigation with wastewater in Andhra Pradesh, India, a water balance evaluation along Peerzadiguda canal

Bevattning med avloppsvatten i Andhra Pradesh, Indien, en vattenbalansutvärdering längs Peerzadiguda kanal

Julia Hytteborn

ABSTRACT

Irrigation with wastewater in Andhra Pradesh, India,
a water balance evaluation along Peerzadiguda canal

Julia Hytteborn

This thesis focuses on the amounts of wastewater irrigating the land along Peerzadiguda irrigation canal in Andhra Pradesh, India. The Peerzadiguda irrigation canal is located north of Musi river downstream Hyderabad, the capital of the Indian state Andhra Pradesh.

In regions where the freshwater resources are scarce, wastewater can become a valuable resource in irrigated agriculture. This is the case along Musi river that contains Hyderabad's untreated and partly treated wastewater. The study area is the land around Peerzadiguda irrigation canal that is irrigated with water from the canal. The flow in the irrigation canal was measured, water losses were estimated and the irrigation amount over the whole study area was quantified. In a Geographical Information System (GIS) the size of the study area was measured and a few maps produced. The actual irrigation on a few farms was also calculated from measurements of the irrigation canals on the farms and from data from interviews with the farmers. The irrigation of the fields was preformed with basin irrigation. The values of the actual irrigation was used in water balance calculations of the root zone for the crops growing in the area: vegetable, paragrass and paddy rice. An optimal irrigation scheme was then calculated.

The irrigation over the whole study area was calculated to 41 mm per day. The actual irrigation measured on the fields was lower but the water balance calculations showed that the irrigation leads to water losses, in some cases large losses. With the optimal irrigation amount used in the water balance the water losses were reduced. The use of basin irrigation and the large amount of irrigation water leads to water losses and larger amounts of pathogenic organisms is added to the soil.

Keyword:
Wastewater, Irrigation, Water balance, India, Andhra Pradesh, Hyderabad, Musi river.

Department of Soil Science, Section of Agricultural Hydrotechniques
Swedish University of Agricultural Sciences
Box 7014
SE-750 07 Uppsala
Sweden

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REFERAT

Bevattning med avloppsvatten i Andhra Pradesh, Indien,
en vattenbalansutvärdering längs Peerzadiguda kanal

Julia Hytteborn

Studien behandlar bevattningsgivornas storlek av avloppsvatten längs Peerzadiguda bevattningskanal i Andhra Pradesh, Indien. Peerzadiguda bevattningskanal är belägen norr om Musifloden nedströms Hyderabad som är huvudstad i delstaten Andhra Pradesh i Indien.

I regioner med knappa vattenresurser kan avloppsvatten vara en värdefull resurs i jordbruk som kräver bevattning. Så är fallet längs Musifloden som innehåller Hyderabads orenade och delvis renade avloppsvatten. Studieområdet är den del av marken runt Peerzadiguda bevattningskanal som är bevattnad av densamma. Flödet i kanalen mättes, vattenförlusterna uppskattades och bevattningen över hela området beräknades. I ett geografiskt informationssystem (GIS) beräknades arean på studieområdet och några kartor tillverkades. För några fält i området beräknades också den aktuella bevattningen med mätningar av flödet i bevattningskanalerna på fälten och med hjälp av intervjuer med lantbrukarna. Bevattningen av fälten utfördes med bassängbevattning. Den aktuella bevattningen användes i vattenbalans-beräkningar för rotzonen för de grödor som växte i området: grönsaker, fodergräs och ris. En optimal bevattning beräknades.

Bevattningen över hela studieområdet beräknades till 41 mm per dag. Den aktuella bevattningen som uppmättes på fälten var mindre men de utförda vattenbalans-beräkningarna visade att vattenförluster förekom, i vissa fall stora sådana. När den optimal bevattning användes i beräkningarna minskade förlusterna. Stora vattengivor och användningen av bassänbevattning och leder till vattenförluster och att stora mängder patogener tillförs jorden.

Nykelord:
Bevattning, avloppsvatten, vattenbalans, Indien, Andhra Pradesh, Hyderabad, Musifloden.

Institutionen för Markvetenskap, Avdelningen för Hydroteknik
Sveriges Lantbruksuniversitet
Box 7014
750 07 Uppsala
Sweden

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PREFACE AND ACKNOWLEDGEMENTS

This study is a graduation thesis at the Aquatic and Environmental Engineering Program at Uppsala University, Sweden. The thesis was performed at the Department of Soil Sciences, Division of Hydrotechniques at the Swedish University of Agricultural Sciences (SLU) with the fieldwork located in India at the International Water Management Institute (IWMI), south Asia regional office in Patancheru. The thesis was carried out within the framework of the Minor Field Studies (MFS) Scholarship Program, which is funded by the Swedish International Development Cooperation Agency (Sida).

My supervisors have been Dr. Abraham Joel at the Department of Soil Sciences, SLU and Jeroen Ensink at IWMI, thank you both for your time.

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Julia Hytteborn, Uppsala in March 2005

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List of Abbreviations

ARWR	Annual internal Renewable Water Resource
CGIAR	Consultative Group on International Agricultural Research
CR	Capillary Rise
D	Drainage
DP	Deep Percolation
EC	Electric Conductivity
ET_0	Reference Evapotranspiration
ET_c	Crop Evapotranspiration
FAO	Food and Agriculture Organization of the United Nations
G	Soil heat flux
I	Irrigation
ICRISAT	International Crop Research Institute in the Semiarid Tropics
IWMI	International Water Management Institute
K_c	Crop coefficient
K_{cb}	Basal Crop coefficient.
K_e	Soil Evaporation coefficient
MFS	Minor Field Study, Scholarship Program founded by Sida
P	Precipitation
R	Runoff
SAR	Sodium Adsorbation Ratio
S_{fc}	Water Storage at Field Capacity
S_i	Water Storage at the end of day i
Sida	Swedish International Development Cooperation Agency
S_{wp}	Water Storage at Permanent Wilting Point
S_{ws}	Water Storage at Water Stress

TABLE OF CONTENT

1 INTRODUCTION

In countries with limited water resources irrigation with wastewater is an increasing practice. Downstream Hyderabad, a 6 million city in Andhra Pradesh, India wastewater is used as irrigation water.

This study investigates one irrigation canal and the area irrigated with water from this canal. The amount of irrigation water used for the whole study area is calculated.

With interviews and flow measurements at two farms the actual irrigation was investigated. A water balance over the root zone of the fields was done with the measured actual irrigation. An optimal irrigation scheme was calculated in an attempt to investigate if the irrigation could have been performed in a better way. The report is concluded with a discussion about alternative irrigation methods to perform a safe and sufficient irrigation in the area.

2 OBJECTIVE

The main objective in this study is to investigate the irrigation with wastewater in an area in Andhra Pradesh India along Peerzadiguda irrigation canal. The study mainly calculates the quantity of irrigation water used but also the quality of the irrigation water is considered. The objectives are:

- to describe the irrigation with the Peerzadiguda canal water,
- to evaluate the water use at field level,
- to propose an optimal irrigation scheme.

3 BACKGROUND

The water resources in the world are not evenly distributed. In many regions, where the human population is large, the freshwater resources are limited. 60 percent of the world population lives in Asia but the continent only has 36 percent of the world river runoff (Harrison and Pearce, 2000).

India has an annual internal renewable water resource (ARWR) of 1244 m^3 per capita (World Resources 2000 – 2001, 2000). According to Falkenmark *et al.* (1989) a country with an ARWR per capita between 1000 - 1700 m^3 tends to be water stressed. Below 1000 m^3 ARWR per capita the water situation begins to influence the development and health in the country. In India the annual water withdrawal, the water used by the human population, is 40% of ARWR or 588 m^3 per capita (World Resources 2000 - 2001, 2000). According to Raskin *et al.* (1997) a country with an annual water withdrawal over 40 % of ARWR is water scarce. India tends to be water stressed both according to Falkenmark *et al.* (1989) and Raskin *et al.* (1997).

India has a dry climate and the agriculture uses lots of water in irrigation during the dry season. Of the total water withdrawal 92% is used by the agricultural sector, the domestic sector uses 5% and the industry sector uses 3% (World Resources 2000 - 2001, 2000).

To produce enough food for the population with limited resources of freshwater, other water sources are often used. This can be water with high content of salt or waste-water, treated or untreated. In many cities in low-income countries water supply is much more prioritized than wastewater treatment (Scott *et al*., 2004). Untreated or partly treated wastewater finds its way to surface water downstream the city. Using wastewater in irrigation results in certain risks, e.g. salt accumulation in the soil and negative health impact for the workers and consumers, but also benefits from the high nutrient value and the access to water. In arid and semiarid regions the use of waste-water in agriculture is increasing (van der Hoek, 2004).

3.1 WASTEWATER IRRIGATION

Farmers are using different methods to irrigate their crops. The systems are at different technical level and are suitable for different conditions. The following is a description of different irrigation methods (Pescod, 1992 and Brouwer, 1988):

Surface irrigation system is when water is let into the field and infiltrate into the soil. There are three different types of surface irrigation, basin, border and furrow irrigation. In *basin irrigation* the water is let into a field that is surrounded by bunds, the fields are usually flat and quite small. This is a common method used on small farms. *Border irrigation* is when irrigation water is let into the upper part of a long graded strip of land surrounded by bunds. *Furrow irrigation* is when the field has ridges where the crops are growing with furrows in between where the water is let in. The irrigation water infiltrates into the soil and reaches the crop roots.

With **sprinkle irrigation** the water is distributed through the air in a similar way as rain.

Sub-irrigation is when the water is distributed underground and is applied directly to the crop roots through pipes or sub-surface canals.

Localized irrigation method is when the water is applied close to the plant with only a small part of the soil wetted. The water is applied by a drip or trickle irrigation system (plastic pipes that drop the irrigation water to the soil at low rate), micro sprinklers (sprinklers that distribute the irrigation water only a few meters) or bubblers (pipes that let the water bubble to irrigate the crops). A problem with drop irrigation is that the system easily gets blocked.

In the selection of the best irrigation method several considerations have to be taken into account, such as the land slope, climate, crop to be cultivated, water supply, cost of the system, infiltration rate and water holding capacity of the soil. The skills of the labourers and farmers are essential to get a good result through irrigation. When wastewater is used in irrigation new considerations have to be taken into account.
Risks associated with wastewater irrigation are:

- salt accumulation in the soil,
- toxicity accumulation in plant and soil,
- health risks for the worker at the irrigated fields and consumers of the products.

In the following chapters these risks are discussed in more detail with some consideration to irrigation techniques.

3.1.1 Salt Accumulation in the Soil

As the salt concentration usually is higher in wastewater than in other irrigation water sources, salt accumulation in the soil can be a problem. The plants need to use more energy in the water uptake process if the salt concentration is high in the soil water. Some crops are more salt tolerant than others and are therefore more suitable for cultivation on wastewater irrigated fields. Many fodder grasses are tolerant to salt.

Salt in water is quantified as electric conductivity, *EC*, or total dissolved solids, *TDS*. Paddy rice is classified by Ayers and Westcot (1985) as moderate sensitive and should not be irrigated with water with an electric conductivity higher than 2 dS/m to achieve full crop yield. If the *EC* in the irrigation water is higher than 7.6 dS/m the paddy rice will not give any yield at all (Ayers and Westcot, 1985).

Processes that prevent salt accumulation are leaching and drainage of irrigation water. If the leaching, the amount of water that percolate under the root zone, is too small, salt will accumulate in the root zone. When the drainage, the subsurface or surface flow that transport the excess water away from the soil, is too small the groundwater can become salt contaminated. If the water table is high a secondary salt contamination of the root zone can occur from the salt contaminated groundwater (Ayers and Westcot, 1985).

The leaching can take place at every irrigation occasion or as seldom as once every season, depending on the water supply and salt content. If the irrigation water is of good quality the normal rain season can be enough to leach the salt below the root zone. Ayers and Westcot (1985) has put together nine advices, listed below, on how to accomplish sufficient leaching without too much water losses:

1) leach during the cool season instead of the warm to increase the efficiency and ease of leaching since the *ET* losses are lower,
2) use more salt tolerant crops which require a lower *LR*[1] and thus a lower total water demand,
3) use tillage to slow overland water flow and reduce the number of surface cracks which bypass flow through large pores and decrease efficiency in leaching,
4) use sprinkler irrigation at an application rate below the soil infiltration rate, this favours unsaturated flow which is appreciably more efficient than saturated flow for leaching. More irrigation time but less water is required than for continuous ponding,
5) use alternate ponding and drying instead of continuous ponding. This is more efficient in leaching and uses less water but the time required to leach is greater. Drawbacks may arise in areas with a high water table which allows secondary salinization between poundings,
6) where possible, schedule leachings at periods of low crop water use or postpone leachings until after the cropping season,
7) avoid fallow periods particularly during hot summers where rapid secondary soil salinization from high water tables can occur,
8) if infiltration rates are low, consider pre-planting irrigations or off-season leaching to avoid excessive water applications during the crop season,

[1] *LR* is the Leaching Requirement calculated in equation 14, chapter 4.5.1.

9) use an irrigation before the start of the rainy season if total rainfall is normally expected to be insufficient to do a complete leaching. Rainfall is often the most efficient leaching method because it provides high quality water at relatively low rates of application.

To prevent salt accumulation in the soil the choice of irrigation method is important, as different methods are not equally good at preventing salt accumulation. Drip (localized) irrigation can be a good method to prevent salt accumulation in the root zone (Pescod, 1992). A problem with localized irrigation is that salt accumulates outside the root zone and transports towards the root zone in case of water scarcity. With border and basin irrigation method the leaching is quite good and the salts do not accumulate in the root zone but more water is used than in localized irrigation (Pescod, 1992). With furrow irrigation salt can be accumulated in the ridges causing difficulties for the crops. A different placement of the seed on the ridges can help (Ayers and Westcot, 1985).

3.1.2 Human Health

The health risks concerning humans with the use of wastewater in agriculture are due to pathogenic organisms like helminthe, bacteria, virus, protozoa and toxic substance e.g. heavy metals. Different human groups are exposed to pathogenic organisms due to wastewater irrigation:

- workers at the field who handle the wastewater and walk on the wetted soil,
- crop handler,
- consumers eating the crops raw or cooked,
- humans living close to the irrigated area.

Another exposed group is people visiting parks and sport fields irrigated by wastewater (Pescod, 1992).

WHO (1998) have divided the regulation requirements in three categories, A, B and C depending of the risk groups. Category A is the most regulated as it affects both fieldworkers and consumers. This category consists of crops consumed uncooked and lawns in public areas. The water should contain less than one intestinal nematodes (ringworms) egg per litre and less than 1000 faecal coliforms per 100 ml. Category B is regulated only because of the health risk for the field workers. Examples of crops are industrial crops, cereals, trees, fodder crops and pasture. The regulation is also less than one intestinal nematodes egg per litre and there is no standard recommendation for faecal coliforms. Category C is localized irrigation of the same crop as in category B. Category C do not have any exposed groups and do not have any regulation of nematodes or coliforms.

The irrigation method influences the risks concerning health. Sprinkler irrigation e.g. contaminates the plants, farm workers get exposed and the water can also be spread with the wind to other places. Basin and border irrigation contaminates the whole soil surface and the lower parts of the plant are in contact with the water. The farm workers are exposed to pathogens through the wetted soil. Nematodes (ringworms) need wet soil to get infectious and some of them infect through the skin. As mentioned above the wastewater is not in contact with the crop when localized irrigation is used and it is for that reason a safe method to avoid infections (Pescod, 1992).

3.1.3 Toxic Ions and Trace Elements

In wastewater it is common that the concentration of some substances get heightened. Toxic ions like boron, B, chloride, Cl^-, and sodium, Na^+, can in high concentrations reduc the crop growth. A boron concentration higher than 0.7 mg/l effects the crop growth (Ayers and Westcot, 1985). Chloride effects the crops if it is higher than 4 me/l and sodium effects the crops in surface irrigation if the sodium adsorbation ratio, *SAR*, is higher than 3 (Ayers and Westcot, 1985). The *SAR* is calculated as $SAR = \frac{Na}{\sqrt{\frac{Ca+Mg}{2}}}$. A high *SAR* value reduces the infiltration capacity of the soil and makes the soil form crusts and makes it hard to till (Ayers and Westcot, 1985).

Also other substances that usually occur in water in very low concentrations can in wastewater reach a concentration that will reduce the crop growth, so called trace elements. Not all trace elements are toxic and some are even essential for the plants. Heavy metals like arsenic, cadmium, chromium, copper, lead, mercury and zink are also trace elements that can be toxic to both crops and humans. In Ayers and Westcot (1985) there are recommendations about the concentration for around 20 different trace elements in irrigation water.

3.2 WASTEWATER IRRIGATION ALONG MUSI RIVER

This study is investigating the use of wastewater in irrigation in an area downstream Hyderabad, the capital of the Indian state Andhra Pradesh. The farmers in the area are using water from Musi river as irrigation water. Musi river flows through Hyderabad and contains its treated and untreated wastewater.

Hyderabad had 2001 an estimated population of 5.4 million inhabitants and an expected population of over 6.1 million inhabitants at midyear 2005 (United Nation, 2002) and it is one of India's fastest growing cities. The sewage and treatment systems are not built for the number of people living there.

Hyderabad was founded at its location because of the water resources in the area. The Musi river was at that time bringing water all year around. Inside the town is a tank[2], called Husein Sagar, which from the beginning was a reservoir for drinking water. It now contains treated wastewater. During the 1920s two new drinking water tanks were constructed, Himayat Sagar and Osaman Sagar, both taking water from Musi river upstream Hyderabad (Kiran, 2005). Because of the water demands of Hyderabad there is no water flowing in Musi river between the tanks and the city during the dry season (Ensink, 2004b). Later two more tanks were constructed, Manjira Barrage and Singur Dam, pumping water from Manjira river to Hyderabad (Kiran, 2005).

Two sewage treatment plants are built to improve the water quality in Musi river. One of them has both primary and secondary treatment and a capacity of 115 000 m^3/day. The other sewage treatment plant has only primary treatment and a capacity of 44 000 m^3/day. The treatment plants have a short retention time, which mean that the treatment is insufficient. The sewage system doesn't cover the whole city but an

[2] In India the word tank is used for large reservoirs.

ongoing project on the Hyderabad Metropolitan Water Supply and Sewage Board is attempting to do so (Kiran, 2005). Many of the sewers are connected to the storm water drains that have its outlet directly into Musi river. Today a lot of the sewage is leaving Hyderabad as untreated wastewater.

The river flows from west to east. East of the town there is wastewater in the river channel. Along the river there are fields irrigated with the Musi water. Anicuts[3] (weirs) are built on a few places in the river. From these anicuts the water is diverted into irrigation canals that provide the farmers with water.

4 METHOD

The study is divided in three parts:

- the average irrigation over the study area,
- the actual irrigation at field level,
- an attempt to determine an optimal irrigation scheme of the fields.

The average irrigation is calculated to get an idea of the water use situation in the study area. The actual irrigation is measured and water balance calculations are done for a few fields. Water balance calculations are also done with the optimal irrigation. The study area is described in detail below.

4.1 STUDY AREA

The study area is the area irrigated with water from a section of one of Musi river's irrigation canals. The area starts with an anicut[3] in Musi river located at latitude 17.39°N and longitude 78.60°E close to Peerzadiguda village and continues along one of the irrigation canals, a distance of 7.5 kilometres. The irrigation canal is visible on the map (Figure 1) as a narrow black line north of Musi river channel. Start and end points of the canal section is marked with arrows.

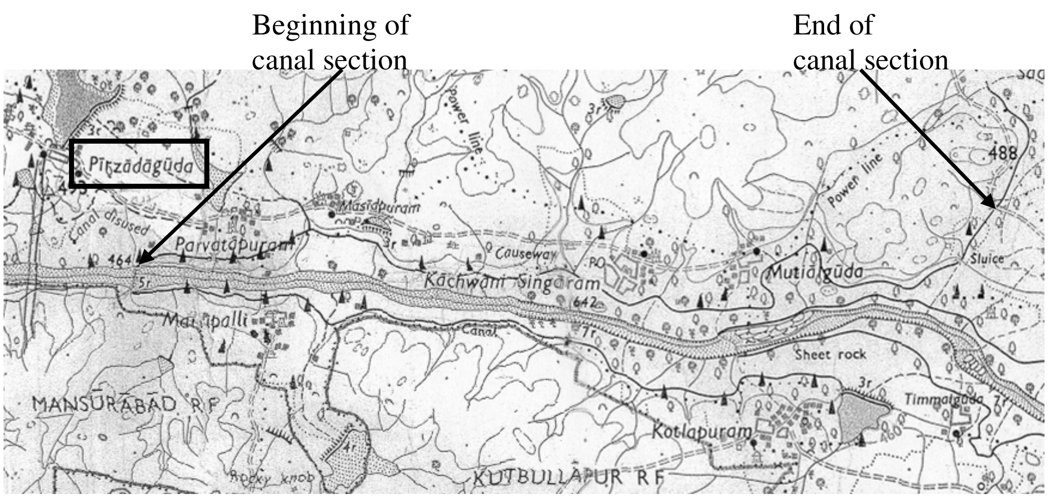

Figure 1. Map over the study area (Hyderabad and Nalgonda district, 1975).

[3] An anicut is: "A dam or mole made in the course of a stream for the purpose of regulating the flow of a system of irrigation." (Webster's, 1998)

The bedrock in the Hyderabad area is granite and granite-gneiss (Andhra Pradesh Soil, 2000). The climate is semiarid with a precipitation of 890 mm per year in Patancheru (ICRISAT Patancheru, 2004). The Musi river is located in the Krishna basin.

The irrigation infrastructure is planned and controlled by the Irrigation Department and was originally not meant to contain wastewater. The crops that are irrigated with the canal water are paragrass, paddy rice, and green vegetables. Paragrass is a fodder grass that grows year around and harvests at a daily basis. The farmer uses the paragrass to feed their own cattle or sell it at the grass market in Hyderabad. Paddy grows in basins but is not standing in water. Paddy and vegetables are grown for consumption within the household of the farmers and to sell at the local market. Other uses of the canal water are bathing of the buffalos and fish breading in a pond beside the canal.

The irrigation canal is built with stones and is six to four meters wide. The flow is around 230 000 m^3/day where the canal starts. Pumps or gravity supply the fields with water. The irrigation is of basin irrigation type. The water supply is safe but the water quality is bad. The quantity of worm egg is high. The occurrence of egg is decreasing downstream the Musi river (Ensink, 2004b). The study area is located directly after the first anicut downstream Hyderabad and the water still has a high content of eggs.

Meteorological data used in the study are supplied by ICRISAT, Patancheru, at latitude 17.53°N and longitude 78.27°E (ICRISAT, 2004).

4.2 DETERMINATION OF AVERAGE IRRIGATION IN THE STUDY AREA

The first part of the study is to determine the average irrigation over the total study area. This is performed with water flow measurements in the Peerzadiguda irrigation canal, calculations and estimations of losses from the canal and measurements of the size of the study area. When the study area and the amount of water leaving the canal as irrigation water is quantified the irrigation can be calculated as in equation 1.

$$I_{StudyArea} = 0.1 * \frac{Q_I}{A_{StudyArea}}$$ **Equation (1)**

$I_{StudyArea}$ = the average irrigation of the study area in mm/day
Q_I = the water flow of irrigation water leaving the irrigation canal in m^3/day
$A_{StudyArea}$ = the size of the study area in ha.

The calculation of the water flow of irrigation water, Q_I, is presented in chapter 4.2.1 below and the calculations of the study area, $A_{StudyArea}$, is presented in chapter 4.2.2.

4.2.1 Determination of Irrigation Water Flow

To calculate the flow of irrigation water both the in- and outgoing water flows in the irrigation canal have to be identified. Figure 2 is an illustration of the different water flows in the canal.

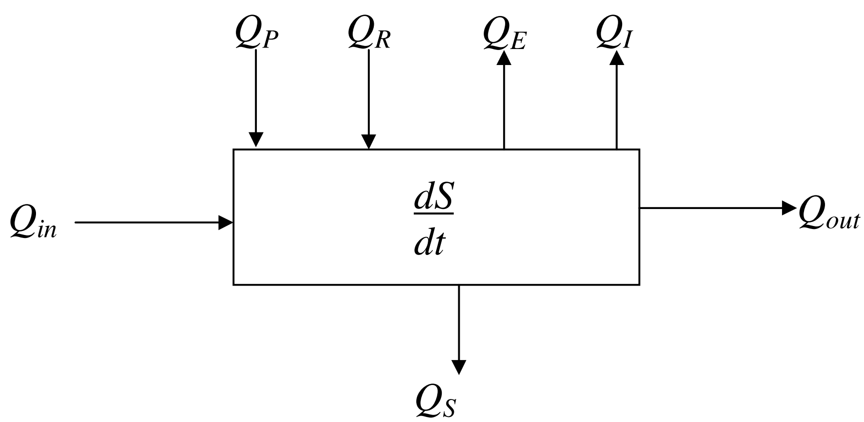

Figure 2. In- and outgoing water flows in the irrigation canal. Q_{in} is the inflow, Q_P is the precipitation, Q_R is the runoff, Q_E is the evaporation, Q_I is the irrigation flow, *dS/dt* is the change in water storage, Q_S is the seepage and Q_{out} is the outflow from the canal.

The water flows are summarized in a water balance equation where the incoming flows are positive and the outgoing flows are negative. The water balance for the canal is written in equation 2 below. The unit is m^3/day.

$$\frac{dS}{dt} = Q_{in} + Q_P + Q_R - Q_{out} - Q_E - Q_S - Q_I \qquad \textbf{Equation (2)}$$

$\frac{dS}{dt}$ = the change in water storage in the canal
Q_{in} = the flow streaming into the canal at the beginning of a chosen canal section
Q_{out} = the flow leaving the canal at the last point of a section
Q_P = the precipitation falling on the canal water surface
Q_R = the runoff
Q_E = the evaporation from the canal water surface
Q_S = the water that leaches through the canal walls
Q_I = the irrigation water flow.

The wanted result from this calculation is the amount of irrigation water leaving the canal and used in irrigation in the study area. Equation 2 is then rewritten as $Q_I = Q_{in} + Q_P + Q_R - Q_{out} - Q_E - Q_S + \frac{dS}{dt}$.

Before the irrigation water flow can be calculated, other flows have to be measured, calculated or estimated. Precipitation, Q_P, and runoff, Q_R, are assumed to be zero as the measuring period is during the driest months and with little rainfall is falling. Also the change in water storage, $\frac{dS}{dt}$, has to be considered. As the canal water is free flowing the change of the storage can probably be assumed to be zero, there are no magazines or other structures where the water is stored.

Seepage, Q_S, in equation 2, is the leakage through the canal bed and walls. The quantity of seepage depends on the groundwater table and the permeability of the canal bed, walls and surrounding soil. The irrigation canal in the study area is built out of stones and concrete with a hopefully low infiltration capacity. In this investigation the seepage is assumed to be zero as it is a small flow compared to the irrigation flow.

The equation for the calculation of the amount of irrigation water can now be simplified and equation 2 is rewritten as:

$$Q_I = Q_{in} - Q_{out} - Q_E \qquad \textbf{Equation (3)}$$

The measurements of the water flow in the canal are taking place at three locations along the canal at three occasions. The measuring points are placed in the beginning, the end and in the middle of the canal section. The first measuring point is situated close to the Peerzadiguda weir and it measures the inflow, Q_{in}. The second is situated in Kashwani Singaram village, 3960 meters downstream the first point (Figure 1). The last measuring point is located close to the fishpond in Pratap Singaram village 7460 meters downstream the first point and it measures the outflow, Q_{out}, from the canal section.

The coordinates of the measuring points were identified with a GPS and are used in a GIS to create a map. A satellite image over the area and a shapefiles, created by staff at IWMI, showing Musi river and its irrigation canals is used. The map was created in the computer program ArcGIS.

The water flow in the canal is measured with the velocity - area method (James, 1988). A thirty meter long homogeneous part of the canal is chosen. The first time the flow measurement takes place a calibration is done. This means that the area of the cross-section of the canal is measured. One point at the canal bed is chosen as a reference point were the water surface height is measured in the following flow measurements.

Figure 3 illustrates the last flow measurement point with arrows indicating the beginning and end of the section. Three bottles, filled to 75 percent with water, are thrown one at the time into the middle of the stream above the measurement area to give the bottle the same velocity as the stream when the bottle passes the start point where the stopwatch is started. The time it takes the bottle to float thirty meter is measured. To show the actual difference in water flow the flow measurements should optimally be taken at the same time at all three measurement points.

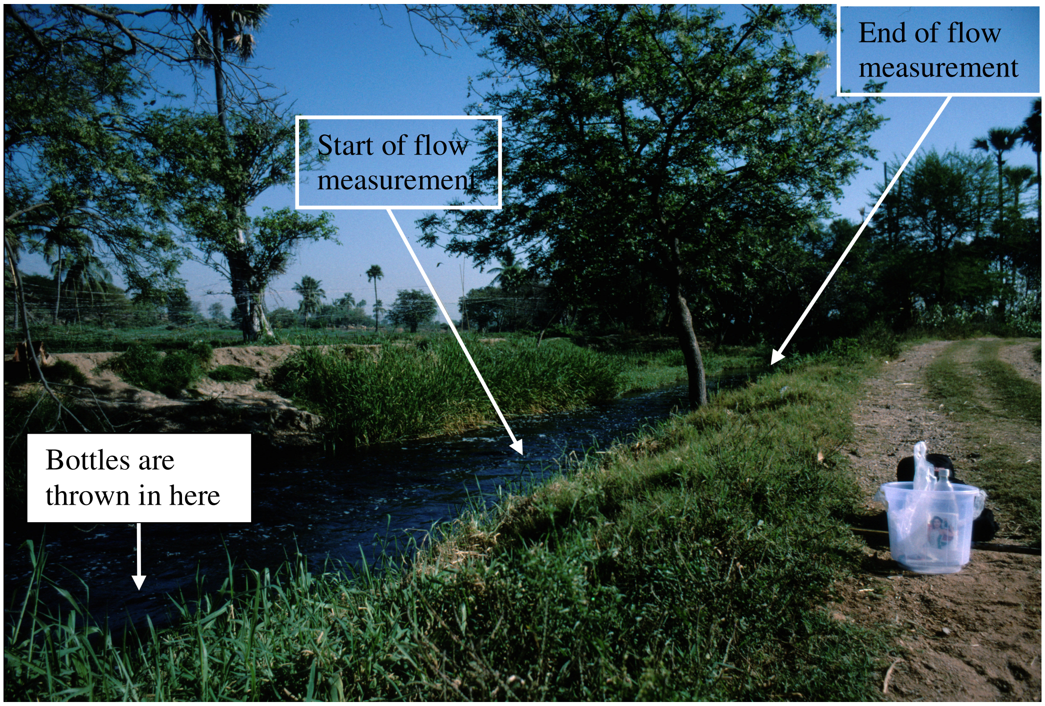

Figure 3. The water flow measurement at the last measurement point. Water flows to the right. Photographer Julia Hytteborn, 2004.

With the floating time and the length of the section the floating velocity, v_f, is calculated. The floating velocity in the middle of the canal is the maximum water velocity. At the canal bed and walls the velocity assumed is to be zero due to frictions. To correct the velocity to represent the total cross section of water the floating velocity is multiplied by a correction factor, *CF*, which depends on the flow depth, see Table 1 (U.S. Bureau of Reclamation, 2001):

Table 1. Correction Factor, CF, for different average flow depth to calculate a velocity that represents the total volume of water (U.S. Bureau of Reclamation, 2001).

Average Flow Depth (m)	0.3	0.6	0.9	1.2	1.5	1.8	2.7	3.7	4.6	≥6.1
CF	0.66	0.68	0.70	0.72	0.74	0.76	0.77	0.78	0.79	0.80

To calculate the water flow the floating velocity is multiplied by the cross section area, $A_{CrossSection}$ and the correction factor, see equation 4:

$$Q = v_f * CF * A_{CrossSection}$$ **Equation (4)**

Q = the discharge in m^3/day
v_f = float velocity in the middle of the canal in m/day
CF = the correction factor with no unit
$A_{CrossSection}$ = the cross section area for the canal in m^2.

The evaporation flow from the canal water surface is calculated from values of pan-evaporation, E_{pan}, measurements at ICRISAT's weather station in Patancheru and a rough estimation of the canal surface area, A_{canal}. The calculations are performed with equation 5:

$$Q_E = 0.001 * E_{pan} * A_{canal}$$ **Equation (5)**

Q_E = the evaporation flow from the canal in m^3/day
E_{pan} = the evaporation measured with the pan method in mm/day
A_{canal} = the canal water surface area in m^2.

A_{canal} is estimated as $A_{canal} = L_{canal} * w_{canal,average}$ where L_{canal} is the canal length and $w_{canal,average}$ is the average width of the canal, measured at the three points where the flow measurements are done. The measurement of the canal length is performed in ArcGIS. The estimation of the canal surface area is not very precise. The evaporation is probably small compared to the in- and outflow and will not make a big difference.

4.2.2 Determination of the Wastewater Irrigated Area

Staff at IWMI in Patancheru, India have already done an analysis over what area is irrigated with wastewater around the whole Musi river system downstream Hyderabad. This data, a satellite image and a shapefile, is used to identify and measure the wastewater irrigated area around Peerzadiguda canal. The measurement of the area is performed in the computer program ArcGIS. Also a map is produced showing the wastewater irrigated area.

4.3 DETERMINATION OF ACTUAL IRRIGATION ON THE FIELDS

The investigation over the average irrigation is complemented with an investigation of the irrigation on a few fields in the study area. Interviews with farmers about their irrigation are taking place. The interviews are complemented with measurements of the farmer's irrigation of their fields.

The irrigation of the farmer's fields is calculated per occasion and per day with the following equation:

$$I_{field} = 0.1 * \frac{t * Q_I}{A_{field}}$$ **Equation (6)**

I_{field} = the irrigation on the field per irrigation occasion in mm
t = time per irrigation occasion in h
Q_I = the flow from the farmer's pump in m^3/h
A_{field} = the size of farmer's field in ha.

Data about the field size and irrigation time is collected during interviews, see chapter 4.3.1, and the flow from the pumps is measured, see chapter 4.3.2.

4.3.1 Interviews with the Farmers

Five farmers are selected along the irrigation canal in the study area. They are chosen with help from field staff at IWMI that know the study area well. Field staff also interprets to telegu, the local language. The criteria in the choice of informants are:

- farmers that take their irrigation water from the irrigation canal,
- farmers from different locations along the canal,
- farmers should be representative for farmers in the area concerning field size and crops.

The interviews are of semi-structured type, this means that questions are planned in advance and work as guidelines in the interview situations. The interview questions cover:

- some basic data about the informant,
- crop data, e.g. what crops they cultivate and the size of the fields,
- irrigation data, e.g. when and how long time they irrigate and what techniques they use,
- fertilizer data.

The interview questions are attached in Appendix 1. During the visits at the fields also the size of the fields were paced out as a complement to the information from the farmers.

4.3.2 Measurements of the Farmers Irrigation

Measurements of the irrigation flow are done on two farmer's fields. The measurements are done with H-flumes installed in the farmer's small irrigation canals right after the pump bringing water to the fields. The measurement is performed once at each farm and the flumes are not permanently installed in the canals (Figure 4).

Figure 4. A H-flume measuring the flow in a small irrigation canal at a basin irrigated farm. Photographer Charlotta Hofstedt, 2004.

Two different size of H-flumes are used, one with 15.24 centimetres (1/2 foot) width and one with 30.48 centimetres (1 foot) width. When the flumes are installed and the water is flowing through, the height of the water is measured. The flow can then be directly read in a calibration table from USDA (1979).

4.4 CALCULATION OF WATER BALANCE AND EVAPTRANSPIRATION

The aim of the water balance investigation of the root zone is to calculate if the crops have enough available water and the size of the water losses. A water balance is done for the root zone on the crop fields. The illustration of the water balance in the root zone (Figure 5) shows incoming and outgoing water.

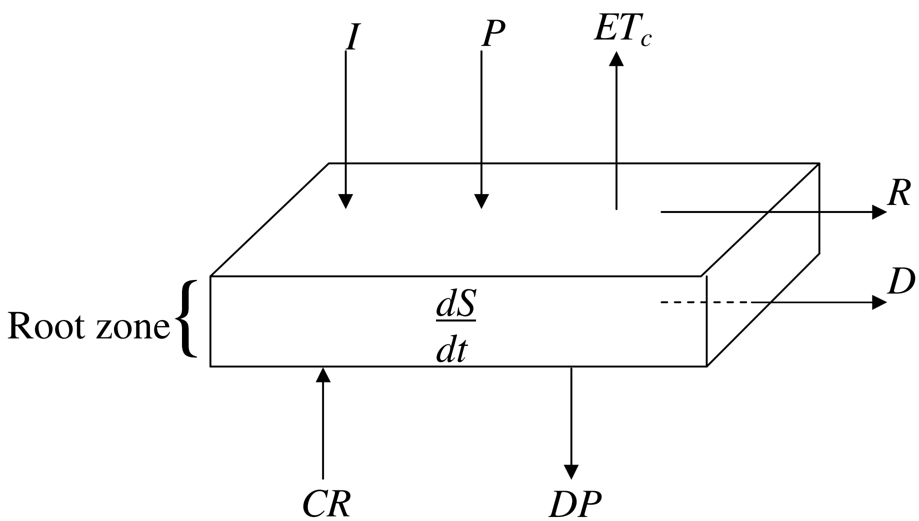

Figure 5. Water balance of the root zone, *I* is the irrigation, *P* is the precipitation, ET_c is the crop evapotranspiration, *dS/dt* is the change in water storage in the soil, *CR* is the capillary rise, *DP* is the deep percolation, *R* is the runoff and *D* is the drainage.

In the water balance for the root zone the positive parameters are the incoming water and the negative the outgoing (equation 7).

$$\frac{dS}{dt} = P + I + CR - ET_C - DP - R - D \qquad \textbf{Equation (7)}$$

$\frac{dS}{dt}$ = the change in water storage in the soil in mm/day
P = the precipitation falling on the field in mm/day
I = the irrigation in mm/day
CR = the capillary rise in mm/day
ET_c = the crop evapotranspiration from the soil and the crops in mm/day
DP = the deep percolation, the water percolation below the root zone in mm/day
R = the runoff flowing from the field in mm/day
D = the drainage in mm/day.

Crop evapotranspiration, ET_c, is also called the crop water demand for an optimal crop growth. ET_c is for that reason a very important parameter in the water balance calculation and it follows in chapter 4.4.1. The calculation of the water balance with actual irrigation is described in chapter 4.4.2.

4.4.1 Evapotranspiration Calculation

Daily values of the reference evapotranspiration, ET_0, are calculated with the FAO Penman-Monteith equation described in Allen *et al.* (1998). The reason to use this method is that FAO Penman-Monteith equation is regarded as being accurate also on short time steps (James, 1988). The data needed for the calculations are climatic data, data about the specific crop and the soil texture.

Evapotranspiration are two different processes – the evaporation from the soil and the transpiration from the crop tissue. The evaporation depends on the solar radiation, air temperature, air humidity, wind speed, shading from crops and available water. Transpiration from the crops depends on the same parameters as evaporation but also on the growth state and the specific character of the crop species. Nearly all crop water uptake is leaving the plant as transpiration. Some species are more water efficient than others.

The reference evapotranspiration, ET_0, is calculated for an ideal crop with defined characteristics. It is also assumed that the reference crop does not experience any water stress. The reference crop is defined as:

> "A hypothetical reference crop with an assumed crop height of 0.12 m, a fixed resistance of 70 sm^{-1} and an albedo of 0.23." (Allen *et al.*, 1998)

The reference evapotranspiration, ET_0, reflects the climate in the specific area. The ET_0 is calculated with the equation 8 below (Allen *et al.*, 1998).

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \qquad \textbf{Equation (8)}$$

ET_0 = the reference evapotranspiration in mm/day
Δ = the slope vapour pressure curve in kPa/°C
R_n = the net radiation at the crop surface in MW/day
G = the soil heat flux in MW/day
γ= the psychrometric constant in kPa/°C
T = mean daily air temperature 2 meter over ground in °C
u_2 = wind speed at 2 meter in m/s
e_s = saturation vapour pressure in kPa
e_a = the actual vapour pressure in kPa.

The calculation of ET_0 is performed in Microsoft Excel. As the characteristics of the reference crop are already defined it is only a few parameters that need to be identified. The following input is used to calculate the parameters in equation 8:

- Temperature,
- altitude,
- relative humidity,
- day of the year,
- latitude,

- solar radiation,
- wind velocity.

The climatic data used in the calculations are collected from ICRISAT, Patancheru. The soil heat flux, *G*, is assumed to be zero as the time step is one day long and it is assumed that the soil has the same temperature at the end of the day and the time steps are one day long. For a full explanation on how the calculations of all the parameters in equation 8 are performed, see Allen *et al.* (1998).

The reference evapotranspiration is calculated to make the calculation of the evapotranspiration of the specific crop easier. This crop evapotranspiration, ET_c, is calculated with equation 9 were an empirical crop coefficient, K_c, is used. The crop evapotranspiration, ET_c, can also be calculated with the FAO Penman-Monteith equation (equation 8) directly if the albedo and resistances are known. In this study the crop coefficient, K_c, approach is used. The ET_c is calculated for the crops growing on the fields where the actual irrigation investigations are done. The crops are vegetables, paddy and paragrass.

$$ET_c = K_c * ET_0 \qquad \textbf{Equation (9)}$$

ET_c = crop evapotranspiration in mm/day
K_c = crop coefficient
ET_0 = reference evapotranspiration in mm/day

The crop coefficient, K_c, is specific for each crop species and is in this study calculated with dual crop coefficients, see equation 10 below. The K_c value consists of two parts: the basal crop coefficient, K_{cb}, and the soil evaporation coefficient, K_e. The K_{cb} value represents mostly the transpiration from the crop and K_e represents the evaporation from the soil (Allen *et al.*, 1998).

$$K_c = K_{cb} + K_e \qquad \textbf{Equation (10)}$$

K_c = the crop coefficient
K_{cb} = basal crop coefficient
K_e = soil evaporation coefficient.

In Allen *et al.* (1998) values of the tabled basal crop coefficient, $K_{cb,tab}$, exist for different crops and crop stages. The tabulated value is used to calculate a more accurate basal crop coefficient, K_{cb}, value. In the calculation the following parameters are included:
- wind speed,
- minimum relative humidity,
- crop height (Allen *et al.*, 1998).

The needed data to calculate the soil evaporation coefficient, K_e, are:
- the amount of water that is available for evaporation from the soil,
- the maximum limit of how much water it is possible to evaporate according to the energy balance of the soil,

- the basal crop coefficient, K_{cb},
- what fraction of the soil that is wetted – depends on the irrigation technique,
- soil expose – depends on the shade of the crops.

The climatic data used in the evapotranspiration calculations and consequently in the water balance calculations are collected at ICRISAT, Patancheru. In Table 2 are the parameters used in the calculation. The crop specific values (maximum crop height, and $K_{cb,tab}$ for different crop stages) come from Allen *et al.* (1998) but not all crops are tabled. Values for rice exist. For vegetable spinach is used and for Paragrass Sudan grass is used. The values of the seasons length come from interviews with the informants and the length of the different crop stages are approximated from information in Allen *et al.* (1998). The crop season in the calculation is divided into initial, development, mid and late crop season. Paragrass grows all year round and is cut frequently and does not have a specific crop season.

Table 2. Values of parameters used in the crop evapotranspration calculations for different crops. Maximum crop height, tabulated values for basal crop coefficient (Allen *et al.*, 1998), length of season's periods (farmers' information).

Parameters used in the crop evapotranspiration calculations	Vegetable	Paddy	Paragrass
Maximum crop height (m)	0.30	1.00	1.2
$K_{cb,tab,ini}$	0.15	1.00	-
$K_{cb,tab,mid}$	0.95	1.15	1.1
$K_{cb,tab,end}$	0.85	0.58	-
Length of total crop season (days)	30	120	-
Length of initial period (days)	5	24	-
Length of development period (days)	10	24	-
Length of mid period (days)	10	48	-
Length of late period (days)	5	24	-

4.4.2 Water Balance for the Root Zone with the Actual Irrigation

The water storage and water losses in the root zone are calculated with daily time steps. The water loss is the water not used by the crops. Assumptions about some of the parameters in equation 7 are made. The runoff, *R*, is assumed to be zero as field plots have borders that prevent runoff. The drainage, *D*, is also assumed to be zero. The capillary rise, *CR*, is assumed to be zero as the water table probably is low, this was not investigated but confirmed by one of the informants. If the above assumptions are correct most of the water loss is due ton the deep percolation, *DP*.

Equation 7 can now be written as $\frac{dS}{dt} = P + I - ET_C - DP$. The input data is given as daily values. Equation 7 is then rewritten as equation 11 below. The water storage at the end of day i, S_i, is calculated with the value of the water storage at the end of the day before, day i-1, as input. The precipitation, P_i, irrigation, I_i, and crop evapo-transpiration, $ET_{c,i}$, for day i, is added and removed from the water storage. The deep percolation, *DP*, is not included in equation 11, more about that later in this chapter.

$$S_i = S_{i-1} + P_i + I_i - ET_{c,i}$$ **Equation (11)**

S_i = the water storage at the end of day i in mm
S_{i-1} = the water storage at the end of day i-1 in mm
P_i = the precipitation during day i in mm
I_i = the irrigation during day i in mm
$ET_{c,i}$ = the crop evapotranspiration during day i in mm.

The water storage, S_i, is calculated with limits. It can not be less than zero mm and not larger than the water storage at field capacity, S_{fc}, plus five millimetre: $0 \le S_i \le S_{fc} + 5mm$. The soil is at field capacity when it has the largest water content it can hold against the gravity. The upper limit for S_i is 5 mm larger than S_{fc} because it takes one to three days after saturation (a large rain or irrigation) before the soil is at field capacity and 5 mm extra is an estimation of the delay.

The water loss, the water that the crops could not use, is assumed to be the deep percolation, *DP*. It is calculated as the water exceeding $S_{fc} + 5mm$ and is calculated as in equation 12.

$$DP_i = (S_{i-1} + P_i + I_i - ET_{c,i}) - S_i$$ **Equation (12)**

Crops are not able to use all the water in the soil. If the water content goes below a certain value the crop will permanently wilt, this water storage is called the water storage at permanent wilting point, S_{wp}. Differing crops vary at water uptake and they will experience water stress at different water content before the wilting point is reached.

Values of the water storage at field capacity, S_{fc}, and the water storage at wilting point, S_{wp}, is calculated for the root zone. In Allen *et al.* (1998) values of the field capacity and wilting point for different soil types are tabulated. Soil data from IWMI are used to identify the soil in the area (Ensink, 2004a).

The crops have varying root depth during the season, values for the root depths are found in Allen *et al.* (1998). Values in Table 3 are used in the calculations. The initial root depth is used during the initial crop period and the maximum root depth is used during the mid and late crop periods. During the development period the root depth is increasing linearly and reaches the maximum root depth at the first day of the mid crop period. When the root depth increase, so does also the water storage in the root zone.

Table 3. Depth of root zone for vegetable, paddy and paragrass used in the water balance calculations. The initial root depth is used during the initial period and the maximum root depth during the mid and late crop period. In the development crop period the root depth is increasing linearly between the two values (Allen *et al.* , 1998).

	Vegetable	Paddy	Paragrass
Initial root depth (m)	0.20	0.20	-
Maximum root depth (m)	0.45	0.70	1.0

4.5 DETERMINATION OF AN OPTIMAL IRRIGATION

In the determination of an optimal irrigation for the crops the following considerations are taken into account:

- the crops should not experience water stress,
- water losses should not be too great,
- salt accumulation in the soil and accumulation of toxic substances should be prevented,
- the health risks should be prevented e.g. pathogens and toxicity.

The evaluation leads to a presentation of an irrigation scheme for the area.

4.5.1 Prevent Water Stress, Water Loss and Salt Accumulation

As mentioned in chapter 4.4.2 the crops usually experience **water stress** before the soil water storage reaches the wilting point, S_{wp}. Water uptake varies with crop species, therefore they experience water stress at different water content. A limit for each crop species is calculated which indicate when the crop starts to experience water stress. In this study this value is called water storage at water stress, S_{ws}, and is calculated in equation 13 below. Water storage at water stress, S_{ws}, is a value between water storage at field capacity, S_{fc}, and water storage at wilting point, S_{wp}, and it depends on the crop species.

$$S_{ws} = S_{fc} - (S_{fc} - S_{wp})\,p \qquad \textbf{Equation (13)}$$

S_{ws} = water storage at water stress in mm
S_{fc} = water storage at field capacity in mm
S_{wp} = water storage at wilting point in mm
p = soil water depletion fraction.

The soil water depletion fraction, p, indicates how water efficient the crop species is. p is found for different crops in Allen *et al.* (1998) (Table 4). Values of p are not tabulated for all crops. Values for spinach are used for vegetable and values for Sudan grass are used for paragrass. Values for rice exist. The soil water depletion fraction, p, depends on the evaporation power of the atmosphere, the crops ability of water uptake and the soil type (Allen *et al.*, 1998). Corrections can be done for the ET_c ratio and soil type but it is not done in this study.

Table 4. Soil water depletion fraction, *p* (Allen *et al.*, 1998).

	Vegetable	Paragrass	Paddy
Tabled soil water depletion fraction, p	0.20	0.55	0.20 of sat

To achieve optimal crop growth the water storage in the root zone should be larger than S_{ws}. If the water storage decreases under S_{ws} the crops will start to experience water stress, the ET_c rate will slow down and the crop growth are affected negatively. To achieve an optimal irrigation this has to be prevented.

If the water content exceed the field capacity during precipitation or irrigation, water leaves as deep percolation and is not used by the crops. This water is considered as **water losses** and is calculated in equation 12 in chapter 4.4.2. In the calculation of an optimal irrigation is the water losses hold low.

Salt accumulation is taken into consideration for the determination of the optimal irrigation. To prevent salt accumulation in the root zone the leaching of water transporting the salt below the root zone has to be big enough. Equation 14 below calculates the minimum leaching requirement that is needed to prevent harmful salt accumulation for the crop roots (Ayers and Westcot, 1985). Data for the electric conductivity in the irrigation water, EC_w, used in the calculations comes from The Indian Pollution Control Board and Ensink (2004a). Values of the electric conductivity in the soil, EC_e, for different crops are tabulated in Ayers and Westcot (1985). The EC_e values used in this study gives 100% crop yield potential which means that the crops do not take any harm by the salt content.

$$LR = \frac{EC_w}{5(EC_e) - EC_w}$$ **Equation (14)**

LR = minimum leaching requirement to control salt accumulation
EC_w = electric conductivity in irrigation water in dS/m
EC_e = average soil salinity tolerance for the crop to achieve a certain percent of yield

With equation 15, the actual amount of water, AW, to be applied at the fields to prevent salt accumulation is calculated (Ayers and Westcot, 1985). It takes time before salt accumulates in a harmful amount in a soil. This means that the leaching does not have to take place at every irrigation, it can be done once every season or year. Equation 15 is a calculation of the amount of water to be applied every year and the leaching can be done during the rainy season when larger amounts of water are available.

$$AW = \frac{ET_c}{1 - LR}$$ **Equation (15)**

AW = actual amount of water to be applied in mm/year
ET_c = crop evapotranspiration in mm/year
LR = minimum leaching requirement to control salt accumulation.

4.5.2 Determination of an Optimal Basin Irrigation

A new water balance where the statements in chapter 4.5.1 are taken in consideration is done for the three crop types. As the soil and climate conditions are assumed to be the same on the two farms only one water balance calculation is done per crop. Except the irrigation amount and the irrigation frequency there is no changes in the parameters from the water balance calculations with actual irrigation in chapter 4.4.

5 RESULTS

Results over the average, actual and optimal irrigation are presented below. In chapter 5.1 about the average irrigation the locations of the flow measurement points in the irrigation canal, the flow in the canal, the canal evapotranspiration, the area irrigated with wastewater and the average irrigation are presented. Chapter 5.2 contains the results from the determination of the actual irrigation on the fields. The answers of the informants are presented and also the size of the fields. The water balance for the root zone of the fields is shown in chapter 5.3 and in chapter 5.4 an optimal irrigation, a water balance and an analysis of the salt situation in the soil with optimal irrigation are presented.

5.1 AVERAGE IRRIGATION IN THE STUDY AREA

The average irrigation in the study area was determined with flow measurements in the irrigation canal (Figure 6) and with a GIS analysis of the irrigated area.

Figure 6. Peerzadiguda irrigation canal with paragrass fields to the left. The photo is taken between point ii and iii (Figure 7). Photographer Julia Hytteborn, 2004.

The three orange dots, i, ii and iii, are the flow measurements points (Figure 7). The water is flowing from west to east. The light blue line is the irrigation canal and the dark blue lines are Musi river shores.

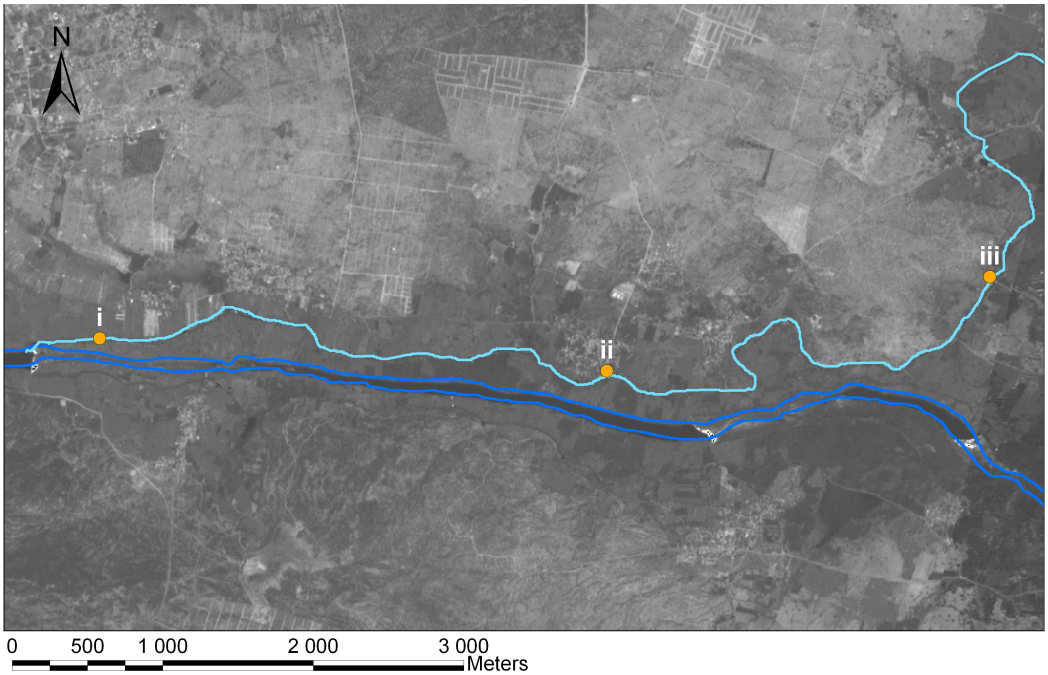

Figure 7. Map over Peerzadiguda irrigation canal with flow measurement points. At point i the inflow is measured and in point iii the outflow is measured. The light blue line is the irrigation canal and the darker blue lines are Musi rivers shores.

The flows at the three measurment points in the canal are presented in Table 5. The flow at i is the inflow, Q_{in}, into the canal and at iii is the outflow, Q_{out}. The measurement of the flow was performed at the same day but not at the same time due to logistic problems. The flow measurement from 17 July 2003 was performed by Ensink (2004a). In the row Average 2004 the three measurements from February and March are included. The average flow, depending on which periods are included, varied from 232 000 m^3/day to 260 000 m^3/day at the uppermost point. At the outflow point the flow is less than half the inflow. The highest flow is measured in February 2004 and the lowest in July 2003 (Table 5). The flow is always smaller downstream then upstream.

Table 5. Flow data from Peerzadiguda irrigation canal.

Date	**Flow (m3/day)**		
	i	**ii**	**iii**
17 July 2003	149 000	-	61 000
11 Feb 2004	270 000	211 000	151 000
04 Mar 2004	261 000	206 000	98 000
15 Mar 2004	248 000	222 000	97 000
Average	**232 000**	**213 000**	**102 000**
Average 2004	**260 000**	**213 000**	**115 000**

The evaporation leaving the water surface of the canal, Q_E, is calculated with an approximation of the canal surface and the pan evaporation measured at ICRISAT. The length of the canal, L_{canal}, is measured in ArcGIS to 7465 meters and the average canal width, $w_{canal,average}$, measured at the three flow measurement points, is 4.4 meters for the values during February and March 2004 and 4.8 meters during the 2003 value. The difference in canal width is due to a difference at measurement point i between July 2003 and February - March 2004. The canal water surface area, A_{canal}, is 32 470 m^2 for the 2004 measurements and 35 460 m^2 for the 2003 measurement. The evaporation flow leaving the irrigation canal is shown in Table 6. It is highest in the middle of March and lowest in July and on average between 240 and 270 m^3/day. Compared to the change in flow between the inflow point i and the outflow point iii the calculated evaporated water is low (Table 6). Also in this table is Average 2004 the average values from February and March 2004.

Table 6. Evaporation leaving the canal water surface.

Date	Canal evaporation (m^3/day)
17 Jul 2003	142
11 Feb 2004	192
04 Mar 2004	253
15 Mar 2004	364
Average	**238**
Average 2004	**270**

The irrigation flow, Q_I, leaving the canal is calculated with the in- and outflow values and the canal evaporation. Highest irrigation occurred in the beginning of March and the lowest in July (Table 7). The average irrigation for February - March is 144 000 m^3/day which is a larger flow than the flow leaving the canal section at point iii (Table 5).

Table 7. Irrigation flow leaving the Peerzadiguda canal.

Date	Irrigation flow (m^3/day)
17 Jul 2003	88 000
11 Feb 2004	119 000
04 Mar 2004	164 000
15 Mar 2004	151 000
Average	**130 000**
Average 2004	**144 000**

The area irrigated by wastewater from the selected part of the Peerzadiguda canal is 349 ha. The study area is the same area. The study area is 6500 meter long and between 500 meter and 1000 meter wide (Figure 8).

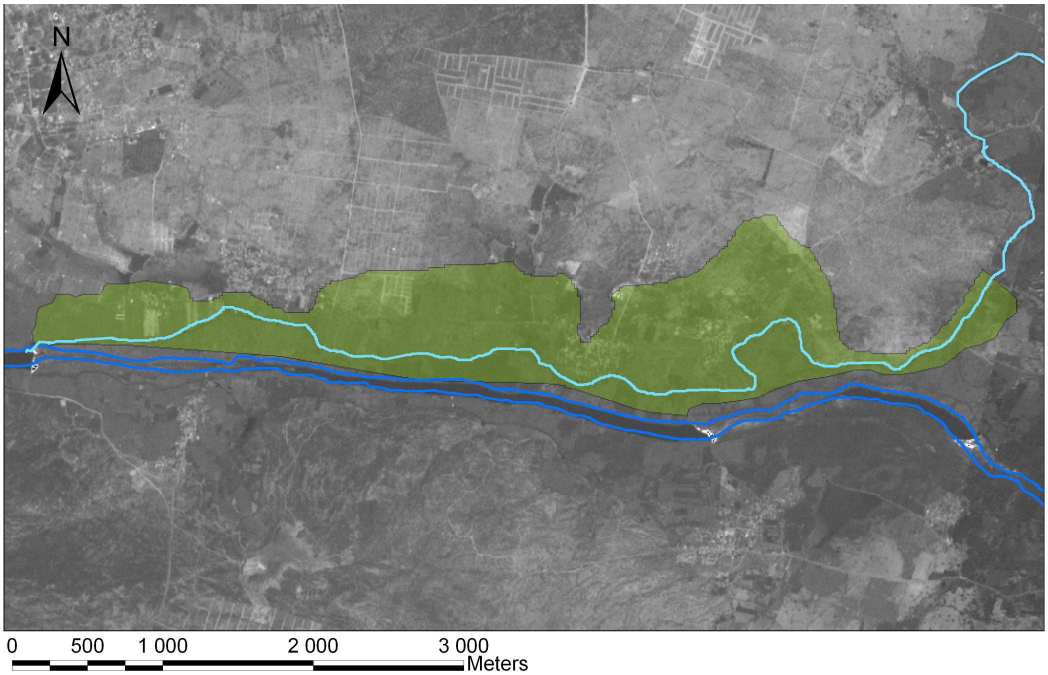

Figure 8. The wastewater irrigated area around the Peerzadiguda canal.

The daily average irrigation of the study area, $I_{StudyArea}$, is calculated with the irrigation flow leaving the canal (Table 7) and the size of the study area (Figure 8). The highest calculated irrigation is in the beginning of March and the lowest in July (Table 8). The daily irrigation in July is slightly more then half the daily irrigation in March.

Table 8. Average irrigation in the study area.

Date	Irrigation (mm/day)
17 Jul 2003	25.2
11 Feb 2004	34.1
04 Mar 2004	46.9
15 Mar 2004	43.2
Average	**37.4**
Average 2004	**41.4**

5.2 ACTUAL IRRIGATION ON THE FIELDS

All the informants had agriculture as their main income. Four of the farms had pumps pumping water from the Peerzadiguda canal to smaller irrigation canals on the fields, 20 to 30 cm wide. One farm had the fields irrigated by gravity from a small opening in the Peerzadiguda canal wall. The irrigation method used by the farmers in the study area was basin irrigation. The farmers had field plots with the size of about 25 m^2 for vegetable and larger fields for paragrass and paddy. Only one informant, farm 1, used fertilizers, urea before the sowing. The informants commonly used pesticides. The informants with large fields of paragrass, farm 3 and 4, also had buffalos for milk production. Answers to the other questions in Appendix 1 like field size and length of crop season are presented in Table 9 below. Most fields are small, less then 1 ha. The crops are usually irrigated with a break of one to three days, but informant 3 irrigated with intervals of one week or one month. The irrigation continued between 2 hours and the whole day or even more.

Table 9. Informants answers to the interview questions. The interview form is attached in appendix 1.

Farm	**1**	**2**	**3**	**4**	**5**
Type of crops	Vegetable	Vegetable Paragrass	Paragrass Paddy	Paragrass	Vegetable Paragrass Paddy
Field size (ha)	Veg = 0.40	Veg =0.20 Para =0.40	Para =0.40 Pad = 0.51	Para = 1.6	Veg = 0.10 Para = 0.10 Pad = 0.20
Intervals between irrigations (day)	Every plot 3	Veg = 2 Para = 4	Para = 30 Pad = 7	Para = 4	2
Length of irrigation (h)	Veg = 2	Veg = 3 Para = 3-4	8	Para = 12-16	8
Length of crop season (months)	Veg = 2	Veg = 1	Pad = 6	-	Pad = 4

Measurements of the irrigation flow on farm 2 and 5 were possible to do. The irrigation flow from the pump on farm 2 was 49 m^3/h and on farm 5 it was 13 m^3/h. Figure 9 shows a pump house and some field plots in the study area.

Figure 9. Pump on a farm in the study area. In the background vegetable field plots ready for sowing. Photographer Charlotta Hofstedt, 2004.

The size of the fields were paced out on these two farms and compared with the information about the field size given by the informants (Table 10). The differences are in several instances very large and close to 10-fold. The total field size on farm 2 is the same but the distribution of the field size are quite different. On farm 5 the paced out field is half the size of the farmer's information of field size.

Table 10. The size of the farmers fields for different crops, both farmers information of field size and a paced out field size.

Farm	2		5	
	Farmers info	Paced out	Farmers info	Paced out
Vegetable (ha)	0.20	0.49	0.10	0.030
Paddy (ha)	-	-	0.20	0.15
Paragrass (ha)	0.40	0.066	0.10	0.032
Fallow (ha)	-	-	-	0.028
Total (ha)	0.61	0.56	0.40	0.24

The irrigation on the farmers' fields is calculated with the irrigation flow, the time the irrigation was performed and the size of the field, I_{field}. As a consequence of the different field size is the irrigation different when it is calculated with the paced out field size or the field size from the interviews. The irrigation is presented per irrigation occasion and per day (Table 11). On farm 2 the paragrass was irrigated every fourth day while the vegetable was irrigated every second day so the irrigation of the total area is hence only presented per day and not per occasion.

On farm 5 the calculated irrigation for vegetable and paragrass is three times larger with the paced out field size then with the farmer's information of field size. The irrigation of the vegetable field on farm 2 is twice the size when it is calculated with the farmer's information of field size then with the paced out field size. On the paragrass field on farm 2 the opposite is true, when the paced out field size is used the irrigation is much larger then when the farmers information of field size is used. The paddy field on farm 5 has around the same amount of irrigation with the farmer's information and the paced out irrigation (Table 11).

Table 11. Irrigation amount for vegetable, paragrass and paddy fields per irrigation occasion and per day. The irrigation for both the paced out and the farmers' information on field size are presented.

Field	Irrigation per occasion (mm)		Irrigation per day (mm/day)	
	Farmers info	Paced out	Farmers info	Paced out
Vegetable				
Farm 2	72	30	36	15
Farm 5	26	89	13	45
Paragrass				
Farm 2	42	259	11	65
Farm 5	26	83	13	41
Paddy				
Farm 5	27	35	13	18
Total area				
Farm 2	-	-	31	22
Farm 5	27	44	13	22

5.3 WATER BALANCE IN THE ROOT ZONE ON FARMERS FIELDS WITH ACTUAL IRRIGATION

The soil in the area is sandy loam according to data from Ensink (2004a). According to Allen *et al.* (1998) a sandy loam is at field capacity when the water content is 0.23 m^3/m^3 and at wilting point when the water content is 0.11 m^3/m^3. The volume distribution of the different soil constituents, except the organic material, of the soil is shown in Figure 10. The mineral part is mainly sand. The water and air content is as at field capacity.

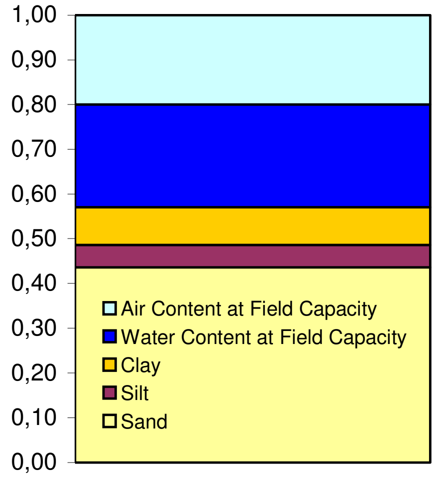

Figure 10. Illustration of the volume distribution of particles, water and air content in the sandy loam soil in the Peerzadiguda area, at field capacity, calculated with data from Ensink (2004a).

According to informant 5 the paddy season is four months long with a start in January and end in May. As the climatic data series ends in March 2004 climatic data from January to May 2003 are used instead in the water balance calculations for paddy.

The evaporation, the irrigation and the water losses for the different crops during one season are presented in Table 12. The length of the vegetable crop season is 30 days and the crop season for paddy is 4 month. The amount of irrigation of the paragrass fields is calculated for a period between 1st of January and 25th of March, 2004. As the irrigation differs if it is calculated with the farmers information of the field size or the paced out field size both are presented in Table 12. In some cases the irrigation is very large: on the paragrass field on farm 2 with the paced out field size used in the calculation, on the vegetable field on farm 5 with the paced out field size, on the vegetable field on farm 2 with farmers information of the field size and on the paragrass field on farm 5 with paced out field size. When the irrigation is large also the water losses are large. The water loss is the water the crop did not use, mainly leaving as deep percolation. In this study evaporation from the soil is included in the evapotranspiration term and not included in the water loss term.

Table 12. Summary of the actual irrigation, crop evapotranspiration and water losses per season on vegetable, paragrass and paddy fields.

Field	Actual irrigation (mm/season)		Crop evapotranspiration per season (mm)		Water losses per season (mm)	
	Farmers	Paced	Farmers	Paced	Farmers	Paced
Vegetable[4]						
Farm 2	1086	445	261	261	771	130
Farm 5	397	1335	261	261	82	1020
Paragrass[5]						
Farm 2	929	5689	698	698	262	5031
Farm 5	1139	3551	711	711	478	2890
Paddy[6]						
Farm 5	1420	1862	1124	1124	356	797

In Figure 11 to Figure 20 are the water storage at different farms and fields shown. At different figures are the irrigation calculated from the farmers information of field size and the irrigation calculated from the paced out field size shown. The water storage in the root zone, S_i, is the line with triangular marks. It is easy to read what day the field is irrigated as the S_i usually goes above the water storage at field capacity, S_{fc} at these times. The water storage at field capacity, S_{fc}, is the straight line with rectangular marks quite high in the figures. The lighter straight line with shorter rectangular marks is the water storage at permanent wilting point, S_{wp}. If the water storage goes below this line the crop will permanently wilt. The figures also shows the water losses – the water not used by the crops - as a dark line with dots usually on the lower part of the figures. All these values, S_i, S_{fc}, S_{wp}, and the water loss are read at the left y-axis. The line with circle marks is the root depth and it is read from the right y-axis. Observe that the water storage in the root zone increases when the root zone expands. In the paragrass diagrams, Figure 15 to Figure 18, the root depths are not plotted as it is assumed that paragrass has a constant root depth of 1.0 meter.

The calculated actual water storage in the root zone was in all examples around the field capacity (Figure 11 to Figure 20). Only after that the irrigation ceased 15 days before the harvest on the paddy field at farm 5, the water storage diminished rapidly and the calculated water storage become lower then the permanent wilting point (Figure 19 and Figure 20). As mentioned above, the irrigation, and hence also the water losses are in some cases large, see Figure 11, Figure 14, Figure 16 and Figure 18. In Figure 15, the paragrass field on farm 2 with the farmer's irrigation of field size is the water storage decreasing in March but it is far from the permanent wilting point.

[4] Calculated with climatic data from 8th of February to 8th of March, 2004.
[5] Calculated with climatic data from 1st of January to 25th of March, 2004.
[6] Calculated with climatic data from 9th of January to 8th of May, 2003.

5.3.1 Water Balance at Vegetable Field, Farm 2

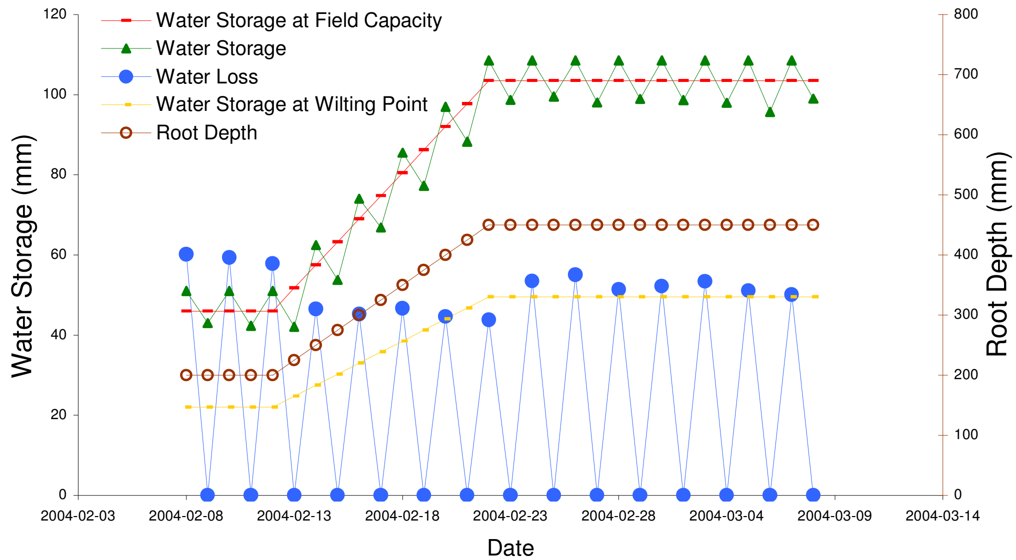

Figure 11. Water balance calculations at vegetable field, farm 2 in February 2004. The irrigation amount was 72 mm every second day, calculated with the farmer's information on field size.

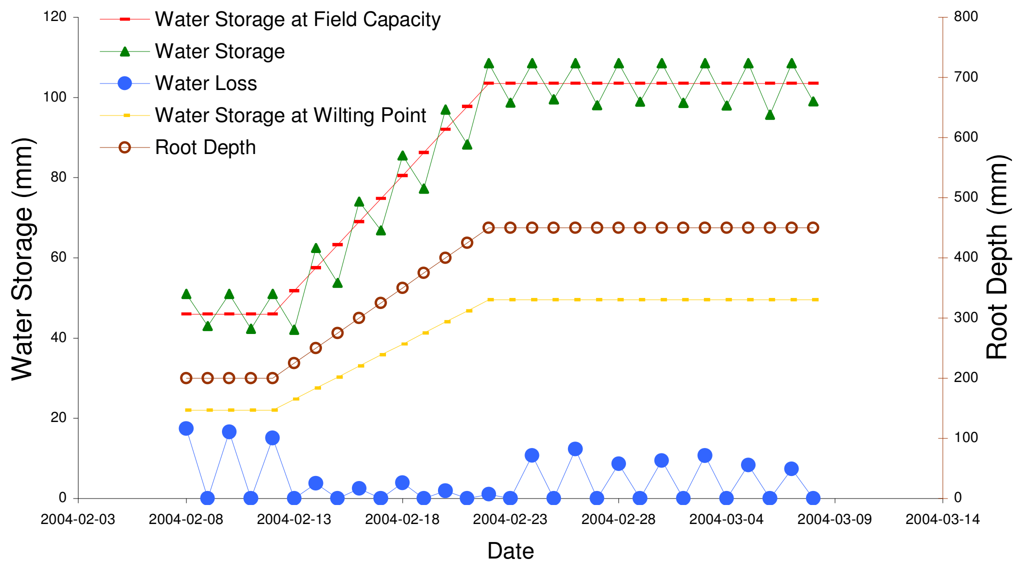

Figure 12. Water balance calculations at vegetable field, farm 2, in February 2004. The irrigation amount was 30 mm every second day, calculated with the paced out field size.

5.3.2 Water Balance at Vegetable Field, Farm 5

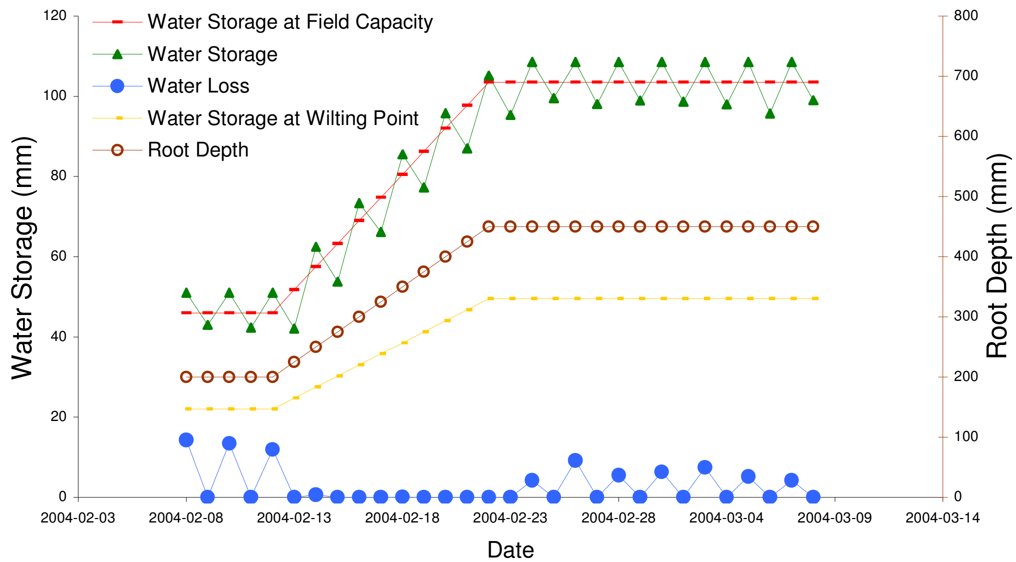

Figure 13. Water balance calculations at vegetable field, farm 5, in February 2004. The irrigation amount was 26 mm every second day, calculated with the farmer's information on field size.

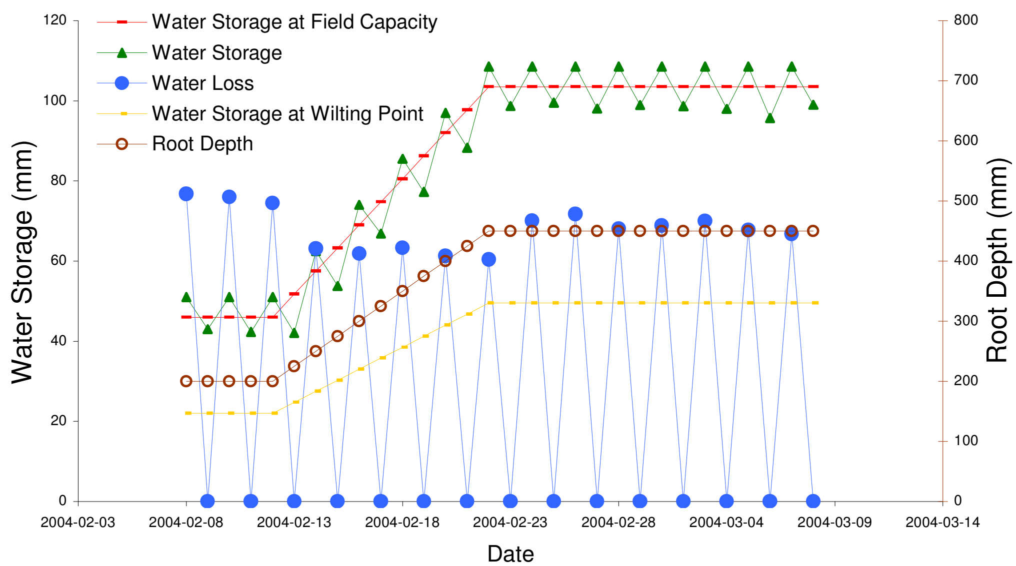

Figure 14. Water balance calculations at vegetable field, farm 5, in February 2004. The irrigation amount was 89 mm every second day, calculated with the paced out field size.

5.3.3 Water Balance at Paragrass Field, Farm 2

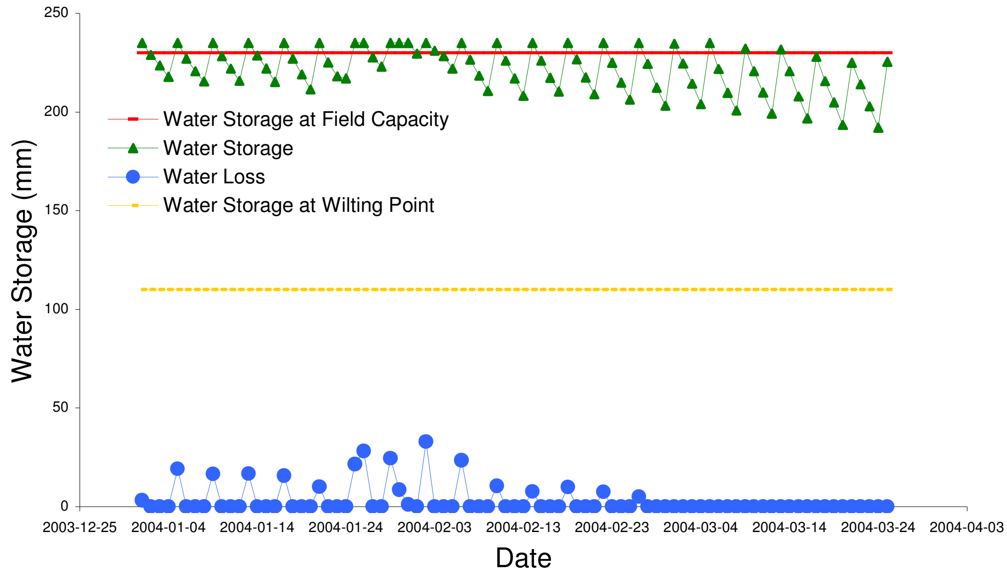

Figure 15. Water balance calculations at paragrass field, farm 2, in January to March 2004. The irrigation amount was 42 mm every fourth day, calculated with the farmer's information on field size.

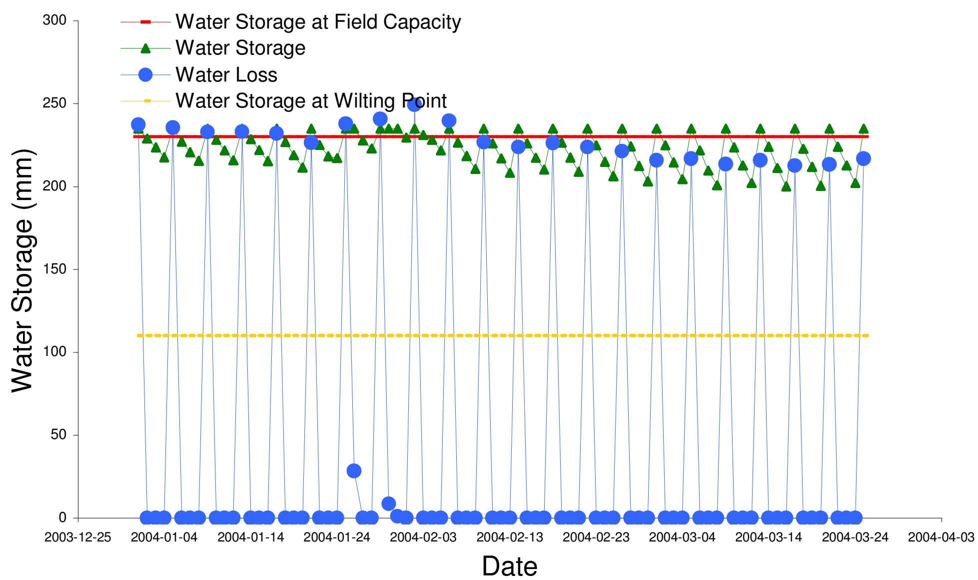

Figure 16. Water balance calculations at paragrass field, farm 2, in January to March 2004. The irrigation amount was 259 mm every fourth day, calculated with the paced out field size.

5.3.4 Water Balance at Paragrass Field, Farm 5

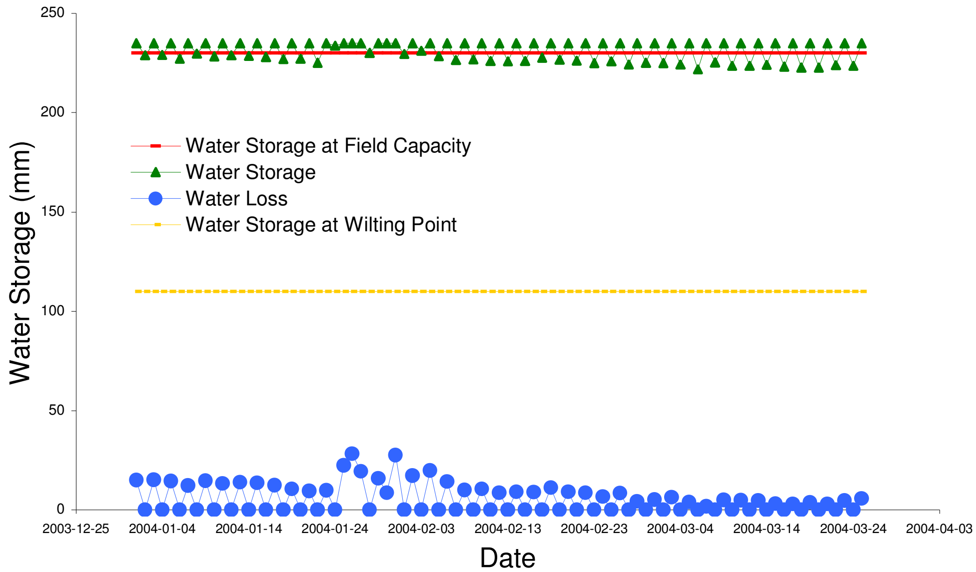

Figure 17. Water balance calculations at paragrass field, farm 5, in January to March 2004. The irrigation amount was 26 mm every second day, calculated with the farmer's information on field size.

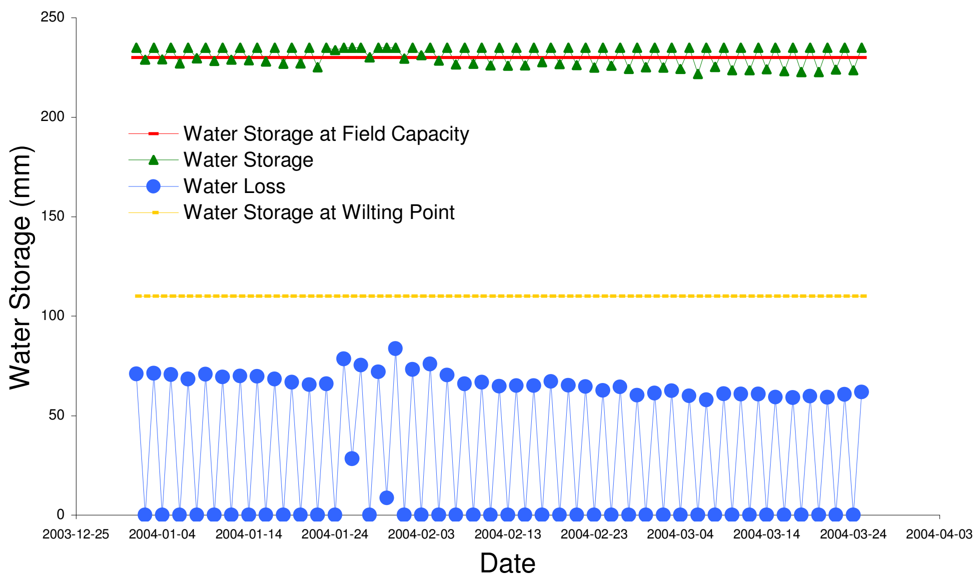

Figure 18. Water balance calculations at paragrass field, farm 5, in January to March 2004. The irrigation amount was 83 mm every second day, calculated with the paced out field size.

5.3.5 Water Balance at Paddy Field, Farm 5

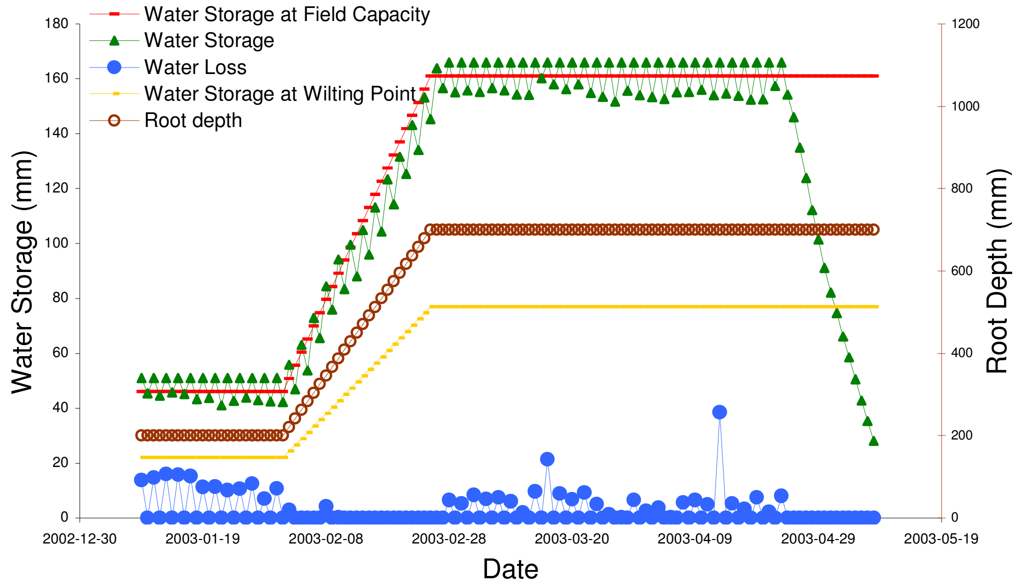

Figure 19. Water balance calculations at paddy field, farm 5, in January to May 2003. The irrigation amount was 27 mm every second day, calculated with the farmer's information on field size.

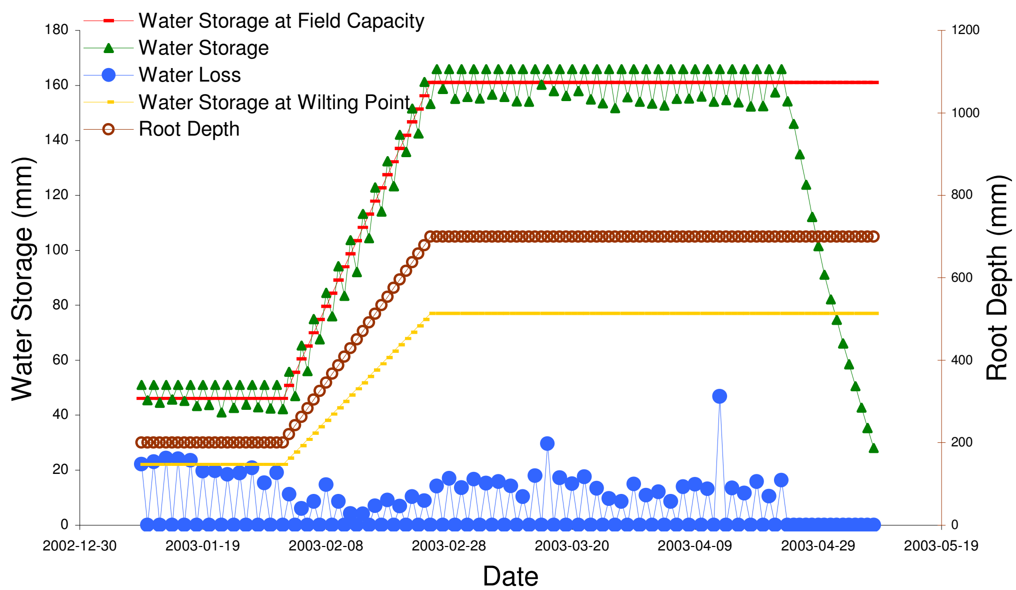

Figure 20. Water balance calculations at paddy field, farm 5, in January to May 2003. The irrigation amount was 35 mm every second day, calculated with the paced out field size.

5.4 OPTIMAL IRRIGATION IN THE STUDY AREA WITH BASIN IRRIGATED FIELDS

A water balance calculation was performed to achieve an optimal irrigation scheme for the vegetable and paragrass fields. A calculation for paddy was not performed. Rice requires a soil water depletion fraction of 0.20 of saturation according to Allen *et al.* (1998). This means that rice plants experience water stress and a decrease in the crop growth when the water storage in the root zone is above the water storage at field capacity. The soil water depletion fraction from Allen *et al.* (1998) is probably valid for rice that is standing in water and not for the paddy rice cultivated in the study area that was not standing in water. As no better p for paddy rice cultivated in the area was found no optimal water balance was calculated. A summary of the optimal irrigation, the crop evapotranspiration and the water losses for vegetable and paragrass during one crop season is presented in Table 13. The crop evapotranspiration is the same for vegetable as in Table 12 and similar for paragrass. The irrigation and water losses are smaller than with the actual irrigation (Table 12 and Table 13).

Table 13. Summary of the optimal irrigation, crop evapotranspiration and water losses on vegetable and paragrass fields.

	Optimal irrigation per season (mm)	Crop evapotranspiration per season (mm)	Water losses per season (mm)
Vegetable[7]	370	261	55
Paragrass[8]	700	675	73

In Figure 21 and Figure 22 the water balance with the optimal irrigation are presented. The water storage in the root zone, S_i, is the line with triangular marks, the water storage at field capacity, S_{fc}, is shown with rectangular marks. The water storage at permanent wilting point, S_{wp}, is a lighter line with shorter rectangular marks and the water storage when the crops first experience water stress, S_{ws}, is between S_{fc} and S_{wp} shown as a line with crosses as marks. The water loss is a darker line with dots. All this values are read at the left y-axis. The root depth is the dark line with the rings and it is read at the right y-axis.

The optimal irrigation scheme for the vegetable field is an irrigation every second day during the 30 day long crop season (Figure 21). The first three times is the field irrigated with 15 mm of water, the following five time with 30 mm and the last seven with 25 mm. The water storage is good at all occasion. During the increase of the root depth the water storage, S_i, appears to be below the water storage of water stress, S_{ws}, but this is not true. The additional depth contains, in the calculation, no water which is not the actual case. This implies that the water storage after an irrigation day, S_i, should be compared to the water storage at water stress, S_{ws}, from the day before. The paragrass field was irrigated ten times with 70 mm of water during the 85 days the water balance calculation occurred (Figure 22). During the 24th and 31st of January 56 mm of precipitation fell and no irrigation had to be performed. The irrigation was performed with shorter intervals as the time passed. In January the irrigation is not so frequent but in March irrigation is performed once a week. The water losses are low in both Figure 21 and Figure 22.

[7] Calculated with climatic data from 8th of February to 8th of March, 2004.
[8] Calculated with climatic data from 1st of January to 25th of March, 2004.

5.4.1 Water Balance in the Root Zone with Optimal Irrigation

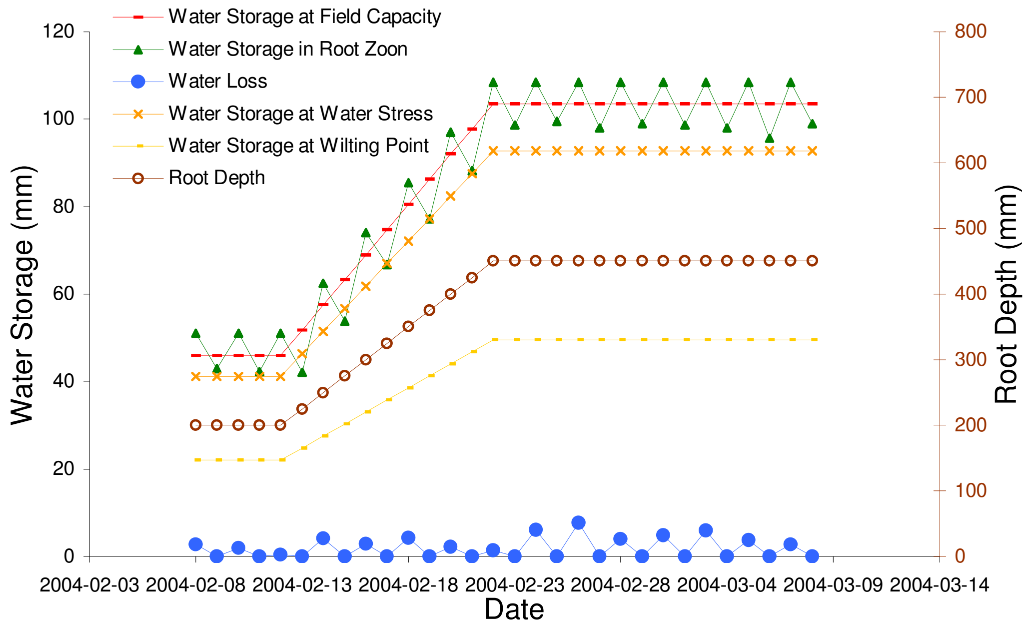

Figure 21. Water balance calculations at vegetable field February 2004, with optimal irrigation amount.

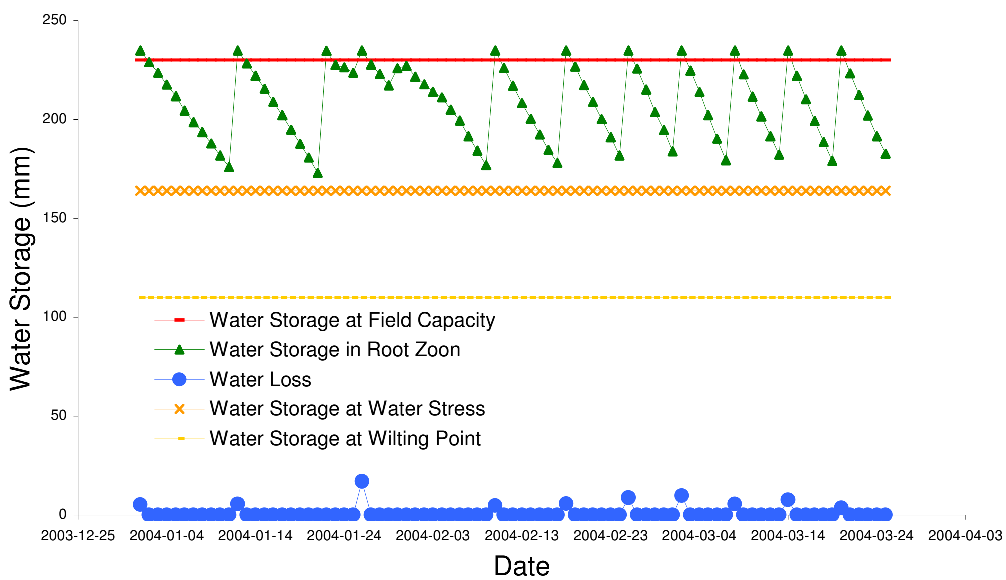

Figure 22. Water balance calculations at paragrass field January to May 2003, with optimal irrigation amount.

5.4.2 Salt Accumulation in the Root Zone

In Hofstedt (2005) values of the electric conductivity in the Peerzadiguda canal water, EC_w, are presented. According to data from Pollution Control Board (PCB) in Hyderabad the EC_w is in average 1.7 dS/m with standard deviation 0.389. The average value is calculated from 66 measurements taken in the period 1993 to 2000, two of the values are taken before 1998. According to data from Ensink (2004a) the average value is 2.15 dS/m with a standard deviation of 0.254. The electric conductivity was measured 15 times during 2002 and 2004. The leaching requirement, *LR*, to avoid salt accumulation is calculated from the data over *EC* and presented in Table 14. The leaching requirement for vegetable is higher then the other two.

Table 14. Leaching requirements to avoided salt accumulation, calculated with values of electric conductivity in the irrigation water, EC_w, from PCB (2004) and Ensink (2004a), the threshold values of electric conductivity in soil, EC_e, from Ayers and Westcot (1985), leaching requirement, *LR*, for vegetable, paragrass and paddy crops.

Crops	EC_e (dS/m)	*LR* with PCB	*LR* with Ensink
Vegetable	2.0	0.21	0.28
Paragrass	2.8	0.14	0.18
Paddy	3.0	0.13	0.17

Salt accumulation in the root zone occurs after a long time of irrigation with saline water. For that reason the calculation of the water that should be applied, *AW*, should be calculated over one year. The values presented in Table 15 are calculated for a shorter period, which mean that they just are an indication of how the irrigation should be performed.

Table 15. The required applied water to prevent salt accumulation, *AW*, and the minimum leaching, with data from PCB (2004) and Ensink (2004a).

Crops	ET_c (mm/season)	*AW* (mm/season)	
		PCB	Ensink
Vegetable[9]	261	329	359
Paragrass[10]	675	782	823
Paddy[11]	1124	1292	1540

6 DISCUSSION

The discussion has the same disposition as the method and result chapters. It starts with the average irrigation in the study area, continues with the actual irrigation on the fields and the water balance, and in the end the optimal irrigation scheme is discussed. A few issues concerning health risks with wastewater irrigation are also discussed.

[9] Calculated with climatic data from 8th of February to 8th of March 2004.
[10] Calculated with climatic data from 1st of January to 25th of March 2004.
[11] Calculated with climatic data from 9th of February to 8th of May 2003.

6.1 AVERAGE IRRIGATION IN THE STUDY AREA

The measured average irrigation in the study area was between 25 and 47 mm per day. The average irrigation amount was lowest on the 17 of July 2003, which is quite natural as it is during the monsoon and not much irrigation is performed. Also the flow in the irrigation canal was smaller during 17th of July, probably was the flood-gate in the anicut adjusted to let a small flow enter the Peerzadiguda canal at that period. The irrigation values in March are around 10 mm higher than the value from February, which is reasonable as the crop evapotranspiration rate was larger during that period due to higher temperature and lower relative humidity.

Uncertainties about the average irrigation in the study area are that the flow measurements in the canal not were performed at the same time at the different measurement points in the canal. This means that the flow measurements do not show the actual changes in the water flow. Another uncertainty is the determination of the wastewater irrigation area. Roads and a few small villages are included in the area and an approximation of this non-irrigated land was not done. This could mean that the average irrigation is larger then what the result in this report shows. On the other hand, all water losses from Peerzadiguda canal are assumed to be zero except the evaporation from the canal water surface, which might not have been the case. This could mean that the average irrigation is lower than the result in this report.

6.2 ACTUAL IRRIGATION ON TWO FARMS

The information the farmers gave about the size of their fields was quite different from the field size that was paced out. This results in problems in determining the actual irrigation of the fields. Because of these uncertainties two actual irrigations were presented per field. Below is a discussion of what this difference in field size depends on and what it leads to.

The farmers information of the field size and the paced out field size on **farm 2** is nearly the same for the **total field** size but the distribution of the crop fields were different (Table 10). The paced out **vegetable field** size was more than twice the size of what the farmer stated and the paced out size of the **paragrass field** was much smaller than the farmer informed. The conclusion of the field size problem is that the informant on farm 2 underestimated the vegetable field size and overestimated the paragrass field size seriously or that the paragrass field was larger then was understood.

On **farm 5** the total paced out field size was nearly half of what the farmer had said. The size of the **paddy field** was of almost the same size, 0.15 ha was paced out and 0.20 ha according to the farmer. The farmer informed and the outpacing confirmed that **vegetable** and **paragrass fields** had the same size. However the pacing of the vegetable and paragrass fields were only one third of what the farmer said. The informant on farm 5 probably overestimated the sizes of the fields.

The irrigation of the **vegetable fields** varies between 26 and 89 mm depending on farm and which field size is used (Table 11). The irrigation is performed every second or third day according to the informants (Table 9). Irrigation of the **paragrass field** varies between 26 and 259 mm per irrigation. Irrigation with 259 mm is clearly larger than the others. It was performed on farm 2 with the paced out field size, but the field was probably larger then was understood. The second largest value of paragrass irrigation is 83 mm irrigated every second day. The irrigation interval for paragrass is between every second day and once a month, according to the informants. Two informants said every fourth day. The paragrass field that was irrigated once a month was on **farm 3** which was located between the irrigation canal and the river and probably received water from the fields above and did not need irrigation as often as other fields. The **paddy field** on farm 5 had an irrigation of 27 or 35 mm every second day. **Farm 3** had also paddy fields and the informants there said that they irrigated their paddy field once a week and as mentioned above this irrigation is not representative for the area. All irrigation, except the very large value of the paragrass field on farm 2, is of the same magnitude, between 26 and 89 mm.

The mean value of the irrigation amount of the total farm area in Table 11 is 22 mm/day compared with the average irrigation over the whole study area that is 41 mm/day (Table 8). This means that the average actual irrigation on the two farms in the study area is half the average irrigation of the whole study area. One explanation to this is that the assumptions of the losses in Peerzadiguda irrigation canal are not reasonable.

Uncertainties in the determination of the actual irrigation are the following: Optimally the water flow flooding into the smaller field plots should been measured instead of the flow directly after the pump, as was the case. These measurements of the pump-flow were just performed once at each farm. They should have been confirmed by more measurements. This pump-flow was then assumed to irrigate the entire farm at a constant rate in the proportion as the informants said. This is an uncertain assumption of the following reasons: the pumps were not pumping water with the same flow at all times due to fluctuations in the electricity and that garbage like plastic bags from the water got stacked in the pump. Power cuts sometimes decreased the planed irrigation time and the farmer probably did not irrigate the crops a certain time period, but ceased with the irrigation when the soil seemed to be sufficiently wetted. It is also assumed that the fields are irrigated with the frequency as the informants told at the interview, but in the irrigation practice the irrigation frequency is dependent on the appearance of the crops, the soil and the weather conditions e.g. no irrigation is performed after a large rainfall.

6.3 WATER BALANCE WITH ACTUAL IRRIGATION

The soil and climate data are assumed to be the same at the two farms, also the irrigation pattern is similar. This is reflected in the resulting water balance figures, the water storage is quite alike for the same crop on the two farms.

The water storage values are good in all the water balance calculations concerning the **vegetable fields**, see Figure 11 to Figure 14. They do not experience water stress but the water losses are large at farm 2 when the farmer's information of field size was used, 771 mm during one season, and at farm 5 when the paced out field size was used, 1 020 mm during one season (Table 12).

The **paragrass** is irrigated every fourth day at farm 2 and every second day at farm 5. Paragrass can handle both waterlogging and water stress. The paragrass field on farm 2 was irrigated with 42 mm per occasion, see Figure 15, and seems to have enough water in January and February, but the water storage tends to decrease during March. The crop evapotranspiration increases from 6.3 mm/day in average in January to 11 mm/day on average during the 1st and 25th of March. The crop evapotranspiration increased due to increasing temperature and decreasing relative humidity. These factors make an irrigation of 42 mm every fourth day too small in the long run. An irrigation of 259 mm every fourth day causes on the other hand large water losses, see Figure 16. An irrigation of 26 mm every second day seams to keep the water storage close to the field capacity at all times (Figure 17). To irrigate the paragrass with 83 mm (Figure 18) gives unjustified water losses.

Paddy was only cultivated on one of the measured farms, farm 5, and Figure 19 and Figure 20 illustrate the water balance for paddy. They show that the paddy plants experience water stress during the end of the paddy season. The farmer said that he did not irrigate the paddy field the last 15 days before the harvest because he wanted the soil to become dry. During this period the water storage went below the wilting point. Water losses do occur from the paddy fields but they are quite small.

The irrigation is in general using more water than necessary. This means that the crops do not experience water stress and that a lot of water is added to the field which is not used for the crops growth. The excess water is assumed to leave as deep percolation.

Another source of error in the water balance calculation is that the soil type is identified with soil samples just outside the study area, no samples were taken on the actual farms. It is assumed that the soil in both the farms is the same, which may not be the case.

6.4 OPTIMAL IRRIGATION

The optimal basin irrigation is lower than the actual irrigation. For **paragrass** the optimal irrigation is with less water, 700 mm per season to compare with 900 to 5 700 mm for the actual irrigation. Still the optimal irrigation achieves a good water balance. The optimal irrigation on the **vegetable** field has the same water storage as the actual irrigation, but it is irrigated with less water, 370 mm, compared with the actual irrigation of 397 to 1 335 mm per season. The water losses are considerably smaller for the paragrass and the vegetable field compared to the actual irrigated fields (Table 12 and Table 13).

The electric conductivity, *EC*, is higher in the Peerzadiguda canal water than in freshwater. The actual irrigation of the paragrass and vegetable fields (Table 12) exceeds the required applied water (Table 15). The applied water criteria are not fulfilled with the optimal irrigation for paragrass (Table 13). As mentioned before, the salt accumulates in the soil during a long period and the leaching can occur once a year to keep the salt content at an acceptable level. As the precipitation in the area is 890 mm/year mostly falling during the monsoon, June to August, salt accumulation would probably not be a problem even with the optimal irrigation schemes. The required applied water is calculated with the value when no negative impacts on the crop growth have been observed. It should also be noticed that the salt in the wastewater does not disappear, it has to go somewhere and even if it does not accumulate in the root zone of the fields it can lead to problems in the groundwater or in streams downstream of the fields.

6.4.1 Localized Irrigation

The use of localized irrigation seems to be a good alternative when the irrigation water quality is low. In Ayers and Westcot (1989) there is a guide over the water criterion that needs to be fulfilled when a drip irrigation system is used.

With irrigation of vegetables that are consumed uncooked a localized irrigation system could work better than the basin irrigation system that is used now. The health risk would be reduced and water would be saved. The salt accumulation in the root zone could also be controlled if required leaching is performed.

The problem with a localized irrigation system is that sediments in the water block the system. The Peerzadiguda canal water contains lots of sediments and some kind of treatment like sedimentation or filtration needs to be done. Bubble irrigation might work better than drip/trickle irrigation, as the flow rate is higher. Another problem with localized irrigation is the cost of the system and the treatment of water. The farmers in the area have small pieces of land and it is not likely that they can afford such a system. The farms in the study area do not experience water stress - there is sufficient amount of water in the canal and the water saving argument is probably not valid for the farmers. A localized irrigation system is also work intensive, but the system they have today with opening and closing the borders around the field plot is also work intensive, so that would not be an extra investment. Most of the farmers also have a pump that they can use in a localized system. The largest benefit with a localized irrigation system would be the health improvement for the labourers working on the fields.

6.5 HEALTH PERSPECTIVE ON THE IRRIGATION WITH PEERZADIGUDA WATER

According to Hofstedt (2005) there is no change in the nematode (ringworm) concentration along the irrigation canal. The average concentration of nematodes in the irrigation canal calculated from 21 samples, taken directly after the Peerzadiguda anicut, is 34 eggs per litre with a standard deviation of 17 (Ensink, 2004a). As mentioned in chapter 3.1.2 in this report, the WHO guideline (1989) recommends that the irrigation water should contain less than one egg per litre if field workers and consumers are likely to be exposed. The water in the Peerzadiguda canal does not fulfil the criteria for restricted irrigation in category A and B from WHO (1998) and should according to the guidelines be used in category C irrigation, this is localized irrigation of cereal crops, industrial crops, fodder crops, pastures and trees. The average irrigation in the area, 41 mm, gives 1408 egg/m^2, with a nematode concentration of 34 eggs per litre.

7 CONCLUSION

- The use of a basin irrigation method in the study area leads to:
  - ⇒ sufficient or large use of irrigation water
    - → water losses from the root zone
    - → large amounts of water are pumped to the fields with no benefit in crop growth
    - → eliminates the risk of salt accumulation in the root zone
    - → could lead to water scarcity for farms downstream
  - ⇒ larger amount of pathogenic organisms are added to the soil.

- An optimal irrigation with basin irrigation would lead to:
  - ⇒ less amount of water loss
  - ⇒ an increased risk of salt accumulation in the root zone, but it can be prevented if the leaching requirement is followed
  - ⇒ a smaller amount of pathogenic organisms in the soil.

- An optimal irrigation with localized irrigation would lead to:
  - ⇒ less use of water
    - → increasing water losses
    - → salt accumulation around the root zone, which can be prevented if the leaching requirement is followed
  - ⇒ decrease of infection risks
  - ⇒ increased capital cost for the farmers
  - ⇒ problems with the irrigation system due to sediments in the water.

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APPENDIX

APPENDIX 1: INTERVIEW QUESTIONS TO THE FARMERS

Time and date:

Travel instructions:

Questions to farmers:

Social data:

1) **What is your name?**

2) **What is your main income?**

Crop data:

3) **What crops do you cultivate?**

4) **What size of fields do you have for each crop?**

5) **When where time of sowing for the crops you cultivate now?**

6) **When is time for harvest for the crops you cultivate now?**

7) **What crops do you cultivate in different periods of the year?**

8) **Do your field lie in follow at any time of the year? (Ligga i träda.)**

Irrigation data:

9) **Do you irrigate any of your crops?**

10) **Where do you get the irrigation water? (Canal water, Groundwater, Musi river water, other alternative)**

11) **When did you irrigate last time? (Each crop.)**

12) **How much did you irrigate? (Each crop.)**

13) **Do you always irrigate with the same amount of water? (Each crop.)**

14) **When do you irrigate next time? (Each crop.)**

15) **How many times do you usually irrigate your crops during one season? (Each crop.)**

16) **When do you start irrigating? (Before sowing?) (Each crop.)**

17) **When do you stop irrigating? (Before harvest?) (Each crop.)**

18) **What criteria do you have for irrigation?**

Fertilizer data:

19) **Do you use any fertilizer for the crops you are cultivating now?**

20) **What kind of fertilizers do you use?**

21) **How often do you add these fertilizers?**

22) **How much do you add?**

Irrigation techniques:

23) **Can you show me how your irrigation system is working? Your pump, canals etc. [Surface irrigation, Furrow (fårbevattning), Border (Tegbevattning), Basin (Bassängbevattning)]**

Future:

24) **Is it ok if I come back and do some water flow measurements in your irrigation canals?**

25) **Is it ok if I come back and ask you some complimentary questions?**

Comments: