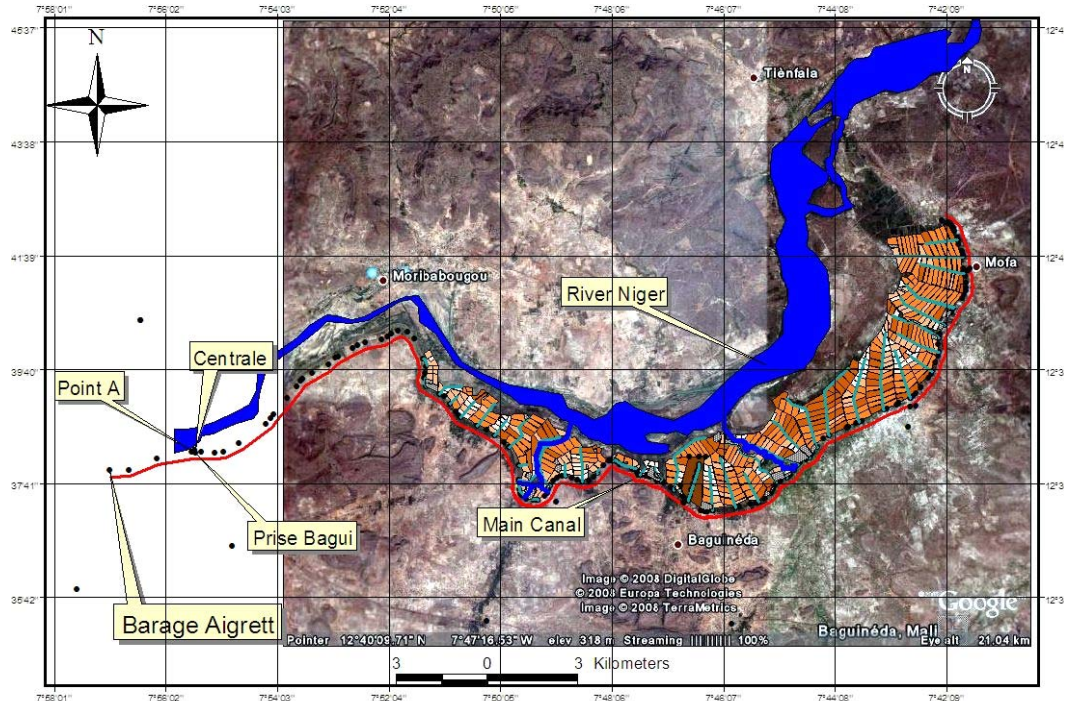


UNESCO-IHE INSTITUTE FOR WATER EDUCATION



Improving Irrigated Crop Land Productivity in Baguinéda, Mali Current Situation and Modernization Scenarios Analyses

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Master of Science Thesis
by
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Summary

Objectives

Baguineda is a small city of Mali, located 30 km away from the Malian Capital Bamako on the right bank of river Niger. This rural district gathers 32 villages with a population of approximately 27,000 inhabitants. A small barrage on the river Niger raises the water level and a feeder canal on the right bank of the river conveys 110 m³/s to a point called point "A". From this point, the flow in a left branch supplies a hydropower plant with more than 100 m³/s. In the right branch some 8 m³/s flows in a 40 km long irrigation canal to irrigate some 3,000 ha at Baguineda where 3,000 families are growing crops. At the beginning the canal was designed to convey 9 m³/s.

Despite of it's proximity with Bamako where a potential market of more 800,000 persons exists, the irrigation scheme of Baguineda faces a certain number of problems: i) the deterioration of the main system, ii) insufficient discharge during the dry season, iii) distorted water supply and iv) low crop yields. As consequence, farmer's revenues are low and a persistent poverty exists.

In 2007 the yields in the dry season of rice, maize, onion and tomato were respectively 4 tons/ha, 1.4 tons/ha, 21 tons/ha and 30 tons/ha. The cropping land area was only 677 ha out of 3,000 ha. The low discharge in the dry season is the main constraint to the development of the cropping land. It has several causes : i) the water withdrawals of the hydropower plant installed on the second branch of the feeder canal, ii) the important seepage along the non lined main and secondary canals (only 12 km are lined in the main canal) and iii) water allocation rules not clarified.

This MSc research report addresses six basic issues related to the above mentioned problems:

- *water allocation rules* to secondary blocks irrigated by secondary canals
- *decision making process* of water allocation to secondary blocks
- seasonal determination of *crop land sizes* and the way to *follow up its changes*
- appropriateness of *conveyance and flow control structures*
- affordability of *water fee* and the determination of *suitable crops*
- evaluation of the impact of the headwork *discharge and seepage* on the flow (discharge and water level) through the water supply network

Method

A Garmin GPS Map 60 CSx measuring campaign was conducted from November 2007 to January 2008 at Baguineda in Mali. This campaign provided the geographic locations of the main canal centreline and its flow control structures: gates, weirs, official and non official intakes and bridges.

With some 207 GPS measurement points there were enough elements to create in a geographic space the entire crop land and the soil suitability maps. But before this development in GIS information software, scanning the maps was required. Therefore, a hard copy at scale 1:1,000 of the crop land with the delineation of the secondary and tertiary blocks was scanned using a digital camera Sony DSC-H3. With the same digital camera, the hard copy soil map at scale 1:2,000 was scanned.

These three components – GPS measurement points, crop land map and soil map - were processed in Arcview GIS 3.3 to produce the main attributes and a database of the irrigation system of Baguineda.

In order to get a sample of the flow through the water supply network, discharge measurements were realized at the headwork gates and on 4 out of 7 regulators of the main canal. The structure at the headwork is a double vertical gate. A typical regulator is composed of a 13 m long central weir accompanied with 2 vertical lateral gates. The elevations were measured with a laser single point level (Single Point Laser Kit) and the distances with a Stanley ultrasound meter.

In addition to the discharge measurements at the gates and on the weirs, 5 measurements were performed with the rod-float method in the main canal (10 m of width).

Using these geometric and hydraulic data, *current* and *modern* scenarios analyses were carried out by spreadsheet computations with MS Excel and hydraulic simulations with HEC River Analysis System (HEC-RAS).

The scenarios were designed to investigate on the influence of four factors which are the:

- increase of irrigation water volume when are lined the 54 km of secondary canals
- increase in discharge and water levels when the main canal is lined
- crop land area gain when deficit irrigation is practiced with 25% of the required irrigation water and 50% of the required irrigation water; both with a yield reduction of 80%
- change in water fee affordability when the water supply network is completely lined

Results

Crop land productivity can be greatly improved by using GPS/GIS and scenario analysis. The 2,846 ha of Baguineda cropland were entirely imported into GIS and a soil map, a crop land map and a nomenclature were created. The lengths, areas, geographic locations and names of the system geometry are now recorded in a GIS database. The system comprises i) the main canal and its flow control structures, ii) the secondary canals, iii) tertiary canals, iv) the tertiary blocks, v) the secondary blocks, vi) the main and secondary drains vii) the tertiary drains and viii) the roads.

As regards with the investigated questions, the main results are :

1. **At the beginning Baguineda was designed for *productive irrigation* but this overall objective has been turned into *protective irrigation*.** The original specific discharge was $q = 3 \text{ l/s/ha}$ under the *upstream control method*. Presently, under the pressure of water scarcity due to seepage, hydropower consumption and cropland extension, the system objective has been turned into *protective irrigation*. Consequently, the system operation became *very complex* in the dry season and transferred discharges are not actually known. **The *equity aimed in protective irrigation* can not be met and spontaneous non-authorized water withdrawals are emerging along the main canal.**

2. During water scarcity, rotations along the main and secondary canals are applied and the flow through the secondary canals is **intermittent**. Along the main canal; a rotation is practiced between two groups of secondary canals. The first is composed by CSK1-CSB14 (regulated with the regulators R1, R2, R3 and R4; see Figure 1) and the second group comprises CSB15-CSB25 (regulated by R5, R6 and R7). The gate openings on a regulator are *complex combinations* that can have at least three configurations: i) both gates are closed, ii) both gates are open and iii) one gate is open and the other is closed. Water can flow also above the central weir.

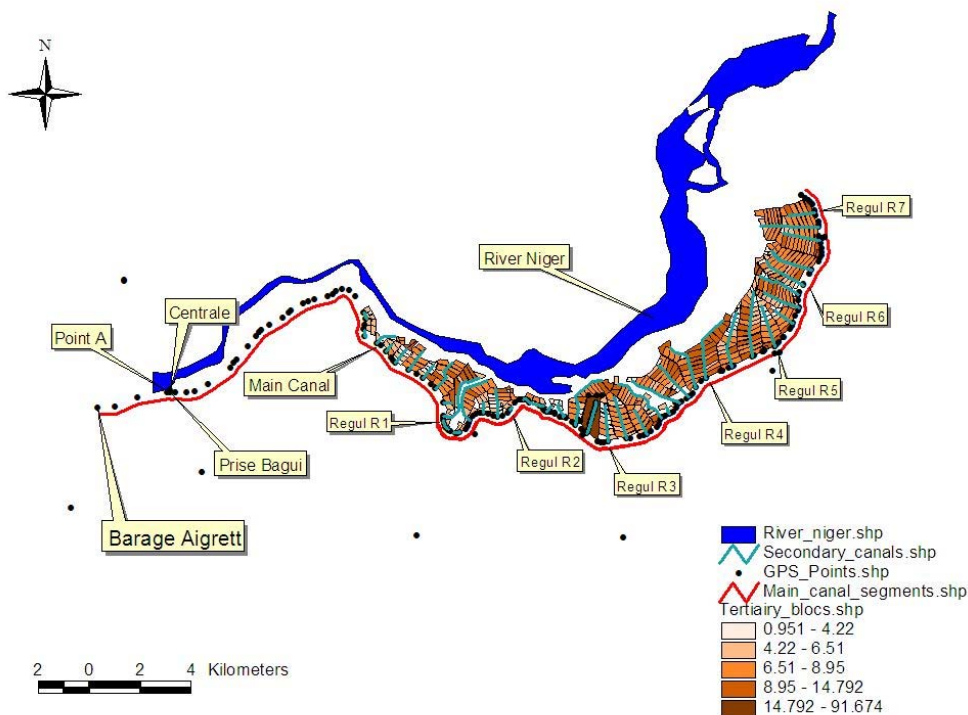


Figure 1: Baguineda Irrigation System
The tertiary block sizes are in ha.

3. **Decision making process: during the dry season, the practice is a *pre-arranged water allocation*.** Although the Committee for Irrigation and Maintenance (CIE) is the highest farmers' organization managing a secondary canal and in which the Office du Périmètre Irrigué de Baguineda (OPIB is the Operation and Maintenance Agency) is not formally involved, CIE has no contract with OPIB. The *organization that takes this decision is the Parity Commission for Exploitation and Maintenance (CPEE)* in which the farmers have representatives.
4. Due to water scarcity in the dry season, the ***upstream control structures of the system are turned into simultaneous control option***. In the dry season, under the concomitant pressure of water scarcity due to seepage and hydropower withdrawals the system water

levels and discharges are changed by manipulation of the gates on the 7 regulators. Flow moves under the *simultaneous control* method. The simulations with HEC-RAS of the 15 km of not lined canal upstream regulator R1 show that i) in the *current scenario* ($8.0 \text{ m}^3/\text{s}$ at the headwork and *not lined main canal* with $0.22 \text{ m}^3/\text{s}/\text{km}$), when the lateral gates of regulator R1 are open, the water level drops 20 cm distorting the discharge taken by the 11 first secondary intakes and ii) in the *modern scenario* (with $9.5 \text{ m}^3/\text{s}$ at headwork and *lined main canal* with seepage of $0.10 \text{ m}^3/\text{s}/\text{km}$) a water level gain of 14 cm upstream R1 is obtained ensuring a better supply to the secondary canals.

5. **Not more than 615 ha are cultivable during the dry season in the current scenario with non lined main canal. Even with the main canal lined (modern scenario) at maximum 2,000 ha can be cultivated.** Assuming that the 416 ha upstream regulator R1 are normally supplied, the *current scenario* hydraulic simulations (HEC-RAS) – with $8.0 \text{ m}^3/\text{s}$ at the headwork and $0.22 \text{ m}^3/\text{s}/\text{km}$ of seepage – yield a specific discharge of $q = 1.50 \text{ l/s/ha}$ for the 2430 ha located downstream R1 while the crop irrigation requirements are 3 l/s/ha . It follows that only 615 ha are irrigable, number in agreement with the 2007 dry season cropping area (677 ha). The *modern scenario* HEC-RAS simulations ($9.5 \text{ m}^3/\text{s}$ at the headwork and lined main canal) yielded a specific discharge $q = 3 \text{ l/s/ha}$ under the constraint that not more than 2,000 ha are cultivated.
6. **Some 160 ha are gained when deficit irrigation is practiced with 25% of the required irrigation water (current scenario). In a modern figure with 50% of the required irrigation water 315 ha more will be recovered.** However, the yields in Baguineda are currently low and this is true for both the dry and the rainy seasons. Therefore, other factors are limiting the yields. Deficit irrigation can be applied only after yields are set free from these other limiting factors.
7. **Land suitability map of Baguineda helps differentiating that in the dry season 60% of the soils are quite good for vegetable production while in the rainy season 80% of the soils are very good for rice.** As results of the soil map processing, four classes were obtained which are 2R, 1P, 2P and 1R. The class 2R is an area of 1,900 ha and is very good for rice but only in the rainy season. In both rainy and the dry season, the two classes 1P and 2P are very good for maize and vegetables. Together, they represent 670 ha. The class 1R is equivalent to 500 ha and very good for vegetables in the dry-season and very good for rice in both seasons. A copy of the soil map files was given to OPIB.
8. **The total cropping area is equal to 2,846 ha. The average secondary block size is 70 ha.** Besides the canals and drains, tertiary and secondary block sizes were computed with GIS. A nomenclature of the farm system was created and made available to the O&M agency (OPIB). On the map produced, the centre of each tertiary block is a point which geographic coordinates are known. Therefore, any agent with a GPS can go to the point.

9. **While producing rice and vegetables farmers can afford the water fee in both seasons, maize appears as a non rational choice in the rainy season.** In fact rainfall is enough to balance maize irrigation water requirements (560 mm) in the rainy season. Paying a fee for maize in the rainy season is not rational. In addition in the dry season the ratio water fee/profit margin for maize equals 30%. The water fee value is currently 48.8 €/ha. The fee in the *modern scenario* was assumed to be 10% higher. The lowest ratio (water fee)/(profit margin) is obtained with tomato (or vegetable) with less than 0.30%, followed by rice with less than 0.70% in *both scenarios*. But it is worth to mention that tomato is only grown in the dry season and that 80% of the rice production is consumed by farmers themselves.

Conclusions

This Master of Science research has opened the way for modelling the entire Baguineda Irrigation System. The canal geometry generated can be completed by the dimensions of the secondary canals. Long throat concrete flumes should be installed along the main canal, one after each secondary intake.

Modelling the entire system to simulate the flow through will permit discharge measurement best location identifications and a possible automation of the gate operations.

On the other hand, the GIS database and maps generated during this research can be used by OPIB to follow up the crop land productivity and the irrigation network maintenance. We recommend providing to the sub-sector responsables GPSs and to assign them to measure the tertiary and secondary block borders. Therefore, the crop land map is updated every season.

Furthermore, we strongly encourage the creation of GIS Centre (GIS-C), a Water Operation Centre (WOC) and the lining of the remaining reaches of the main canal and all the secondary canals. Otherwise, OPIB cannot provide a reliable water service.

Key words: Aigrettes – Baguineda – Bamako – canal – crop land – crop water requirements – decision making – deficit irrigation – discharge measurement – European Union – flow control structures – GIS – GPS – hydraulic – hydro power – irrigation system – Kobala – Logical Framework – maize – Mali – MDGs – modelling – modernization – nomenclature – OPIB – rice – river Niger – scenarios analyses – seepage – simulation – soil map – Sotuba – tomato – UNESCO-IHE – vegetables – Water Mill Project

Sommaire

Baguinéda est une petite ville située sur la rive droite du fleuve Niger, à quelque 30 km de la capitale du Mali, Bamako. Ce district rural rassemble 32 villages avec une population d'environ 27 000 habitants. Un petit barrage sur le fleuve Niger élève le niveau de l'eau pour l'introduire dans un canal d'amenée qui transporte 110 m³/s jusqu'à un point appelé « point A ». De ce point, l'écoulement dans une branche de gauche alimente une centrale hydroélectrique avec plus de 100 m³/s. Dans la branche de droite, quelque 8 m³/s coulent dans un canal d'irrigation de 40 km de long pour aller irriguer 3000 ha à Baguinéda où 3000 familles cultivent le périmètre. Au commencement, le canal était dimensionné pour transporter 9 m³/s.

En dépit de sa proximité avec Bamako où existe un marché potentiel de plus de 800 000 personnes, le projet d'irrigation de Baguinéda fait face à de nombreux problèmes : i) la détérioration du système principal, ii) l'insuffisance du débit durant la saison sèche, iii) la distorsion de l'approvisionnement en eau par rapport aux besoins des cultures et iv) la faiblesse des rendements. Par conséquent, les revenus des agriculteurs sont faibles et la pauvreté persiste.

En 2007 les rendements de saison sèche du riz, du maïs, de l'oignon et de la tomate étaient respectivement de 4 tonnes/ha, 1.4 tonnes/ha, 21 tonnes/ha et 30 tonnes/ha. La terre cultivée ne dépassait guère 677 ha sur les 3000 ha disponibles. La faiblesse du débit est la contrainte principale au développement de l'espace agricole. Cette faiblesse a plusieurs causes : i) les prélèvements d'eau par la centrale hydroélectrique installée sur la branche gauche du canal d'amenée, ii) l'importante fuite d'eau le long des non revêtus canal primaire et secondaires (seulement 12 km sont revêtus sur le canal primaire) et iii) les règles d'attribution de l'eau non clarifiées.

Ce rapport de thèse de recherche en Master of Science (MSc) aborde six préoccupations fondamentales :

- les règles d'attribution de l'eau aux blocks secondaires irrigués par les canaux secondaires
- le processus de prise de décision d'allocation de l'eau aux blocks secondaires
- la détermination saisonnière de la surface de terre cultivée et les moyens de suivre son évolution
- le degré d'adéquation des structures de transport et de contrôle de l'eau
- la capacité de paiement de la redevance eau et les cultures appropriées
- l'évaluation de l'impact du débit de tête et des fuites d'eau sur l'écoulement (débit et hauteurs d'eau) à travers le réseau de distribution de l'eau

Méthodes

Une campagne de mesure avec le Garmin GPSMap 60CSx fut entreprise de novembre 2007 à janvier 2008 à Baguinéda, au Mali. Cette campagne permit d'obtenir les positions géographiques de l'axe du canal principal et de ses structures de control de l'écoulement : vannes, seuils, prises officielles et non officielles, et ponts.

Avec quelques 207 points de mesure, il y'avait assez d'éléments pour créer dans espace géographique la totalité de l'aire agricole et la carte d'aptitude agronomique des sols. Cependant avant ce développement dans un logiciel Système d'Information Géographique (SIG), il était nécessaire de scanner des cartes. Par conséquent, une

copie papier à l'échelle 1 : 10 000^e de l'aire agricole avec délimitations des blocs secondaires et tertiaires fut scannée en utilisant un appareil photo numérique Sony DSC-H3. Avec le même appareil, la copie à l'échelle 1 : 2 000^e de la carte d'aptitude des sols fut également scannée.

Ces trois pièces – mesures au GPS, carte de l'aire agricole et carte d'aptitude des sols – furent traités avec le logiciel Arcview 3.3 pour produire les principaux attributs et une base de données du système irrigué de Baguinéda.

Dans le but d'obtenir un échantillon de l'écoulement à travers le système d'approvisionnement en eau, des mesures de débits furent réalisées à la prise amont de Sotuba et sur quatre des sept régulateurs du canal principal. La prise principale amont de Sotuba est une double vanne verticale. Un régulateur type est composé d'un seuil central de 13 mètres de long accompagné latéralement de deux vannes verticales. Les mesures d'élévation ont été effectuées avec un niveau laser à point unique (SPK ou Single Point Laser Kit) tandis que celles de distance l'ont été à l'aide d'un mètre à ultrason type Stanley.

En plus des mesures de débit aux vannes et sur les seuils, cinq mesures furent effectuées selon la méthode du bâton-flotteur sur le canal principal (10 m de large).

En utilisant ces données géométriques et hydrauliques, des analyses de scénarios actuels et modernes ont été effectuées à l'aide de feuilles de calculs de MS Excel et du logiciel de simulation hydraulique HEC-River Analysis System (HEC-RAS).

Les scénarios ont été conçus pour investiguer sur l'influence de quatre facteurs qui sont :

- l'augmentation du volume d'eau d'irrigation disponible lorsque les 54 km de canaux secondaires sont revêtus
- l'augmentation de débit et de niveau d'eau quand le canal principal est revêtu
- le gain en terre cultivable lorsque la technique de l'irrigation déficitaire est appliquée avec successivement 25% et 50% de l'eau nécessaire, avec dans les deux cas une perspective de rendement valant 80% du rendement maximum
- le changement en terme de capacité de paiement de la redevance eau lorsque le système est entièrement revêtu

Résultats

La productivité de la terre agricole peut être grandement améliorée par l'utilisation de GPS/SIG et d'analyses de scénarios. Les 2846 ha de terre irriguée de Baguinéda ont été entièrement importée dans un SIG et des cartes d'aptitude agronomique des sols et d'aire agricole ont été créées. Les longueurs, les aires, les positions géographiques et les noms de la géométrie du système sont à présent enregistrés dans une base d'information SIG. Le système comprend : i) le canal principal et ses structures de contrôle de l'eau, ii) les canaux secondaires, iii) les canaux tertiaires, iv) les blocs tertiaires, v) les blocs secondaires, vi) les drains principaux et secondaires, vii) les drains tertiaires et viii) les routes.

En rapport avec les questions de recherches, les principaux résultats sont :

1. **Au commencement, le réseau de Baguinéda était conçu pour l'irrigation productive, mais cet objectif global a été changé en irrigation protectrice.** Le débit spécifique originel était de $q = 3 \text{ l/s/ha}$ sous la méthode de *régulation par l'amont*. Actuellement, sous la pression de la pénurie l'eau due aux fuites, à la compétition de la consommation de la centrale hydroélectrique et de l'extension des terres irriguées, l'objectif du système a été muté en *irrigation protectrice*. En conséquence, la manipulation du système est devenue très complexe en saison sèche et les débits transférés sont en réalité inconnus. L'équité visée dans une irrigation protectrice ne peut pas être obtenue et des points de prélèvement illicite d'eau émergent le long du canal principal.
2. **Durant la période de pénurie d'eau, des rotations sont appliquées le long du canal principal et des canaux secondaires et les écoulements y sont intermittents.** Une rotation est pratiquée le long du canal primaire entre deux groupes de canaux secondaires. Le premier groupe est composé des canaux CSK1 à CSB14 (régulés par les régulateurs R1, R2, R3 et R4, voir ?????) et le second groupe comprend CSB15 à CSB25 (régulés par R5, R6 et R7). Les ouvertures des vannes sur les régulateurs sont des combinaisons complexes qui peuvent avoir au moins trois configurations : i) les deux vannes sont fermées, ii) les deux vannes sont ouvertes et iii) une vanne est ouverte et l'autre fermée. L'eau peut simultanément s'écouler au dessus du seuil central.
3. **Processus de prise de décision : durant la saison sèche, la pratique consiste en une allocation d'eau pré arrangée.** Bien que le Comité d'Irrigation et d'Entretien (CIE) soit la plus haute structure d'organisation paysanne gérant un canal secondaire et dans laquelle l'Office du Périmètre Irrigué de Baguinéda (OPIB est l'Agence d'Opération et de Maintenance) n'est formellement représentée, le CIE n'a aucun contrat qui le lie à l'OPIB. L'organisation qui prend les décisions est la *Commission Paritaire d'Exploitation et d'Entretien (CPEE)* dans laquelle les agriculteurs ont des représentants.
4. **A cause de la pénurie d'eau durant la saison sèche, les structures de régulation d'eau par l'amont du système sont opérées à présent par la méthode du control simultané.** Au cours de la saison sèche, sous la pression concomitante de l'insuffisance de l'eau due aux fuites dans le primaire et aux prélèvements de la centrale hydroélectrique, les débits et hauteurs d'eau du système sont changés par manipulations des vannes sur les sept régulateurs. L'eau transite par la méthode dite de *contrôle simultané*. Les simulations d'écoulement avec HEC-RAS sur les premiers 15 km du canal principal situés en amont du régulateur R1 montrent que : i) dans le *scénario actuel* ($8.0 \text{ m}^3/\text{s}$ venant de la prise de Sotuba et une perte de $0.22 \text{ m}^3/\text{s/km}$ sur le *canal principal non revêtu*), quand les 2 vannes du régulateur R1 sont ouvertes, le niveau de l'eau en son amont chute de 20 cm réduisant les débits prélevés par les 11 premiers canaux secondaires, et ii) dans le *scénario moderne* (avec $9.5 \text{ m}^3/\text{s}$ venant de l'amont et un *canal principal revêtu* perdant $0.10 \text{ m}^3/\text{s/km}$) un gain en niveau d'eau de 14 cm est obtenu en amont du régulateur R1, assurant un meilleur approvisionnement des canaux secondaires.

5. **Pas plus de 615 ha ne sont cultivables pendant la saison sèche dans le scénario actuel avec un canal primaire non revêtu. Même avec le canal principal revêtu (scénario moderne), on ne peut cultiver plus 2 000 ha.** En supposant que 416 ha en amont de R1 sont convenablement approvisionnés en eau, les simulations (HEC-RAS) du *scénario actuel* – avec 8.0 m³/s en amont et une perte de 0.22 m³/s/km – conduisent à un débit spécifique de $q = 1.5$ l/s/ha pour les 2430 ha situés à l'aval de R1, alors que les besoins en eaux d'irrigation de pointe sont de $q = 3.0$ l/s/ha. Il en découle que seulement 615 ha sont irrigables, chiffre en accord avec la superficie emblavée en 2007 qui s'élevait à 677 ha. Les simulations HEC-RAS du *scénario moderne* (9.5 m³/s de débit amont et canal primaire revêtu) résultent en un débit spécifique de $q = 3.0$ l/s/ha sous la contrainte que pas plus de 2000 ha sont irrigués.
6. **Quelque 160 ha seront gagnés en plus quand la technique de l'irrigation déficitaire est appliquée avec 25% de la quantité d'eau normalement requise (scénario actuel).** Dans un scénario moderne avec 50% de la quantité d'eau normalement nécessaire, 315 ha additionnels peuvent être irrigués. Cependant, les rendements à Baguinéda sont présentement bas, et cela aussi bien en saison sèche qu'en saison pluvieuse. Par conséquent, des facteurs autres que l'eau sont en train de limiter les rendements. L'irrigation déficitaire ne peut être appliquée que lorsque ces autres facteurs seront élucidés et neutralisés.
7. **La carte d'aptitude agronomique des sols permet de distinguer que durant la saison sèche 60% des sols sont bons pour la production maraîchère, alors qu'en saison pluvieuse 80% des sols sont très bons pour la riziculture.** Le processus de traitement SIG de la carte d'aptitude agronomique a permis d'obtenir quatre classes de sols qui sont 2R, 1P, 2P et 1R. La classe 2R est une aire de 1 900 ha qui est très bonne pour le riz mais uniquement en saison pluvieuse. Aussi bien en saison sèche qu'en saison pluvieuse, les deux classes 1P et 2P sont très bons en culture maraîchères et en maïs. Ces deux classes couvrent un total de 670 ha. La classe 1R équivaut à 500 ha et est très bonne pour le maraîchage en saison sèche d'une part, et très bonne pour le riz dans les deux saisons d'autre part. Une copie des fichiers de la carte d'aptitude agronomique a été remise à l'OPIB.
8. **L'aire agricole totale irriguée (sans Tanimba et Sienkoro) s'élève à 2846 ha. La taille moyenne des blocs secondaires est de 70 ha.** En plus, les dimensions des canaux et drains, des blocs tertiaires et secondaires ont été calculées au SIG. Une nomenclature du système agricole a été créée et remise à l'Agence d'Irrigation et de Maintenance (OPIB). Sur la carte produite, le centre de chaque bloc tertiaire est un point dont les coordonnées géographiques sont connues. Par conséquent, tout agent muni d'un GPS peut « naviguer » pour aller s'arrêter sur le point en question.
9. **Alors qu'en produisant du riz et des cultures maraîchères dans les deux saisons les agriculteurs peuvent payer la redevance eau, le maïs est apparu comme un choix de culture irrationnel en saison des pluies.** En fait, la pluie est suffisante pour satisfaire les besoins en eau d'irrigation du maïs (560 mm) en saison pluvieuse. Payer une redevance d'eau pour le maïs est donc irrationnel. En plus, en saison sèche le rapport *redevance eau/marge de profit*

pour le maïs vaut 30%. La redevance eau est *actuellement* de 48.8 €/ha en saison pluvieuse. Dans le *scénario moderne* la redevance eau a été supposée supérieure de 10% à au montant actuel. Le rapport le plus faible *redevance eau/marge de profit* est obtenu pour la tomate (ou les cultures maraîchères) avec moins de 0.30%, suivi du riz avec moins de 0.70% dans les deux scénarios. Mais il est important de remarquer que la tomate (représentant le maraîchage dans l'étude) est cultivée seulement en saison sèche et que 80% du riz produit sont autoconsommés par les exploitants.

Conclusions & recommandations

Cette thèse de recherche en Master of Science a ouvert la voie pour une modélisation de la totalité du système d'irrigation de Baguinéda. Un Système d'Information Géographique (SIG) comportant une carte d'aptitude agronomique des sols, le réseau d'irrigation et de drainage ainsi que l'espace agricole et le réseau de routes ont été créés.

Comme exprimé dans la section discussion dans ce rapport, les recommandations suivantes sont formulées :

1. L'OPIB devrait utiliser le SIG développé dans la gestion quotidienne du réseau d'irrigation et de l'espace agricole.

Avec le temps, les cartes doivent être affinées et mises à jour. Par conséquent, nous recommandons aussi que l'OPIB *dote les chefs sous-secteurs de GPS et incluse dans leurs activités de faire des mesures au GPS*. D'abord, on procèdera à la délimitation des blocs secondaires. Ensuite, les limites des blocs tertiaires et finalement les limites des parcelles seront déterminées au GPS.

L'importation progressive de ces données dans le Système d'Information Géographique (SIG) créé permettra un suivi très précis et très flexible de la terre emblavée chaque saison. Ainsi, les mesures des rendements des cultures seront précises et régulièrement mises à jour dans le SIG. De plus, la redevance eau basée sur la taille du champ cultivée sera réellement adaptée.

Un *Centre SIG* composé d'agents venant des deux divisions de Conseil Rural et Vulgarisation Agricole et des Travaux pour collecter, traiter et interpréter les données SIG serait créé.

2. Le système d'irrigation devrait réorienter son objectif global vers l'irrigation productive (hauts rendements et espaces prioritaires) pendant la saison sèche en mettant l'accent sur la production maraîchère.

L'objectif est de simplifier les opérations et d'accroître les revenus des exploitants. La production maraîchère requiert bien entendu des mesures d'accompagnement en termes d'outils de conservation et de transformation des produits agricoles. Néanmoins, l'autorité de l'OPIB doit être renforcée. Cela ne sera possible que si l'OPIB peut assurer un *service d'eau fiable en*

quantité et en précision. Par conséquent, deux choses sont recommandées : i) en plus du revêtement présentement programmé de 10 km sur le canal primaire par le projet d'Intensification de l'OPIB, nous recommandons de *revêtir tout le canal primaire et l'ensemble des canaux secondaires*, ii) étant donné que le système est conçu sur la base de la *régulation par l'amont*, un *Centre d'Opération d'Eau* (COE) devrait être créé au sein de l'actuel Division des Travaux ; ce centre doit être bien formé pour collecter, traiter et interpréter les données relatives au réseau d'irrigation et de drainage (Ankum, 2004).

Il est indispensable de connaître exactement les débits transférés aux canaux secondaires à n'importe quel moment de la saison. Cela sera possible en installant sur le canal primaire des seuils à gorges longues en béton après chaque prise secondaire (Figure 2). De tels seuils peuvent être facilement dimensionnés à l'aide du logiciel WinFlume (USBR et al., 2001). Leur avantage réside dans leur grande précision, leur robustesse et leur localisation permanente sous l'eau. Par conséquent, ils seront très difficile à atteindre et à briser par qui que ce soit.

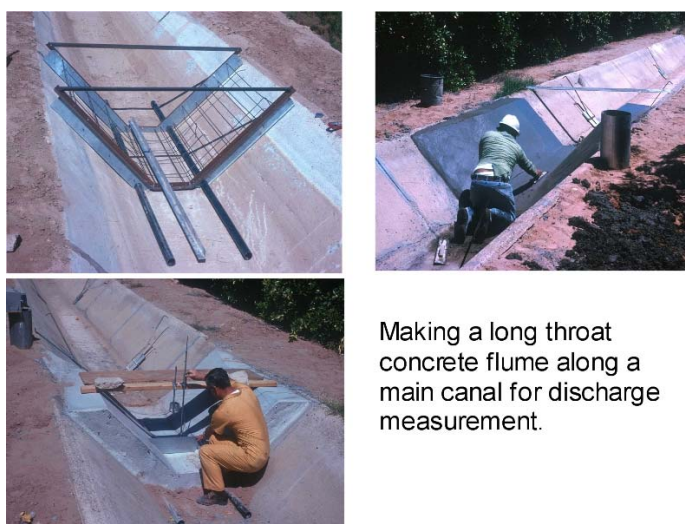


Figure 2: Seuil à gorge longue pouvant être dimensionné et calibré avec WinFlum

3. **La modélisation de l'ensemble du réseau d'irrigation en complétant la géométrie créée au cours de la présente recherche devrait être continuée.** Cela permettrait une appréciation plus complète de l'écoulement à travers le système et d'ouvrir la voie pour une future automatisation des opérations du canal.

La difficile manipulation actuelle des vannes sur les régulateurs par les chefs secteurs peut être électrifiée et plus tard automatisée. Cela serait un processus, mais il est essentiel que l'opération des vannes soit rendue plus aisée afin d'affiner les ajustements et d'adapter les débits et les hauteurs d'eau selon les zones de cultures prioritaires, particulièrement durant la saison sèche.

L'automatisation va nécessiter l'installation de capteurs pour mesurer les hauteurs d'eau et calculer les débits basés sur les données des seuils à gorge longue. Le Centre d'Opération d'Eau (COE) serait responsable de ces activités.

4. La productivité de la terre irriguée s'accroîtrait à Baguinéda si l'OPIB pouvait prendre en main le canal principal et faire des *contrats* avec les CIE en charge de la gestion des canaux secondaires et de l'aire agricole dominée.

Cependant, comme mentionné ci-dessus, cela suppose que l'OPIB est capable de fournir *un service d'eau fiable*. D'un autre côté, les canaux secondaires devraient être revêtus avant le transfert de leur gestion au CIE composé entièrement d'exploitants (pas de représentants de l'OPIB). De plus, il est nécessaire que les agriculteurs soient accompagnés, bien formés pour constituer des *Groupements d'Utilisateurs de l'Eau*, capables de gérer jusqu'à concurrence de 200 ha comme cela apparaît sur la carte de Baguinéda. Par conséquent, ce qui proposé ici est un processus pour le moyen terme.

Le CIE s'occupera de tous les aspects organisationnels et techniques – avec une assistance rémunérée si nécessaire – parmi les exploitants, et fera un contrat dans lequel le débit qui doit être délivré par l'OPIB à la prise du secondaire pour la saison en cours est clairement stipulé. Le CIE gèrera le block secondaire et l'infrastructure y afférent, libérant l'OPIB de ces aspects. Le bloc secondaire devient une entité autonome d'Unité d'Agriculteurs (UA) *recevant indépendamment des autres blocs la quantité d'eau contractuelle*.

Dans un tel cadre, l'OPIB prendra en charge l'opération et la maintenance du canal et des drains principaux. *L'eau fournit par l'OPIB au CIE sera conséquemment tarifiée.*

5. En ce qui concerne les prélèvements illicites d'eau sur le canal primaire, deux solutions sont envisageables. La *première* – et aussi celle que nous recommandons – consiste à intégrer les surfaces additionnelles illégales au système en leur faisant payer la redevance légale.

Les chefs sous-secteurs peuvent localiser exactement avec un GPS tous les points de prélèvement d'eau illicites et mesurer les aires agricoles y afférentes. Cela justifie une fois de plus que les chefs sous-secteurs soient équipés de GPS et suffisamment entraînés pour pouvoir collecter les données.

La *seconde solution* serait d'interdire les prélèvements illicites sur le canal primaire. Les contraintes majeures à cette solution sont que l'OPIB doit i) régulièrement inspecter le réseau et prendre des sanctions contre les contrevenants à la réglementation, et ii) assurer un *service d'eau si fiable* qu'il n'y aurait pas d'incitation aux prélèvements illicites durant la saison sèche.

6. Puis que les rendements sont faibles également en saison pluvieuse au cours de laquelle il n'y a aucune pénurie d'eau, nous recommandons des investigations sur les facteurs non hydrauliques de réduction des rendements.

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Abbreviations & symbols

A	Area
B	Length of a weir
C	Weir coefficient
Cd	Discharge coefficient
CIE	Comité d'Irrigation et d'Entretien
CPEE	Commissions Paritaire d'Exploitation et d'Entretien
CPIE	Comité Paritaire d'Irrigation et d'Entretien
CSB	Canal Secondaire de Baguineda
CSK	Canal Secondaire de Kobala
CWR	Crop Water Requirements
DTM	Digital Terrain Model
E.U.	European Union
Eff	Efficiency
ETa	Actual Evapotranspiration
ETo	Reference Evapotranspiration
g	Gravity acceleration
GIS	Geographic Information System
GPS	Geographic Positioning System
GUE	Group d'Utilisateurs de l'Eau
h	Energy head or water depth
HEC-RAS	Hydrologic Engineering Center-River Analysis System
IWR	Irrigation Water Requirements
kc	Crop coefficient
ky	Yield response factor
L	Length or width
LogFrame	European Union Logical Framework
O&M	Operation and Maintenance
OPIB	Office du Périmètre Irrigué de Baguinéda
P	Production or Precipitations
Perc	Percolation
Q (m ³ /s)	Discharge
q(l/s/ha)	Specific discharge
R1	Regulator number 1
TIN	Triangulated Irregular Network
UN	United Nations
UTM	Universal Transverse Mercator
V	Volume
w	Gate opening
XS	Cross Section
Y	Crop Yield
y ₁	Upstream water depth of a gate
Z	Elevation

1 Introduction

A rehabilitated structure is restored in its original function. A modernized structure draws the best from contemporary technology to respond to users' present and mean term future needs.

According to these definitions, rehabilitation is oriented toward the past. Due to population growth, the availability of new commodities, the change in human consumption habits or generally in the environment, it may result in infrastructure that does not meet the actual population needs.

On the contrary, modernization is oriented toward the present and the mean future. It uses appropriate available technology to meet the demand. From this view point, modernization deals not only with the structures, but also available effective and appropriate management tools.

In the perspective of modernization, GPS/GIS and hydraulic simulation are tools that can bring a major contribution to the efforts made to improve cropland productivity. They can be used to prospect what will be the benefit if e.g. an irrigation system is modernized by lining an earthen canal and installing flow control structures that can reduce the water losses. It becomes possible; for example, to follow up the evolution of cropping lands or to locate the type of soils and their agro-aptitudes.

In this thesis, the followings issues are considered:

- the historical background of the irrigation scheme of Baguineda,
- an application of GPS/GIS equipment and software to carry out the crop land and canal network characteristics and propose a dynamic management database
- current and modern cropping and hydraulic scenarios analysis
- proposals to improve crop land productivity in Baguineda

1.1 The Millennium development goals and the Watermill Project

Baguineda is a city of Mali, located 30 km from the Capital Bamako on the river Niger. Its geographic coordinates are: W7°47 and N12°37 (Figure 3). This rural district gathers 32 villages with a population of approximately 27,000 inhabitants. Agriculture is the dominant economic activity. An irrigated scheme allows the cultivation of rice, maize and vegetables. Baguineda is also a zone of mangoes production.

The total rice production of Mali (pop 12 millions) was estimated to 800,000 tons in 2002 (BCEOM-BETICO, 2002) while maize production was 500,000 tons. The rice production is not sufficient and some supplementary 250,000 tons are imported. The total rice production of the irrigation scheme of Baguineda was 6,570 tons in 2007 which represents 0.8% of the national production (OPIB [3], 2007).

Despite of considerable efforts undertaken during the last 2 decades, an important social deficit remains in Mali. In 2002, the proportion of poor was estimated to 64%. The GDP

was 0.63 USD/cap/day in 2002 against 0.82 USD/cap/day in 1997. Hence, poverty is increasing.

In fact, Mali is among the Sub-Saharan Africa countries “not on track” to meet the Millennium Development Goals or MDGs (UN, 2007). Although the contribution of Baguineda irrigation scheme seems very little in Malian production, it has an important impact on the 2,900 families living in that place. In fact, 80% of the rice production is auto consumed and an important vegetable commerce exists after the dry season harvest.

The first goal of the MDGs is to “eradicate extreme poverty and hunger”. The Water Mill project is part of the Netherlands effort programme to help developing countries in their pursuit of the MDGs by 2015. This MSc research was undertaken in the framework of the Water Mill Project activities in UNESCO-IHE Institute for Water Education.

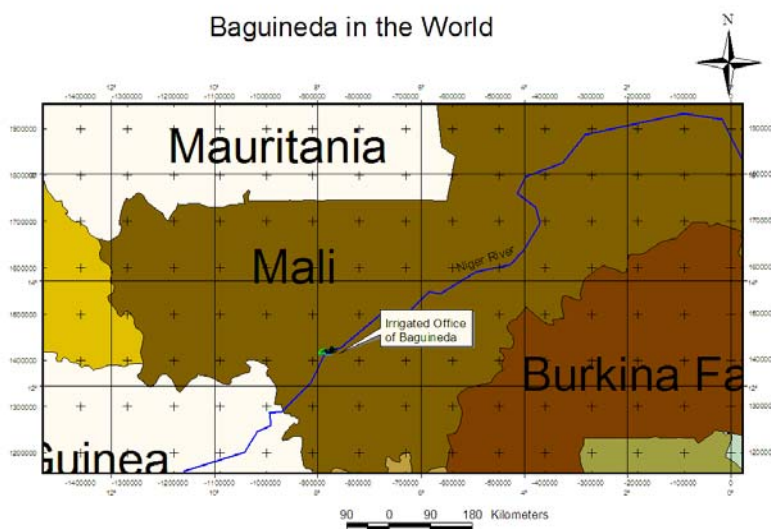


Figure 3: Georeferencing Baguineda in the world

1.2 Historical background of Baguineda irrigation scheme

Two small weirs called “Barrage des Aigrettes” and “Barrage de Damanda” are constructed on the rocky falls of river Niger close to the city of Sotuba, 6km at the east of Bamako center. These weirs were built between 1925 and 1928 (BETICO-BCEOM, 2005).

The 2 weirs raised water level that flows through vertical gates installed on the left bank of river Niger. The gates were the entrance to a 22 km long canal with a capacity of 10 m³/s conveying water to Baguineda where 3,000 ha were irrigated.

In the years 1960's, it was decided to develop the hydro power production on Sotuba falls where the weirs were constructed. Hence, the number of gates at the entrance of the feeder was to 8 (each of which is 7.5 m wide), and the canal widened over 3 km till the location known today as “Point A”. The feeder canal could now convey a discharge of 110 m³/s. At Point A – as the shape of the letter A – this head canal splits (Figure 4) into two branches:

- the left branch provides water to the hydropower plant of Sotuba
- the right branch is closed by a headwork double-vertical gate that delivers water to the initial main canal of Baguineda

Nowadays, the barrage of Damanda is located 400 m upstream the derivation canal, on the northern branch of river Niger. It is composed of i) a first 715 m long weir which crest is between 316.20 and 316.35 m, and ii) a second 51 m long concrete weir.

The barrage of Aigrettes is located on the southern branch of river Niger. It is composed of i) a 300 m long weir which crest is at the altitude 316.35m¹ and ii) a flushing structure made of 4 openings with 10 m width each one.

The rehabilitation study of BETICO-BCEOM led to the conclusion that a discharge of 9.5m³/s is required to feed 2,000 ha of the irrigated lands during the dry season (BETICO-BCEOM, 2005). This exploitation would be obtained – among other things – by:

- an agreement between the Hydro Power plant authorities and OPIB² to release for Baguineda 9.5 m³/s at the minimum water altitude of 316.20 m
- adding 2 more gates at the intake of the feeder canal at the Aigrettes
- enlarging the headwork by adding 1 more gate to the 2 existing ones of Baguineda intake located downstream point A
- lining some 4960 m + 5565 m = 10,525 m in the main canal where 12,793 m³ are currently lined over a total canal length of 37 km from the headwork to Tanima canal intake.

A view of the headwork intake at Barrage des Aigrettes is presented on Figure 4

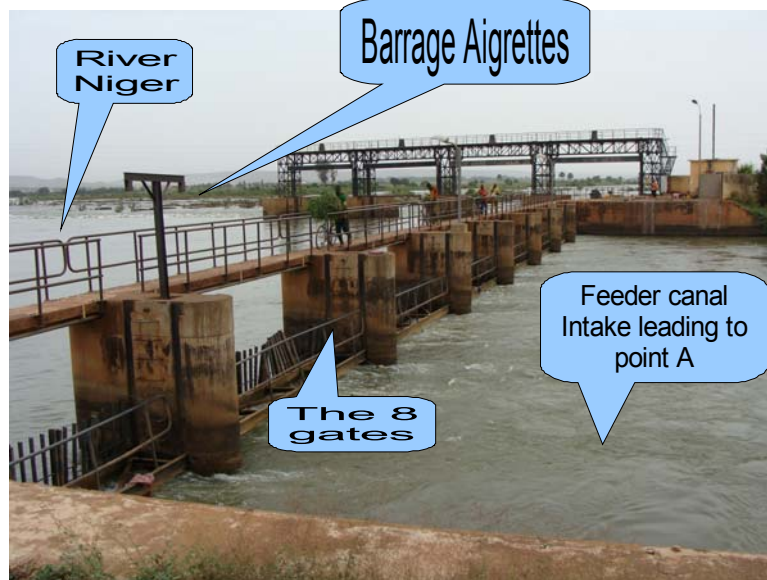


Figure 4: Feeder canal intake at the Barrage des Aigrettes

¹ BETICO-BCEOM estimated this altitude at 316.64 m.

² Office du Périmètre Irrigué de Baguineda

³ From regulator R1 to R4. measured by GPS/GIS.

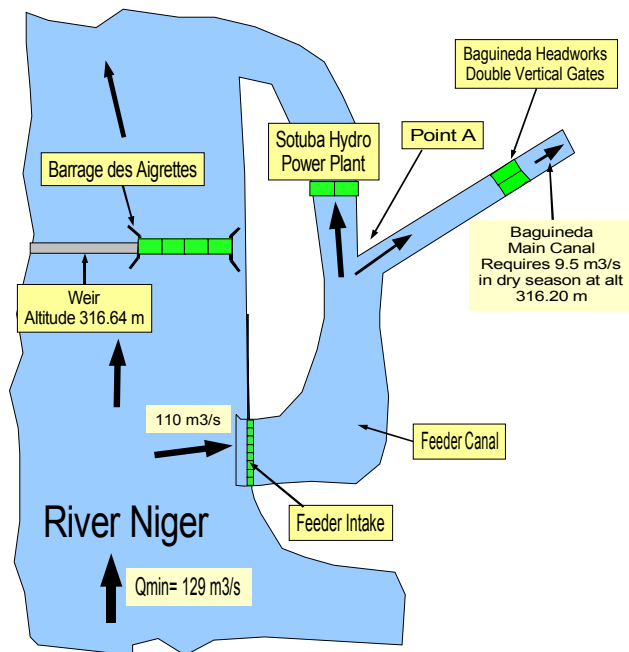


Figure 5: Detail of the feeder canal at the Barrage des Aigrettes of Sotuba

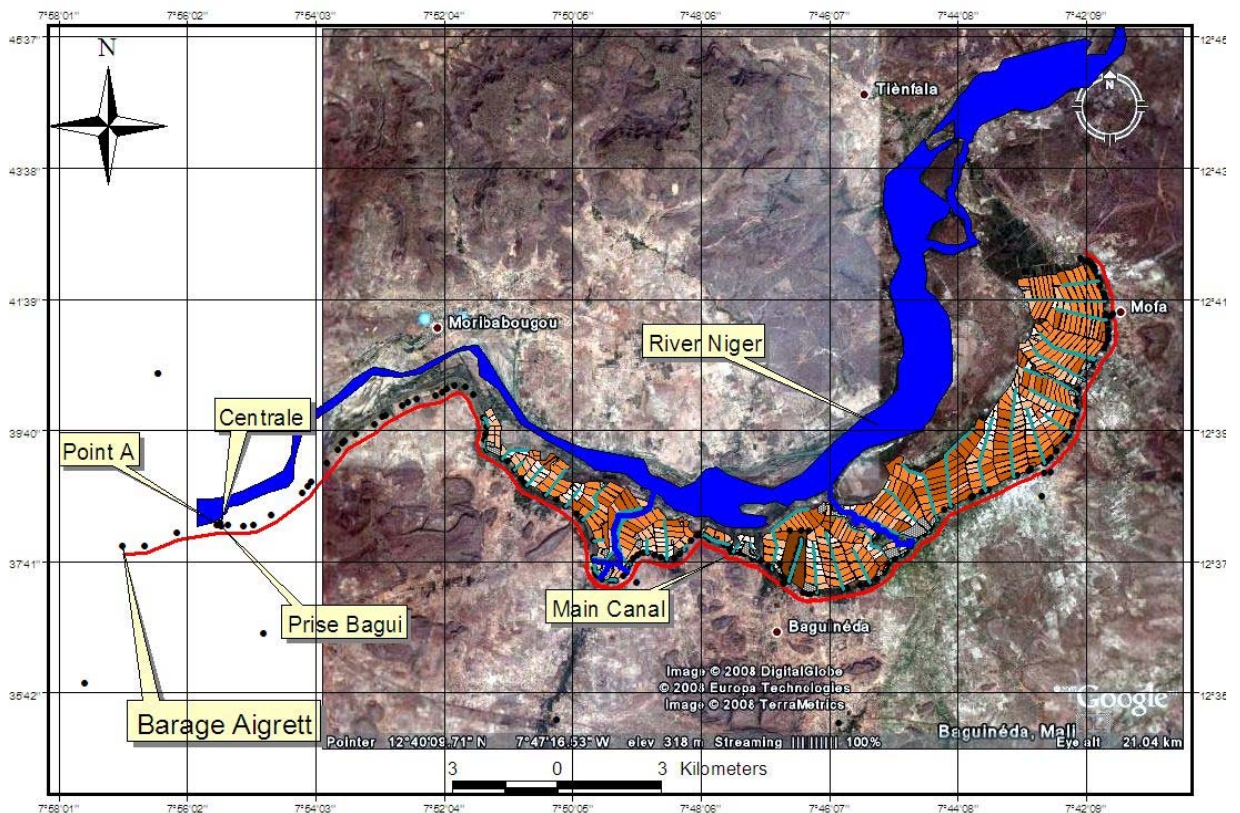


Figure 6: View of the irrigated land of Baguineda

1.3 Description of the irrigation scheme

From the main double-gate at Sotuba to the intake of the Tanima canal, the 37 km long main canal of Baguineda conveys water supplying 42 secondary canals located on its left bank (Figure 6). Seven regulators are located along the main canal, regulating water levels at secondary canals intakes.

Each of the secondary canals furnishes water to an area called secondary block through a vertical gate. The discharge capacity of these gates ranges from 40 to 500 l/s.

The irrigated area is divided into 4 “sectors” by grouping the secondary blocks (Table 1). The total cultivated area (without dead areas equivalent to 145 ha) was computed by GPS/GIS to be 2,846 ha. The secondary canals are nominated by OPIB as follows :

- CSK : “Canal Secondaire de Kobala” Coura
- CSB : “Canal Secondaire de Baguineda”

Table 1: Sectors and sub sectors of Baguineda

Sectors	Sub-Sectors	Secondary Canals	Villages
Kobala-Coura Area=532.4 ha	Dougourakoro Area=288.85 ha	From CSK1 to CSK8	Dougourakoro and Kognini
	Kobalacoura Area=243.55 ha	From CSK9 to CSK17	Kobalacoura and Nimzatt
Baguineda camp Area=635.04 ha	Baguineda Camp Area=342.09 ha	From CSB4 to CSB7	Baguineda Camp, Baguineda village and Kognimba
	Soundougouba Area=292.95 ha	From CSB8 to CSB12	Soundougouba II, Soundougouba I, Gnogan and Kobalacoro
Sébéla Area=643.81 ha	Sébéla 317.62 ha	From CSB13 to CSB15	Sébéla, Tiéman, Sadiouroubougou and Wérékéla
	Kokoun Area=326.19 ha	From CSB16 to CSB18	Kokoun, Massakoni
Tanima Area = 819.69 ha	Farakan Area=201.53 ha	From CSB19 to CSB22a	Farakan and Palasso
	Mofa Area=274.36 ha	From CSB22b to CSB25	Mofa
	Tanima Area=343.80 ha	From CST1 to CST6 and From CSS1 to CSS4	Tanima and Sienkoro

Source : (OPIB[5], 2007). The areas in this table are those provided by OPIB.

Downstream of the Tanima intake are located the extension irrigated areas of Tanima and Sienkoro (460 ha), which are not covered by this study. They are represented on Figure 6 by the dark trapezoidal area downstream.

Some 3,000 farmers are registered, with a farm size varying from 0.15 ha to more than 1.20 ha.

1.4 The European Union logical framework

The European Union logical framework (LogFrame) is a general methodology to help constructing and assessing projects. It is applied to the current study as basic methodology. Despite of its effectiveness in building or evaluating development projects, a major difficulty of the LogFrame consists in the potential existence of several parallel strategies to solve a problem. If a problem box has many causes and many

consequences (Commission of the European Union, 2002), it will not be easy to determine which strategical paths to choose and how they can be coordinated. How this challenge can be overcome?

In the LogFrame, the logical sketch of *causes-problems-consequences* is compared to a tree, reason for why it is also called the “problem tree”. It would be helpful to deepen this analogy.

In LogFrame, the boxes are compared to the leaves of a tree. But, on a tree, each leaf is a terminal or end point in contact with atmosphere. There is usually no leaf at the intersections of the branches. Hence one can say (Figure 7) that:

- each terminal leaf is a basic problem or a fundamental cause
- each intersection of branches – usually 2 branches – is a node called also a higher level problem
- a problem has several causes but *one unique consequence*. If no consequence then the problem is an *Overall* one
- in the problem tree flow lines are from top to down (reversed)

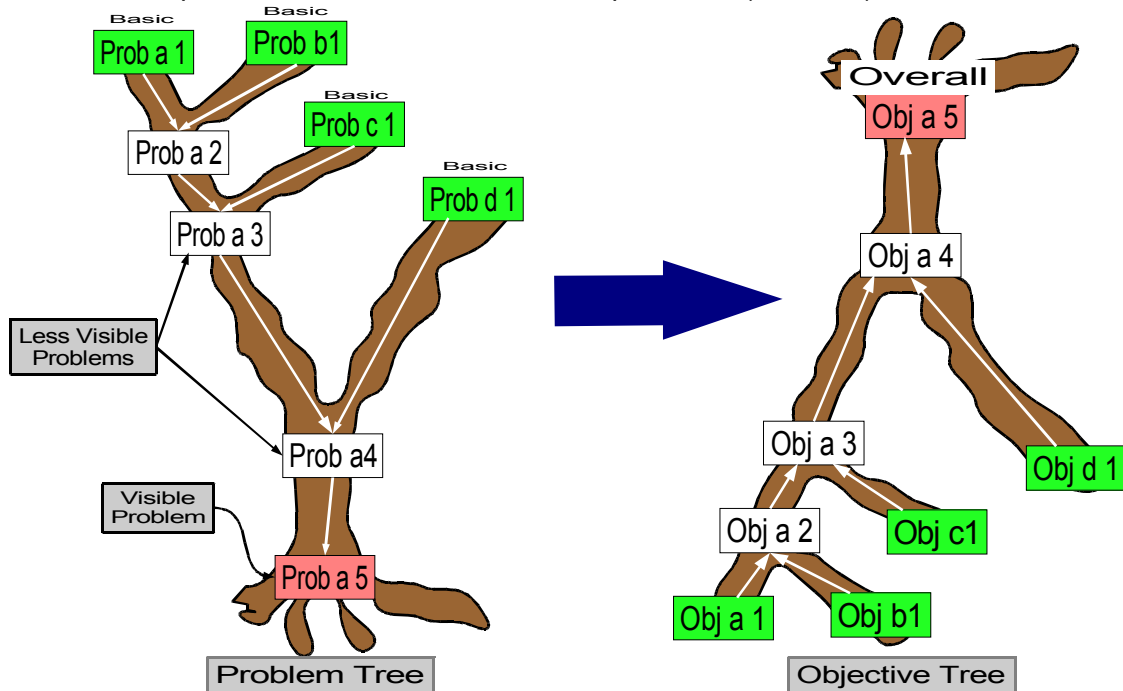


Figure 7: How a tree can help building a methodology addressing problems

In a actual tree, a unique flow path leads from the roots to an end-leaf or terminal leaf. These terminal leaves are called *Basic Problems*. The intersections of the branches or “nodes” are intermediate problems on the flow path from top to down. A problem defined this way has only one direct consequence but can have several direct causes. Flow lines provide a way to construct a non redundant methodology to solve interlinked problems from the underlying causes to the most visible problem (overall problem). The inversion of the tree yields the sketch for the construction of the Objectives Tree.

The problem tree presented on Figure 7 with flow lines from to top to down offers a method to build non redundant strategies that address the overall problem located at the “root” of the tree. For example, “Prob a1” is a basic problem that leads to the consequence “Prob a2” etc. until the problem “Prob a5” at the roots of the tree. This last problem is the one that will be more visible, but the basic causes are Prob a1, Prob b1,

Prob c1 and Prob d1 located at the top of the tree. A sequence such as Prob a1/Prob a2/Prob a3/Prob a4/Prob a5 constitutes what is called a *chain of problems*.

When the problem tree is reversed, it yields the *objective tree* (Figure 7). On the objective tree, the overall objective corresponds to the previous *visible problem* and is located at top. The specific and operational objectives are located at a lower level of the tree. At the bottom the three, the *specific objectives* correspond to the aims of the activities to be undertaken to address the overall objective through a *strategy*. In fact, a sequence such as *Obj a1/Obj a2/Obj a3/Obj a4/Obj a5* is called a *strategy*. Another; but shorter strategy; is the sequence *Obj d1/Obj a4/Obj a5*.

When addressing the overall objective Obj a5, it is important to keep in mind that often several parallel strategies are required to achieve completely an overall objective. In this example, 3 strategies are required. Therefore, a strategy here is a contribution to the solution of the overall problem.

This MSc research work is also a contribution to scientific and technical development in general and a contribution to the solution of the *poverty eradication* in Baguineda. In the next sections the LogFrame is applied to build the problem tree of Baguineda. That will lead to the general methodology used to address specific problems.

1.5 Log Frame applied to Baguineda irrigation scheme

The Log Frame problem tree of Baguineda is presented on Figure 8. It was constructed and reversed so that the flow lines are oriented from bottom to top. In this figure, the gray boxes indicate basic problems (the leaves of the tree). On the top of the sketch the box represents the most visible problem: *high poverty level*.

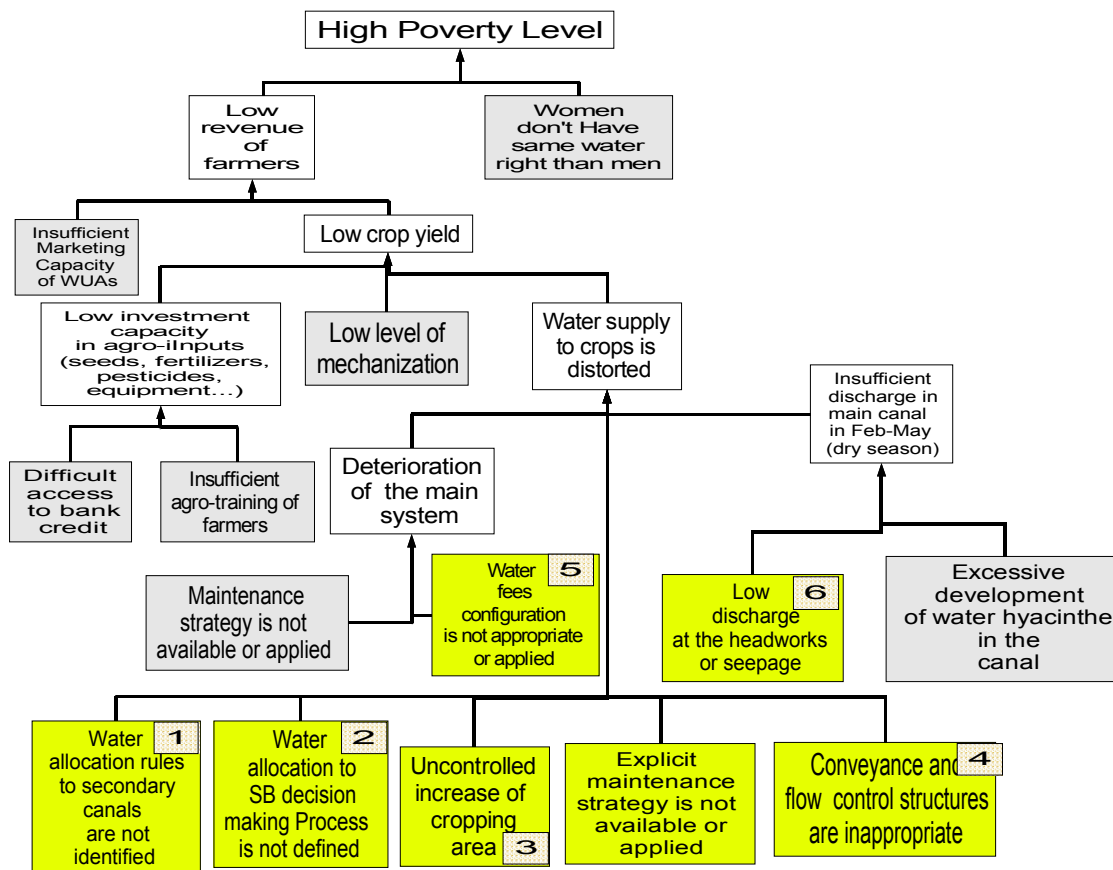
It appeared that the major *basic problems* in Baguineda are related to the infrastructure:

- water allocation rules to secondary blocks are not clearly identified (box 1)
- the decision making process for water allocation are not clearly stated (box2)
- there an uncontrolled increase of cropping land (box 3)
- conveyance and flow control structures are inappropriate (box 4)
- water fees configuration is not appropriate (box 5)
- low discharges in the main system and seepage (box 6)

Several other basic problems are reported in the literature of Baguineda. Some of them are :

- lack of explicit maintenance strategy
- the water hyacinth development
- gender inequality in water right
- etc.

Many of theses problems are already being addressed by the Operation & Maintenance Agency (OPIB). This MSc research will focus on the 6 mentioned above. It can be noticed that those are important land and water development issues.



Legend: SB = Secondary Block or unit managed by farmers' organization

Figure 8 : Problem tree of Baguineda

1.6 Research objectives

The objectives are logically derived from the problem tree shown on Figure 8 by making positive statements of the problems. Hence the overall objective of this MSc thesis is "*Eradicate extreme poverty and hunger*" (first goal of the MDGs) in Baguineda. However, due to time constraints and the scope of the issues, the MSc research selected the specific objectives related to problems 1 to 6. Therefore, the objectives or targets addressed are :

- water allocation rules to secondary blocks (SB) are clearly identified (target of TG. 1)
- water allocation to SBs decision making process is clearly defined (TG.2)
- the cropping areas are identified and measured every season (TG.3)
- conveyance and flow control structures are defined and their appropriateness is assessed (TG.4)
- the appropriateness of water fees is evaluated (TG.5)
- discharge in the main canal and seepage effects are investigated and described (TG.6)

As it appears from Figure 8, to fully achieve the purpose *high crop yield*, a special effort is required for mechanization and the use agro-inputs such as high yield seeds, fertilizers, pesticides. These aspects must be dealt with in parallel.

On the other hand, to ensure *high revenue* to farmers, increasing crop yields is not enough. Only 30 km away from Baguineda, the market of Bamako counts at least 800 000 consumers from which farmers can take more profits. Yet, the farmers need to acquire a *good marketing capacity* since it remains a persisting poverty among the population. This objective must be addressed as well.

Finally, to achieve the general objective of *poverty eradication in Baguineda*, the gender issue is to be solved. More than 50% of the population is composed of women. In practice, the water right of a woman is the water right of her husband, i.e. she has not her own. As consequence of the increasing number of single women (and also the existence of widows) they would benefit from the possibility to be owner and managers of farms, to be well trained in agri-business practices, to be active elements of the water user associations, etc.

1.7 The Research questions

In order to achieve the objectives of targets TG.1 through TG.6, a number of legitimate research questions come up. The purpose is to build activities orientations. These questions are:

1. How can be applied GPS/GIS application to determine the cropping areas? How they can be followed up?
2. How hydraulic modelling can be applied to study flow transfer (discharge and water levels) through the canal network?
3. In Baguineda Irrigation Scheme, what is the overall objective? Productive irrigation? Protective irrigation?
4. During water shortage, what are the operational rules?
5. What is the decision making process in the dry season for water allocation to the secondary blocks? Pre-arranged? Semi-demand? On demand?
6. What type of flow control method is used and how can the system be improved?
7. What are the crop water requirements?
8. In the dry season, how big is the area (out of 3,000ha) that can be cultivated?
9. How much bigger can be the cropping land in the dry season if deficit irrigation method was applied? What yields to expect?
10. How can be produced a land suitability map? How can this map help to improve crop yields?
11. The crop lands: where are they and how big are they?
12. Water fee: how much can a farmer afford? What type of crops are suitable.

These questions are addressed using scenarios analysis based on i) current situation with non lined canals and ii) a modern situation with lined canals.

1.8 Working out the activities

Once defined the objectives and the research questions, related activities were described. These activities were divided into two groups: i) the Fieldwork at Baguineda, and ii) the office work at UNESCO-IHE. The detailed schedule is presented in Appendix I.

The first step consisted in getting to know the current situation on the irrigation scheme of Baguineda. That has involved technical, economical and agronomical aspects.

Discussions with the OPIB agents, archives data and field measurements on the network coupled with a network analysis lead to problem diagnosis ascertainment. Afterwards, the current situation and the modern network (mainly lined canal with improved flow conditions) were studied.

After this introduction the **chapter 2** will present the methods that were used to collect data in the site of Baguineda. The precautions taken during the data collection and processing are also discussed.

The results generated from the data processing are exposed in **Chapter 3**. It was endeavoured to present these results as they came out of the computations and simulations. Not any discussion or personal opinion is inserted in this chapter. First, OPIB farm system characteristics are reported, followed by the objectives of the Baguineda Irrigation System. Afterwards, the discharge measurements on the main canal and the hydraulic simulation with HEC-RAS are shown. The chapter ends with the presentation of agro-economical calculations results.

Recalling the main results, **Chapter 4** discusses them and shows how they help to answer the research objectives and the questions in the introduction of this report.

In **Chapter 5** are brought the answers to the research questions taking into account the analyses and observations made about the results in the previous chapter. Finally the report ends with some key recommendations.

2 Methods

2.1 Using GPS/GIS to record locations

The use of Geographic Positioning System receivers (GPS) and Geographic Information System software (GIS) has considerably reduced the means and time required to make field measurements or surveys related to objects locations on the earth.

The possible studies include elements for which the geographic position, or merely the location on earth surface explains at least partially their values. Such elements are (x,y), or (x,y,z), dependent objects. These objects can be :

- the limits or area of a town compared to the commercial area
- a forest distance to a big city, a farm or irrigated land location versus the river
- the location of a category of consumers
- the location of wild animal colonies in a given biosphere etc.

In hydrometry (Boiten, 2003) GPS is used to determine e.g. i) the coordinates a canal network key points for digital flow modelling or ii) the cross sections for geometric measurements.

The most important factors influencing the accuracy of the GPS measurements are (Freycon V., 1998) :

- the relativist effects : non synchronization of the satellites and GPS receiver watches, satellites deviations from normal orbits
- the multi-path of the radio beam due to trees or buildings etc. lengthening the way of the waves
- the choice of the satellites used by the receiver to determine its own position : if the satellite is too low in horizon, its beam is too sensitive to multi-path effect
- the configuration of the satellites position in the sky, called "constellation"

To these factors can be added the:

- type of receiver
- working mode that can be *absolute* or *DGPS* (differential GPS). With DGPS, the correction supplied by a local service provider can draw the inaccuracy to less than 1mm

The GPS used in Baguineda field measurements is a Garmin GPSMap 60CSx which can provide a precision of ± 3 m in absolute mode if adequate utilization conditions are assured. In fact ± 2 m was often obtained.

The canal cross sections located had to be in line with the expected modelling requirements HEC-RAS (HEC, 2005). Considering an aerial view of Baguineda, the measurements locations were:

- where changes occur in discharge, in slope, or shape
- at hydraulic structures (bridges, culverts, inline weirs/spillways, and lateral weirs/spillways)

The measurement locations are shown on Figure 9.

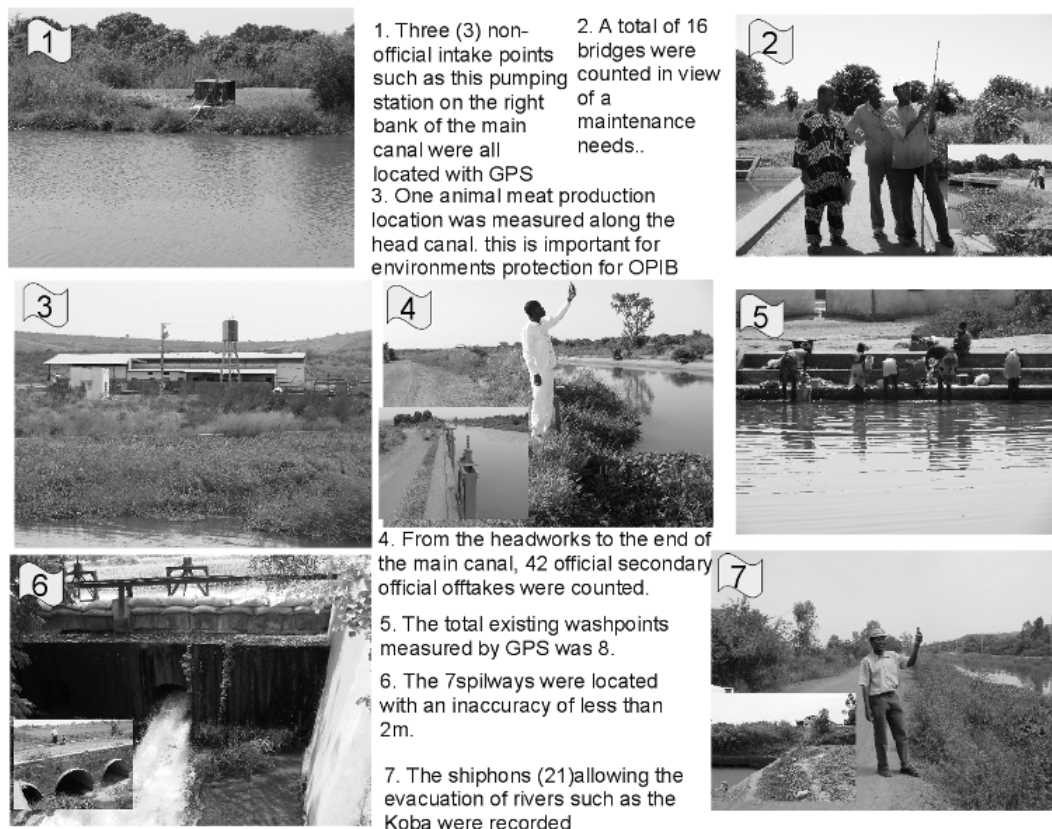


Figure 9: GPS Measurement locations

2.2 GPS measurements in Baguineda

The Garmin GPS Map 60CSx (Figure 10) provides the latitude and longitude of any point on the earth surface with a positioning error *less than 3 m in absolute mode*. This deviation is considered not to affect the accuracy of the modelling results of the 40 km main canal. The altitudes and slopes of the canal would have bigger negative influence. However, these parameters were already measured – not with the GPS – but with a topographic level (BCEOM, 1992).

It seems that there is no local correction of the positioning values of GPS in Mali, withdrawing then any possibility of working in *Differential GPS* (DGPS) mode.



Figure 10 : Garmin GPSMap 60 CSx

This reason led to the selection of Garmin GPS Map 60CSx, introduced into the market in 2007. Several tests on Internet proved the accuracy of this tool. Furthermore, it displays on the screen the probable deviation from the actual location value.

Repeated measurements at different hours and different days were done to find the location of a house corner in Delft and the GPS provided an accuracy of $\pm 3\text{m}$.

As mentioned in section 2.1, the satellite configuration in the sky - shown on the screen of the Garmin – must be favourable to precise measurements. Obstacles such as high buildings or dense trees foliage must be distant as well. To be precise, the GPS must acquire signals from at least 4 satellites. According to some authors (Freycon V., 1998), the ideal constellation is to have 3 satellites *located just above the point to measure* and 3 others equidistant ones in the same horizon (45° above horizon line). This could be checked directly on the screen of the GPS Map 60 CSx.

The GPS was used to measure the following locations:

- Cross sections on the network for deducing the lengths and angles of the reaches
- the local structures on the network

The tertiary blocks areas were available in hard copy at OPIB. They were introduced after scanning (see section 2.3) into the GIS Arcview.

An important advantage of the geographic coordinate determinations is to be able to integrate the studied zones onto the earth surface. Any future extension of the irrigated area may therefore be located in relation with the earlier area. The dimensions and the distances will be known. This is capital in a master plan implementation, not only for Baguineda but also for the whole country of Mali.

2.3 Accuracy of GPS measurements in absolute mode

Among the 207 measured points by GPS in Baguineda, 199 were followed up for error analysis. The Mean error obtained was 5.22 m, which is rather good given that the hard copy map of the system used later is at 1:10,000 (1 mm for 10 m).

A total of 90% of the measurements errors was between 4.86 m and 5.59 m and the standard deviation 3.11 m, testifying the accuracy (Table 2).

Table 2: Statistics for GpsMap 60 CSx measurement errors

Mean: 5.22 m	Variance: 9.68
Lower 90% Conf. Limit: 4.86 m	Standard Deviation: 3.11 m
Upper 90% Conf. Limit: 5.59 m	Total Records: 199
Minimum: 2.00 m	Number of Null Values: 0
Maximum: 10.00 m	Sum: 1040.00 m

2.4 Digitizing the canal network and the crop land

The canal network and the tertiary blocks hard maps are used to determine the block locations sizes. In case important structures locations are not provided by the maps, the GPS is used to determine their positions on the land surface. Afterwards, these values are imported in the GIS to overlap the scanned imported maps.

Two challenges hence arose: i) how to import the GPS waypoints (measured points) data into the Arcview GIS 3.3 software? (Arcview GIS 3.3 is not delivered with this possibility), ii) How to attach any map of the irrigation scheme to the earth surface with precise geographic coordinates?

The irrigation scheme of Baguineda had a 2 m long map of the tertiary blocks at scale 1:10 000. Four complementary parts of the soil map, each one at scale 1:2,000 were also available. Planning field operations and analyzing the crop production requires unifying those maps on the “screen” of the earth surface.

Failing to automate as much as possible the importation process of the data in Arcview would have led to a considerable amount of time and multiply errors. Hence, a tool to import directly from the GPS receiver to Arcview was needed.

On the other hand, the maps available in Baguineda – tertiary blocks, and soil maps – are hard copies (analogical). To build a numerical model of the network and the locations of farms, a scanner or a digital *high resolution* camera was also required.

This last exigency of *high resolution* is due the extent of the area: more than 3000 ha. In fact, a first picture of the whole zone taken with Google Earth, from an altitude of 23.4 km did not show enough detail to work with.

2.4.1 Scanning and sharpening the map pictures

Actually, when the area to be covered becomes large, the resolution plays a key role. On Figure 11, the black square (a) with a resolution of 2601 “black tiles” appears more homogeneous at the current display than the black square (b) which has a lower resolution of 16 black tiles.

Therefore, using a classic desktop scanner raises the difficulty of merging the different parts of maps. A high resolution camera that can capture detailed pictures of the extensive maps is more indicated. However, a flash would create non homogenous lightened zones on the image and, hence, is avoided. The light must come by sides and behind the photographer.

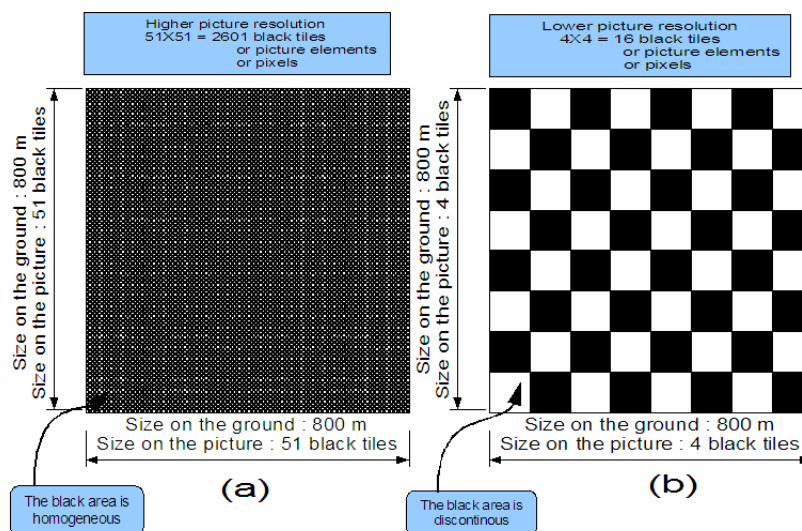


Figure 11 : Importance of image resolution

The areas of the 2 black squares (a) and (b) are equal on the earth: 160 000 m² (16ha). However, the pictures constructed to represent the 2 areas have different resolution. The area (a) is more homogenous than (b), having smaller and greater number of pixels (black tiles). When it becomes necessary to zoom in and study details of a picture, the higher the resolution the more the details one can see without discontinuity of the image. This fact is to be taken into account when working with scanned (raster) images of an extended land in GIS.

Once the maps are captured with a camera, a pre-treatment is done using MS-Picture it V7.0 as explained on Figure 12.

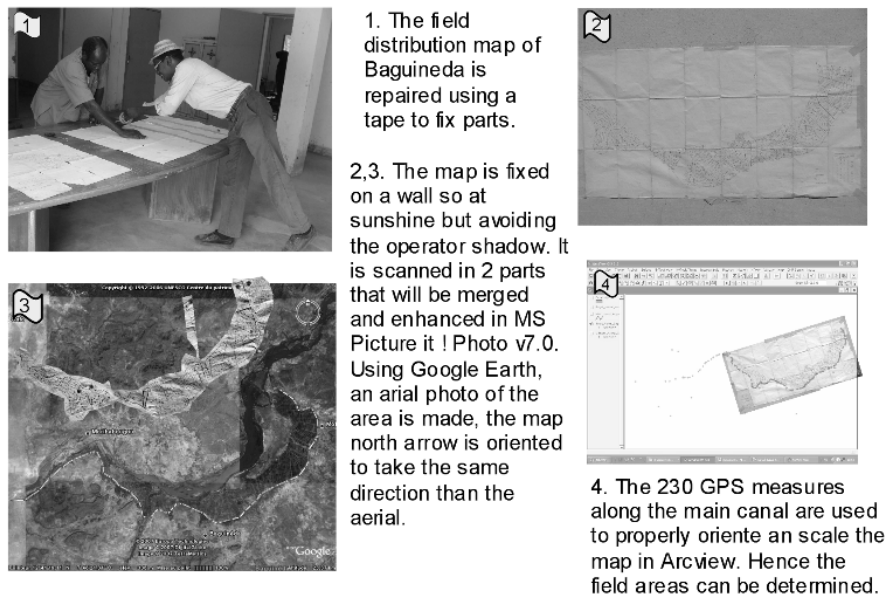


Figure 12: Preparing the maps for the GIS processing

2.4.2 Importing GPS data in Arcview

Next to this preparation step; the maps had to be georeferenced and imported into the GIS. Georeferencing is the process in which the geographic coordinates (latitudes and longitudes) of a given location are determined. That can be done using the values obtained with Google earth or – better – measuring with a GPS the position of identified elements on the earth surface. A GPS is used in Baguineda.

Once the maps were photographed, existing objects are identified on them: the main canal and its structures. The coordinates of the main canal and its structures were measured by GPS. Therefore, the outputs of these 2 series of operations were: scanned maps and GPS waypoints x,y values of the main canal.

The extension is called from Arcview 3.3 menu

Select File/Set Projection /ESRI/None

WGS84 will automatically be selected (meaning geographic coordinate lat and long will be sent to arcview shape file)

The option None is selected here

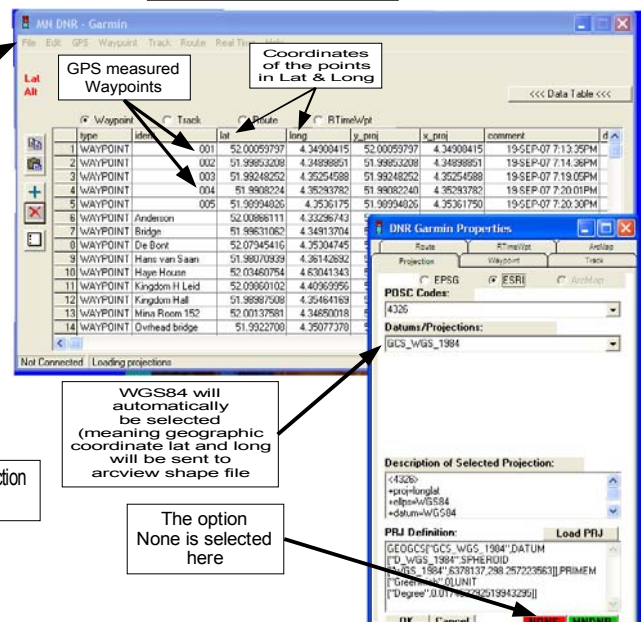


Figure 13 : The GPS points must be imported in Arcview in geographic coordinates

While GPS is an instrument or hardware, a Geographic Information System (GIS) is a software in which tabular information are linked to each feature drawn on a map. The contents of the table are the attributes of the features, a description of their characteristics (Anderson & Lambert, 2003). The features themselves are represented as 3 types of shapes: points, lines and polygons.

The point feature represents objects whose surface is small in comparison with the area being considered. It can be a well, a tree, a gate etc. A line feature is used when one dimension of the object cannot be neglected in comparison with the area considered. A road, a canal, a river may be represented by a line. A polygon feature is used when 2 dimensions of the object can not be neglected at the scale in which the area is being analyzed.

An important property of a GIS is that it allows representing in space a feature with a symbol linked to its attributes data (in the related table of data records).

Two questions arose: i) How to import in Arcview GIS 3.3 the measured points with little distortion in the coordinates? ii) How to import the scanned maps pictures and georeference them in such a way that the existing objects locations coincide with the GPS equivalent measured points?

This process required some investigations. Garmin GPS Map 60CSx comes with a software called "Mapsource" (GARMIN, 1999-2006) which allows downloading and displaying the waypoints (measured points) on a computer. The data can be saved in ".gdb", ".mps" or ".txt" formats, but *not in shape files format used by Arcview GIS*. Therefore, this program is only used to check the displayed positions. But how are the points imported in Arcview?

A research on Internet led to a useful extension for Arcview GIS 3.x called DNR Garmin (GIS Section DNR-Minnesota, 2001). The extension was developed by the Department of Natural Resources of Minnesota (USA) and used by the forest investigation group.

The extension must be copied in the Ex32 folder of Arcview GIS 3.3. Afterwards, it is invoked from inside Arcview and downloads the points' data from the GPS using USB 2.0 port. The data are displayed in the program's own screen as a table of waypoints (Figure 13) before exporting *shape files* to Arcview.

It should be noticed that the "projection" issue must be handled properly when importing the GPS measured data into Arcview. The non projected coordinates (in fact latitude and longitude) of WGS84 (Figure 14) referential must be imported in Arcview. The non projection is done in DNR Garmin by selecting File/Set Projection/ESRI/None, as explained on Figure 13.

Afterwards, the table of data is saved in a shape file that will automatically be displayed in Arcview (already running). The screen shows geographic coordinates. A referential must be set and a projection selected in Arcview by View/Properties/Projections/Standard/Category "Projection of the World"/Type "Mercator". The result is the change from geographic coordinates seen on the top right corner of the screen into projected coordinates. The importation of the scanned maps and their georeferencing starts from this point.

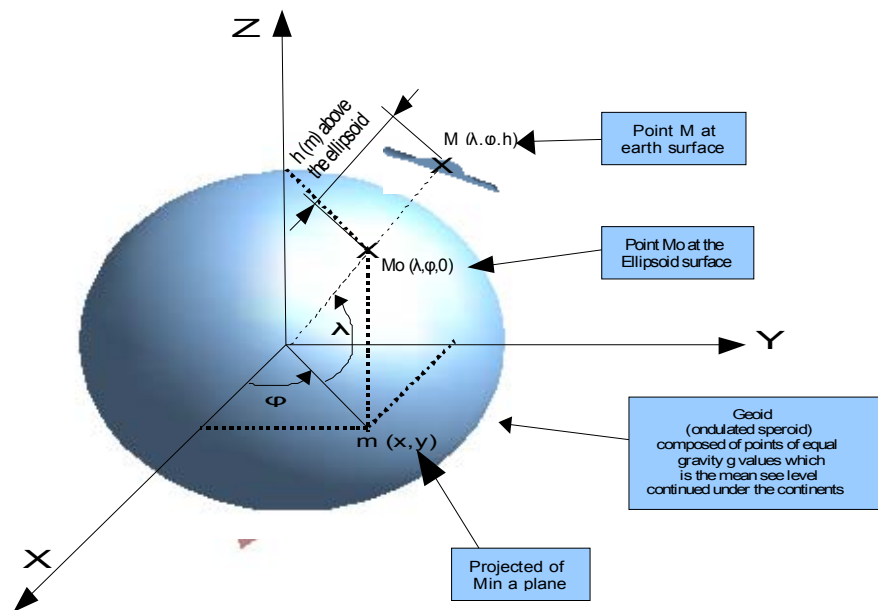


Figure 14: Projected and non projected coordinates of a point M on the earth

The geoid is the 3 dimensional volume constituted by all the points of equal gravity value g , that is the mean sea level continued under the continents. The geoid is not regular geometric figure, easy to model. It is replaced in practice by a close ellipsoid. Several ellipsoids with different values of parameters exist. Some are more close to the geoid at a certain location on the earth. That explains why some countries have adopted a local ellipsoid. A set of an ellipsoid and an associated axis system is called a *referential* or *datum*. The couple ellipsoid named GRS80 and its axis system is a referential called *WGS84*, considered to be valid for the whole earth surface. The geographic coordinates of M on WGS84 are (λ, φ) at the earth's surface. These coordinates are known respectively as latitude and longitude. The coordinate h represents the elevation above the WGS84, i.e. the geoid or the mean sea level. The point $m(x, y)$ is the projection of M on a plan : several types of projection exist according to the expected deformation, such as Universal Transverse Mercator (UTM), Robinson, Miller Cylindrical etc.

2.4.3 Georeferencing the maps

Arcview GIS 3.3 is not delivered with a georeferencing extension. The georeferencing extension found on the net is called "imagegeoref.avx". It was downloaded from Geo Community website. Although the extension was programmed first for Arcview 3.1 (Raber, 1999), it works with version 3.3 as well.

As explained on Figure 15, the maps are captured (digital camera) with a high resolution and imported in Arcview. They will appear in a layer to be under the GPS measured points. These points are brought in coincidence with the equivalent ones on the maps by creating a so called *world file* of the picture with the extension *imagegeoref* in Arcview. The *world file* contains the scales of x and y expressed in m or km/pixel for example and the projected coordinates of the upper left corner of the map. But the extension allows moving and adjusting the maps on the screen so that to fit the GPS point measured.

The great advantage of georeferencing the existing plans or maps of Baguineda irrigation scheme resides in unifying them for:

- modelling the entire network
- allowing the agronomic management of the entire scheme
- monitoring the yearly changes in cropping area
- easy integration of future development areas

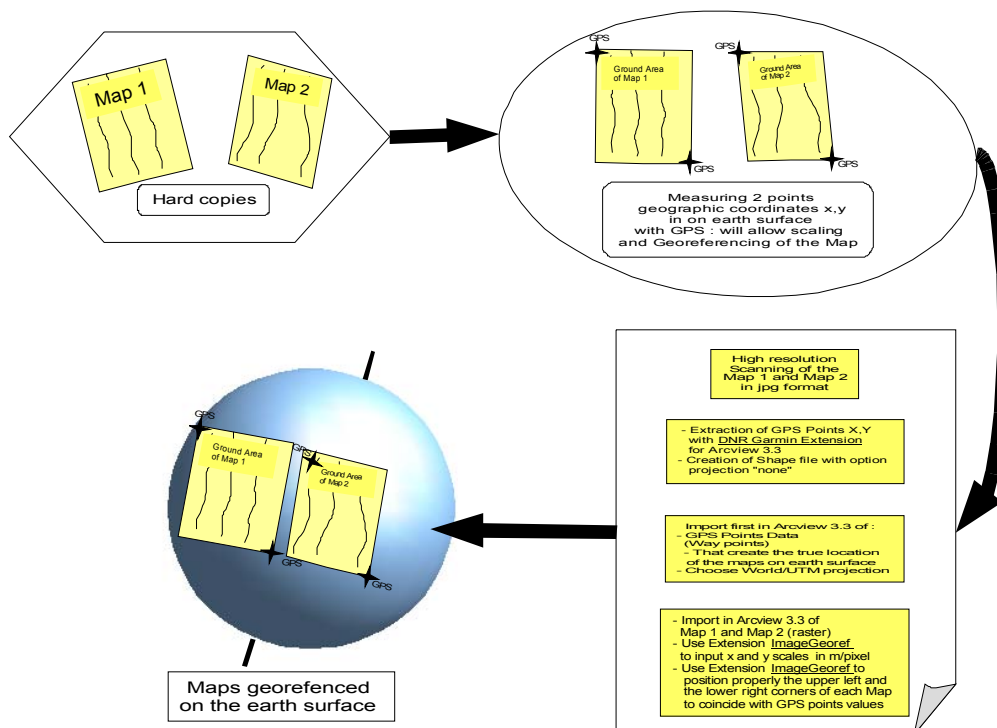


Figure 15: How scanned maps and GPS data of Baguineda are used in GIS

When the whole system is digitized, the management data are more easily updated and the analysis of the situation of the irrigation system and decision making process will be strengthened.

Both the canal measured by GPS and the tertiary blocks map are used to delineate and compute land surfaces. This process is applied as well for the digitization of the cropland map as explained on Figure 17.

2.5 Accuracy of the maps

Errors – when compared to actual field sizes on the ground – are inevitably introduced during the scanning/area delineation process using a digital camera of 8 mega pixels. Three sources of errors can be notified: i) the small bindings of the hard copy surface of the scaled 1:10,000 map; ii) the zooming scale at which in Arcview the operator draw the features (lines and polygons – the point features are GPS measuring locations and the average error is 5 meters), iii) the joining operation of the portions of a multiple part map and iv) the errors existing on the original map.

Those errors are difficult to evaluate precisely. An important GPS measuring campaign would be necessary in order to check and render as accurate as possible the GIS digitized map produced. Furthermore, this will give a really up to date map of the area.

A second method, less accurate than the preceding suggested one, will consist in re-digitizing the same map with a big scanner. The hard copy in contact with the scanner glass produces more readable pictures with fewer distortions due to bindings. This method will be slightly more precise than the use of a digital camera which pictures from a certain distance.

Nevertheless, errors were minimized using the following precautions.

Basic hypotheses:

- i) the lengths and the angles of the secondary canals are correct
- ii) the GPS measured position of the secondary canal gates are correct
- iii) the irrigation blocks angles are correct
- iv) the irrigation blocks polygon sides lengths are *incorrect*

Adjustment procedure:

- i) the secondary canals are inserted between group of irrigation blocks appearing on the scanned map, independently from their GPS “real” origin on the main canal. Hence, their lengths are determined
- ii) an adjustment is made by translation of the secondary canals locations to coincide with their gates located by GPS on the main canal side
- iii) then it appears that the distances between 2 secondary canals are different from the distance between them on the scanned map
- iv) Conclusion: the field sizes on the scanned map were distorted during the scanning process. They must be extended – or contracted – to fit in the area between (gates) georeferenced secondary canals. (See Figure 16)

This procedure was used for producing both the irrigation blocks map and the soil map.

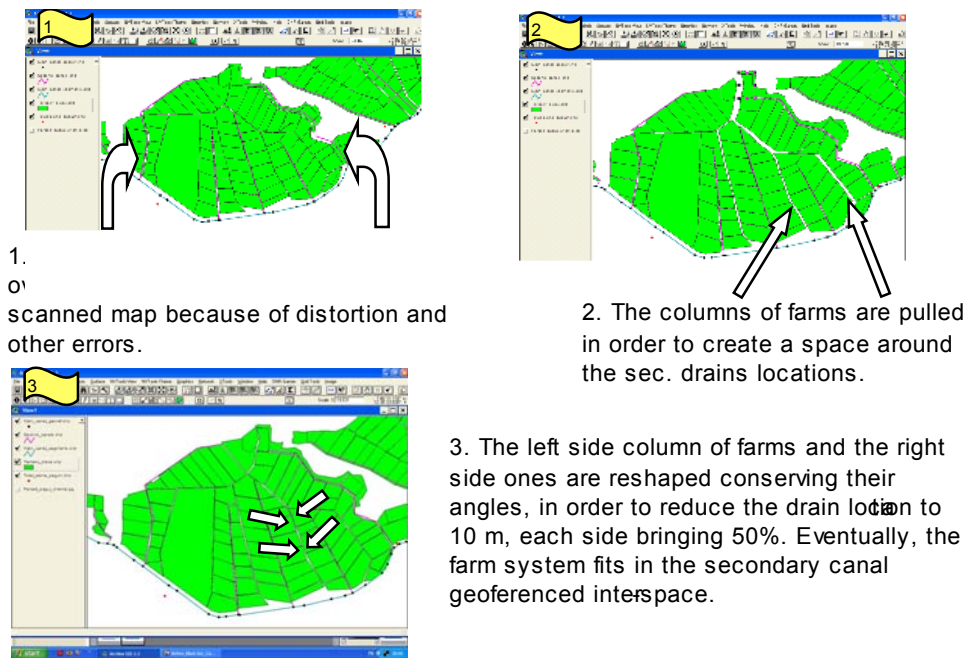


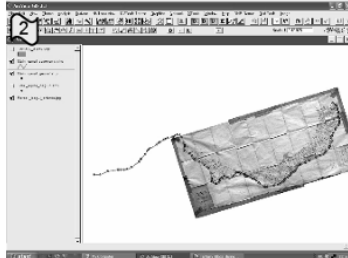
Figure 16: Digitizing and correction process of the scanned maps

2.6 Generating canal and crop land statistics

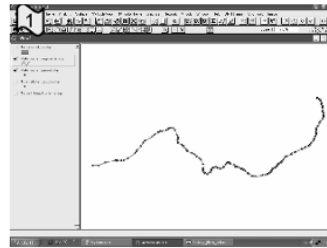
The following statistical parameters were calculated for the canal network and the crop land areas:

- central trends : mean of the values
- dispersion : confidence interval, variance, standard deviation, maximum and minimum values
- total recorded values
- sum of the values

1. The 207 black points belonging to the canal are isolated from the 215 measured using the extension DNRGarmin « convert points. » to polyline. This ensure using the gravity center of the points.



3. The scanned map of the area is underlayed such a way that the measured main canal coincide with the scanned one. Hence, the tertiary blocks (green areas) are delineated as a polygon theme and their areas computed by the extension NVTools of Arcview directly. Total in this figure is 805 ha.



2. Final Georeferencing of the area is done not using the aerial photo but the 207 GPS measures along the canal (black points).

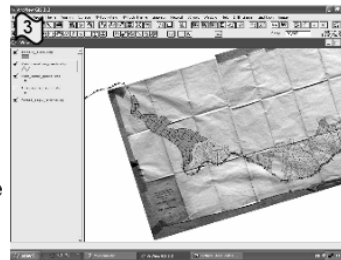


Figure 17: Tertiary blocks area delineation in Baguineda irrigation scheme

To perform these computations, Arcview 3.3 specific extensions were used. These extensions are:

- stats_dist.avx (Jenness, 2003)
- Xtools.avx (Delaune, 20003)
- NVTOOLS.avx (Morefield, 2006)

The last two extensions can perform other computations such as theme intersection or union, geographic coordinates calculations and so one. Once the GIS object is constructed, more detailed analysis becomes possible.

2.7 Discharge measurements at selected cross sections for flow check

Three measurements methods were used:

- vertical gate : at the headwork and at the regulators
- broad crested weir : at the regulators
- improved rod-float method : at the headwork

The formula for a sluice with N gates used is (Ankum, 2004):

$$Q \text{ (m}^3/\text{s)} = \sum_{i=1}^N \left[C d_i A_i \sqrt{2 g y_1} \right] = \sum_{i=1}^N \left[C d_i (B_i w_i) \sqrt{2 g y_1} \right]$$

In which:

- N = number of gates ;
- $C d_i$ = discharge factor of gate i ;
- B_i (m) = width of gate i ;
- w_i (m) = vertical opening of gate i
- y_1 (m) = upstream water depth.

The rod-float velocity measurement method is shown on Figure 18. Some authors advance an accuracy of 3 to 5% (Troskolanski, 1960) in absence of wind and on a canal reach free from turbulence.

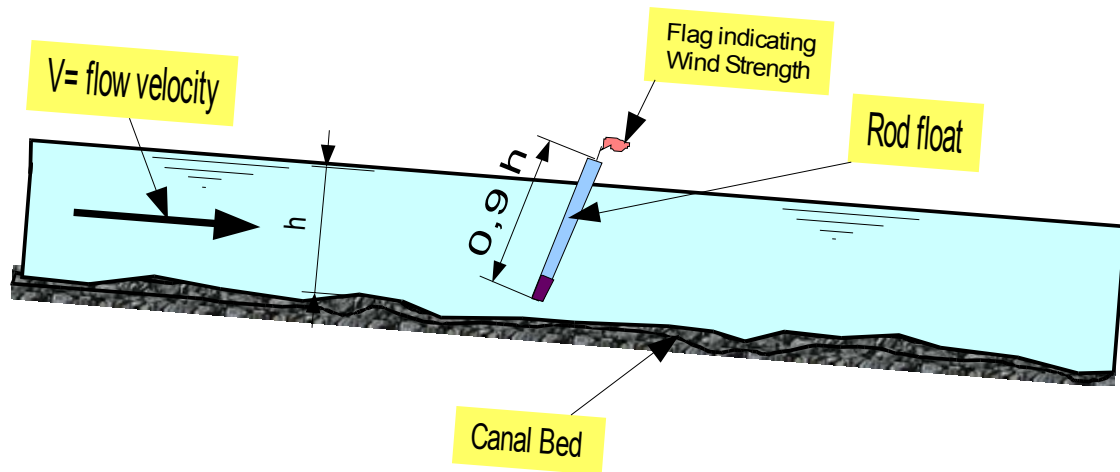


Figure 18 : Rod-float for mean velocity measurement

By repeating measurements in absence of turbulence, an accuracy of 3 to 5% may be obtained according to some authors.

At the regulators, the weir formula used is

$$Q \text{ (m}^3/\text{s)} = c \cdot B \cdot h^{3/2} = \left(\frac{2}{3} \cdot \sqrt{\frac{2}{3} g \cdot c_d} \right) \times B \times h^{3/2} = (1.71 \cdot c_d) \cdot B \cdot h^{3/2}$$

In which:

- $c \text{ (m}^{1/2}/\text{s)} =$ weir coefficient,
- $c_d =$ discharge factor,
- $B \text{ (m)} =$ length of the weir
- $h \text{ (m)} =$ energy head above the crest (generally measured upstream at a distance = 3-4 times the weir height).

2.8 HEC-RAS hydraulics

Hydrologic Engineering Centre's River Analysis System (HEC-RAS) is a modelling software created by the hydrologic division of US Army Corps of Engineers. The first version of HEC-RAS was released in July 1995 and the version 4.0 beta in November 2006. The program is in public domain (freeware), although in exchange of support service some companies trade it. The version 3.1.3 was used for Baguineda and can simulate i) steady flow water surface profiles and ii) unsteady flow. In the version 4.0 beta (Brunner et al., 2004), can be performed in addition to the preceding three other simulations: i) quasi unsteady flow, ii) sediment transport/mobile bed, and ii) water temperature.

Inputting the canal reaches characteristics and the cross section parameters is simplified by the following:

- easy to grasp graphic interface for geometry characteristics (reaches, junctions and cross sections)
- flow routes analyses simplified
- capacity of including georeferenced pictures under the network image
- data exchange capacity with Arcview GIS 3.x
- direct copies of the generated tables and graphics into the clipboard for reporting

HEC-RAS is designed to perform one-dimensional flow hydraulic calculations for a full network of natural or men made channels (HEC[3], 2002). The program can evaluate flow conditions in existing canals or be used to design new canals and structures. The 2 components in versions 3.1.3 are described below.

2.8.1 Steady flow water surface profiles

This component computes water surface profiles for steady gradually varied flow. It is capable of modelling subcritical (Froude number < 1), supercritical (Froude number > 1), and mixed flow regimes water surface profiles (hydraulic jump occurs in the flow).

The fundamental computation process is based on the solution of the one-dimensional *energy equation*. Energy losses are calculated by friction using Manning's equation and by expansion/contraction multiplying a factor by the velocity head change. The *momentum equation* is utilized in situations in which the water surface profile varies quickly. These situations occur when mixed flow regimes exist (i.e. hydraulic jump), in hydraulic of bridges, or at river confluences (junctions).

Obstructions such as bridges, culverts, weirs, spillways and other structures have an impact on water surface profiles that can be computed. This steady flow component is designed for application in flood management and flood insurance studies. Changes in water surface profiles due to canal improvements and levees can be also assessed.

2.8.2 Unsteady flow simulation component

An unsteady one-dimensional equation solver was firstly developed for subcritical flow computation and has been later adapted to process all the 3 flow regimes (subcritical, supercritical, and critical). The simulation can be performed for a full canal network.

The hydraulic calculations routines that were developed for steady flow have been incorporated in this module as well. These routines can compute profiles for cross sections, bridges, culverts, weirs, spillways and other structures.

2.8.3 Steady flow water surface profiles computation process

The version 3.1.3 of HEC-RAS is capable of computing one-dimensional flow water surface profile for steady gradually varied flow in natural and men made canals. The equations used are presented below.

Equations for basic computations

The water surface elevations are calculated from one cross section to the next using the energy equation of Bernoulli which reads:

$$Y_2 + Z_2 + \frac{\alpha_2 \bar{V}_2^2}{2g} = Y_1 + Z_1 + \frac{\alpha_1 \bar{V}_1^2}{2g} + h_e \quad (1)$$

Where: Y_1, Y_2 = water depths at cross sections 1 and 2
 Z_1, Z_2 = elevations of the main canal invert
 $\bar{V}_2, \bar{V}_1$ = average velocities (total discharge/total flow area)
 α_1, α_2 = velocity weighting factors
 g = gravitational acceleration
 h_e = energy head loss between cross sections 1 and 2

These terms are shown on Figure 19 in which the cross section 1 is located downstream, while cross section 2 is upstream.

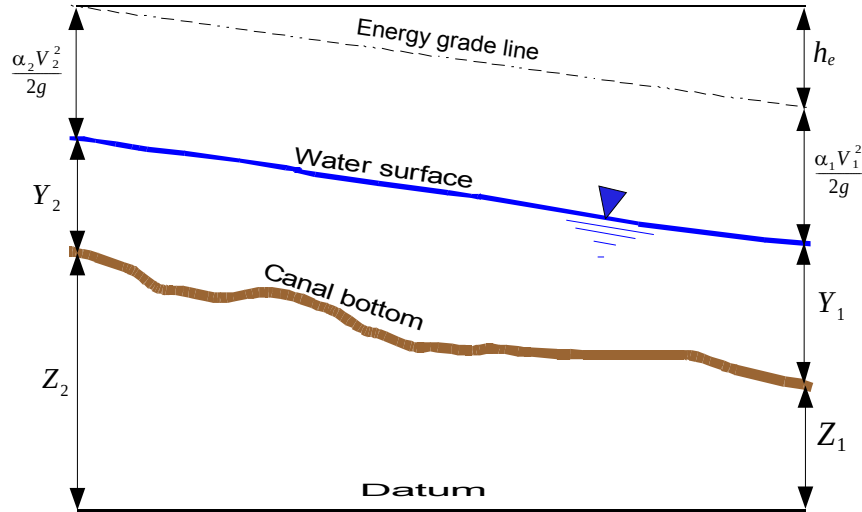


Figure 19: Terms of the energy equation

The energy head loss h_e is composed of 2 terms: the friction loss and the contraction/expansion loss. Therefore, its explicit expression is:

$$h_e = L \cdot \bar{S}_f + C \left| \frac{\alpha_2 \bar{V}_2^2}{2g} - \frac{\alpha_1 \bar{V}_1^2}{2g} \right| \quad (2)$$

Where: L = weighted reach length
 C = contraction or expansion coefficient
 $\bar{S}_f$ = representative friction slope between two cross sections

The weighted reach length is expressed by:

$$L = \frac{L_{lob} \bar{Q}_{lob} + L_{can} \bar{Q}_{can} + L_{rob} \bar{Q}_{rob}}{\bar{Q}_{lob} + \bar{Q}_{can} + \bar{Q}_{rob}} \quad (3)$$

Where: $L_{lob}, L_{can}, L_{rob}$ = reach lengths downstream a cross section specified for the left overbank, the canal and the right overbank respectively
 $\bar{Q}_{lob}, \bar{Q}_{can}, \bar{Q}_{rob}$ = arithmetic average of the flows between 2 cross sections for the left overbank, the canal and the right overbank respectively.

Cross section subdivision for conveyance computations

The cross section may have different Manning's roughness coefficients in the both overbanks, i.e. the cross section can be composite. In that case, HEC-RAS subdivides the flow in overbank areas into units for which the velocity is uniformly distributed. This subdivision is based on the input cross section n-value break points (locations where n-values change). Hence, conveyance K is calculated within each subdivision from:

$$Q = A \cdot V = A \cdot \frac{1}{n} R^{\frac{2}{3}} \cdot S_f^{\frac{1}{2}} = K \cdot S_f^{\frac{1}{2}} \Rightarrow K = \frac{1}{n} A R^{\frac{2}{3}} \quad (4)$$

Where: A = flow area in a cross section
 V = velocity
 n = Manning's roughness coefficient
 R = hydraulic radius
 K = conveyance subdivision
 S_f = friction slope (energy grade line slope)

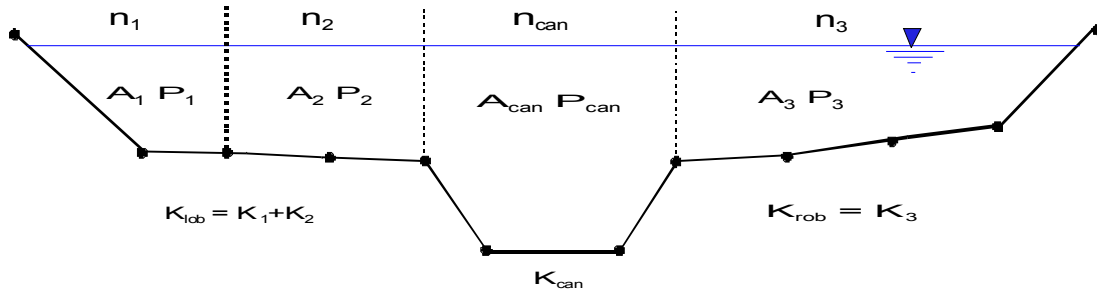


Figure 20: Default HEC-RAS conveyance subdivision method

Source : adapted from (HEC[3], 2002)

In a composite cross section (Figure 20), S_f remains the same, but the Manning roughness coefficient, the flow area and the hydraulic radius are different. Therefore conveyance for subdivision "i" in the cross section is expressed by :

$$K_i = \frac{1}{n_i} A_i R_i^{\frac{2}{3}} \quad (5)$$

And if N is the total number of different Manning's coefficient values (or subdivisions), the *total conveyance* through the composite cross section is given by:

$$K = \sum_{i=1}^N K_i = \sum_{i=1}^N \frac{1}{n_i} A_i R_i^{\frac{2}{3}} \quad (6)$$

Flow in the main canal is not subdivided, except when the n of Manning changes within the canal area. In that case, HEC-RAS uses an equivalent roughness coefficient computed from:

$$n_c = \left[\frac{\sum_{j=1}^M (P_j n_j^{3/2})}{P} \right]^{2/3} \quad (7)$$

Where:

n_c = composite coefficient of roughness

P = wetted perimeter of entire main canal

M = number of subdivisions

n_j = roughness coefficient of subdivision “ j ”

Evaluation of the mean kinetic energy head

Since HEC-RAS is a one-dimensional flow software, only a single water surface and thus a single mean energy are calculated at each cross section. For a given water surface elevation the mean energy is obtained by making a weighted average from the 3 subsections of the cross section (left overbank, main canal and right overbank).

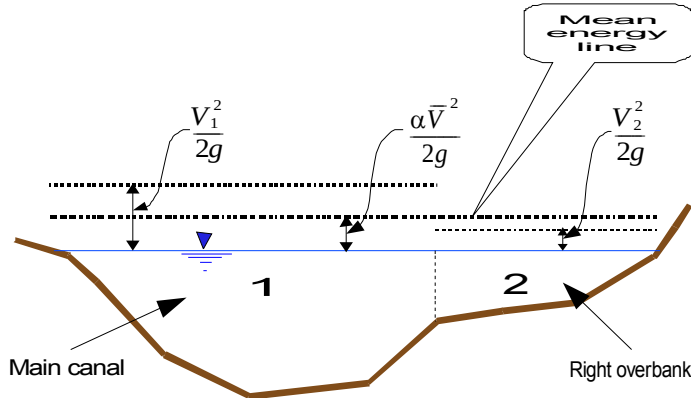


Figure 21: Mean energy head in a cross section comprising the main canal and a right overbank flows

Source: adapted from(HEC[3], 2002)

The *velocity head weighting coefficient* alpha (Figure 21) is calculated making the weighting average of the velocity heads in the subsections, the weights being the respective discharge portions. Therefore:

$$\alpha \frac{\bar{V}^2}{2g} = \frac{Q_1 \frac{V_1^2}{2g} + Q_2 \frac{V_2^2}{2g}}{Q_1 + Q_2} \Rightarrow \alpha = \frac{Q_1 V_1^2 + Q_2 V_2^2}{(Q_1 + Q_2) \bar{V}^2}$$

In general, alpha is computed by:

$$\alpha = \frac{Q_1 V_1^2 + Q_2 V_2^2 + \dots + Q_N V_N^2}{Q \bar{V}^2} \quad (8)$$

Friction loss evaluation

The friction loss is evaluated by the making the product of the friction slope and the weighted reach length downstream the cross section (Eqs 2 and 3). However from the conveyance expression it comes:

$$S_f = \left(\frac{Q}{K} \right)^2 \quad (9)$$

Several alternative expressions – depending on the heterogeneity of the cross section – may be used by the program such as:

- average conveyance equation $\bar{S}_f = \left(\frac{Q_1 + Q_2}{K_1 + K_2} \right)^2$, (the default equation used)
- average friction slope : $\bar{S}_f = \frac{S_{f1} + S_{f2}}{2}$
- geometric mean friction slope equation $\bar{S}_f = \sqrt{S_{f1} \times S_{f2}}$
- harmonic friction slope equation $\bar{S}_f = \frac{2(S_{f1} \times S_{f2})}{S_{f1} + S_{f2}}$

Contraction and Expansion loss evaluation

As seen above, the loss between cross sections 1 and 2 is calculated by the expression:

$$h_{ce} = C \left| \frac{\alpha_1 \bar{V}_1^2}{2g} - \frac{\alpha_2 \bar{V}_2^2}{2g} \right| \quad (10)$$

Where: C = contraction or expansion coefficient

The software assumes that a contraction occurs whenever the velocity head downstream is greater than the velocity upstream. On the contrary, when the velocity head downstream is smaller than upstream, an expansion is assumed. The Table 3 provides typical C values.

Table 3: Subcritical Flow Contraction and Expansion Coefficients C

	Contraction	Expansion
No Transition Loss Computed	0.00	0.00
Gradual Transitions	0.10	0.30
Typical Bridge Sections	0.30	0.50
Abrupt Transitions	0.60	0.80

Source : (HEC[3], 2002)

Computing the water surface at a cross section

The equations 1 and 2 are used iteratively to determine the unknown water surface elevation (WSE) at a cross section 2. In the case for example of subcritical flow, the WSE is set as boundary condition at the downstream cross section, i.e. WSE1 is known. The procedure is as it follows (Figure 22):

1. a water surface elevation is assumed at the upstream cross section 2 (or downstream cross section if a supercritical flow is being calculated)
2. based on this assumed water surface elevation, compute the corresponding total conveyance and velocity head
3. with values from step 2, calculate friction slope $\bar{S}_f$ and solve equation 2 for h_e
4. with the values from steps 2 and 3, solve equation 1 for WSE₂ (water surface elevation at section 2)
5. compare the calculated value of WSE₂ with the value assumed in step 1. Repeat steps 1 though 5 till the values agree to 0.003 m, or a user defined tolerance

Actually, the criterion used to assume water surface elevation at the beginning varies from trial to trial. The 0.70 of WSE_{2,b} on Figure 22 is applied to the first trial only.

There 4 boundary conditions that can be used in the program, according to the flow regime:

1. known water-surface elevation
2. critical depth
3. normal depth
4. rating curve

2.8.4 Application of the momentum equation

Whenever the water surface passes through the critical depth, the energy equation is not applicable. It is used only in gradually varied flow situations. The transition from critical to supercritical or vice versa is a rapidly varied flow situation. Rapidly varied flow take place when there are significant changes in channel slope, bridges constrictions, drop structures, weirs and junctions.

The functional form of the momentum equation used in HEC-RAS is the following:

$$\frac{Q_2 \beta_2}{g A_2} + A_2 \bar{Y}_2 + \left(\frac{A_1 + A_2}{2} \right) L S_0 - \left(\frac{A_1 + A_2}{2} \right) L \bar{S}_f = \frac{Q_1 \beta_1}{g A_1} + A_1 \bar{Y}_1 \quad (11)$$

Where:

Q = discharge

β = momentum coefficient that takes into account the varying velocity distribution in irregular channels

A_i = wetted area of the cross section at locations 1 and 2

Y_i = depth measured from the water surface to the centre of gravity of the cross sectional area at locations 1 and 2

All the applications of the momentum equation in HEC-RAS are derived from this equation.

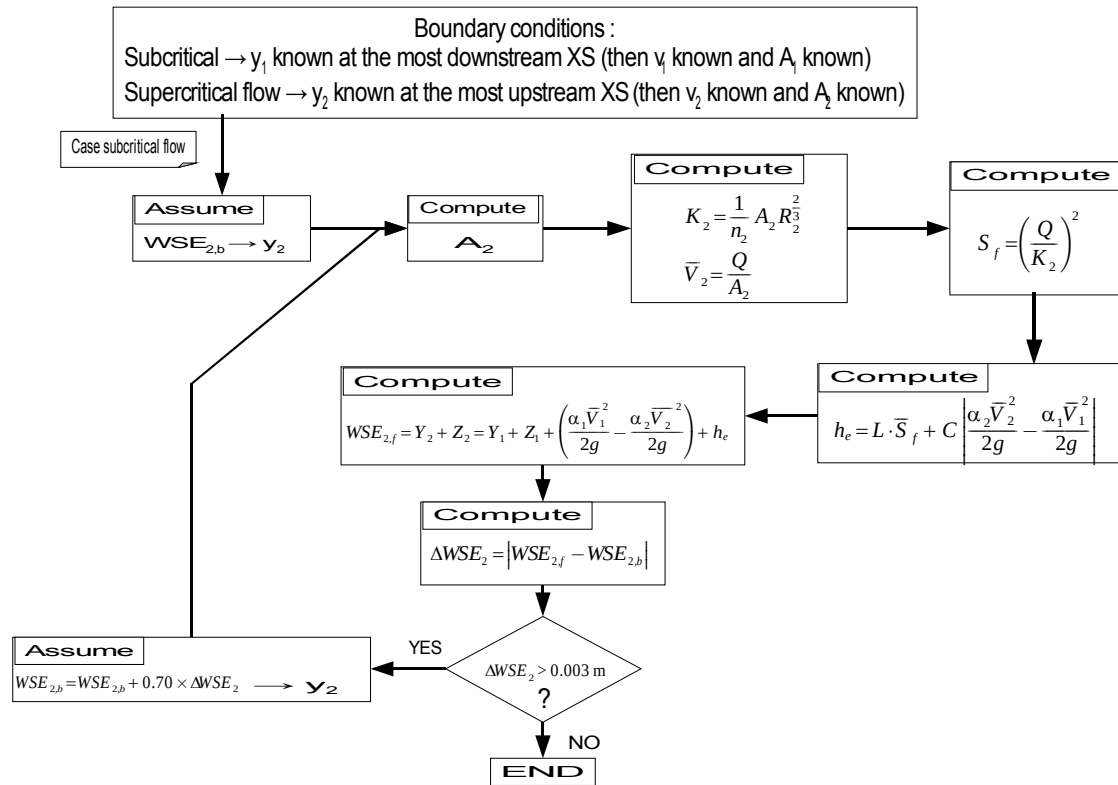


Figure 22: Water surface elevation computation algorithm of HEC-RAS

Note: XS= cross section, WSE = water surface elevation, $WSE_{2,b}$ = water surface elevation assumed or at the beginning, $WSE_{2,f}$ = water surface elevation computed or final.

2.8.5 Limitations of the steady flow program

HEC reports the following assumptions which set the limitations of the steady flow module:

1. flow is steady
2. flow is gradually varied, except at hydraulic structures such as weirs, bridges, culverts. At these locations, the momentum equation is applied since flow can vary rapidly
3. flow is one-dimensional. That is the velocity has only one component, which is in the flow direction
4. river channels have “small” slopes, i.e. less than 1:10

2.9 Modelling canal geometry with Arcview/HEC-GeoRAS

The irrigated land of Baguineda was modelled using the GIS Arcview 3.3. During this modelling, the top view of the canal network and the farming area of 3,000 ha were processed in GIS. Therefore, it was logical that the canal network geometry must be built using the same GIS environment.

Although Arcview GIS can not perform hydraulic simulations, one of its extensions called GeoRAS.avx was produced by HEC (HEC [1], 2002) to permit the construction of the canal network geometry in the GIS environment. This geometry is then exported to the

hydraulic simulation model HEC-RAS for steady flow, quasi-unsteady flow and unsteady flow processing (Figure 23).

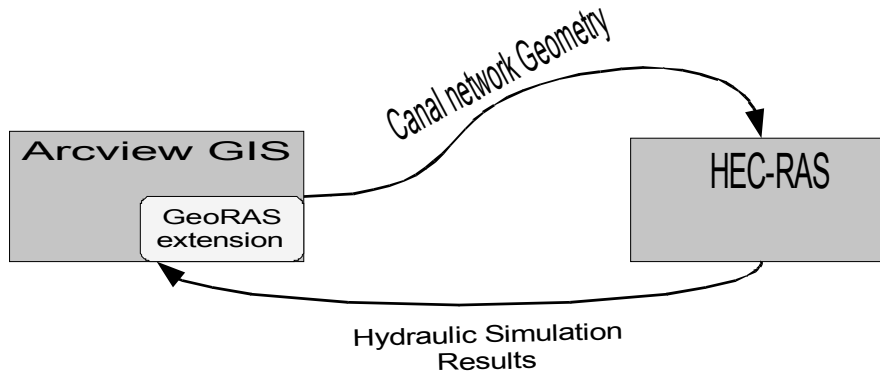


Figure 23 : GeoRAS is a tool for integrated work with Arcview GIS and HEC-RAS

Because GeoRAS extract the canal geometry from the DTM (Digital Terrain Model), a triangulated irregular network (TIN) of the entire irrigated terrain, incorporating a detailed topographic description of the main canal was created. How was realized the TIN?

2.9.1 Triangulated irregular network generation

A detailed topographic map for the entire area of Baguineda is not required since the focus is on the canal network, specially the main canal. However as regards with the main canal, the topographic description required accuracy.

Neither the main canal nor the 42 secondary canals of Baguineda are lined. Hence the canals are not prismatic (Figure 24). Fortunately, some 200 cross sections topography where available at BETICO and in KOEI documents (Nippon-KOEI, 1989). Whereas BETICO's cross sections were in AUTOCAD 2004 files format, the KOEI cross sections were in hard copy. In both cases, these cross sections were introduced in the GIS manually⁴. Therefore, 147 cross sections were selected so that to have at least 2 cross sections per reach in between two secondary offtakes. These cross sections were completed by 87 others but less accurate on the secondary canals which were not planned to be modelled. Interest was only on the discharge values at the secondary off takes.

The procedure to introduce the cross sections topographic data was as follows:

- 1) In a "cross section cutline" (XS cutline) theme overlapping the canal network theme in the GIS, were drawn a multi-segments or polyline. The cutline is perpendicular to the canal centreline. Each vertex of the cutline is clicked at a distance corresponding to an angle in the cross section profile (Figure 24). Actually, the interest is about the vertices to each of which an (X,Y,Z) value must be attributed. Hence, how to transform the cutlines "line theme" into a "point theme"?

⁴ The AUTOCAD 2004 files imported directly in Arcview GIS were lacking the elevations data

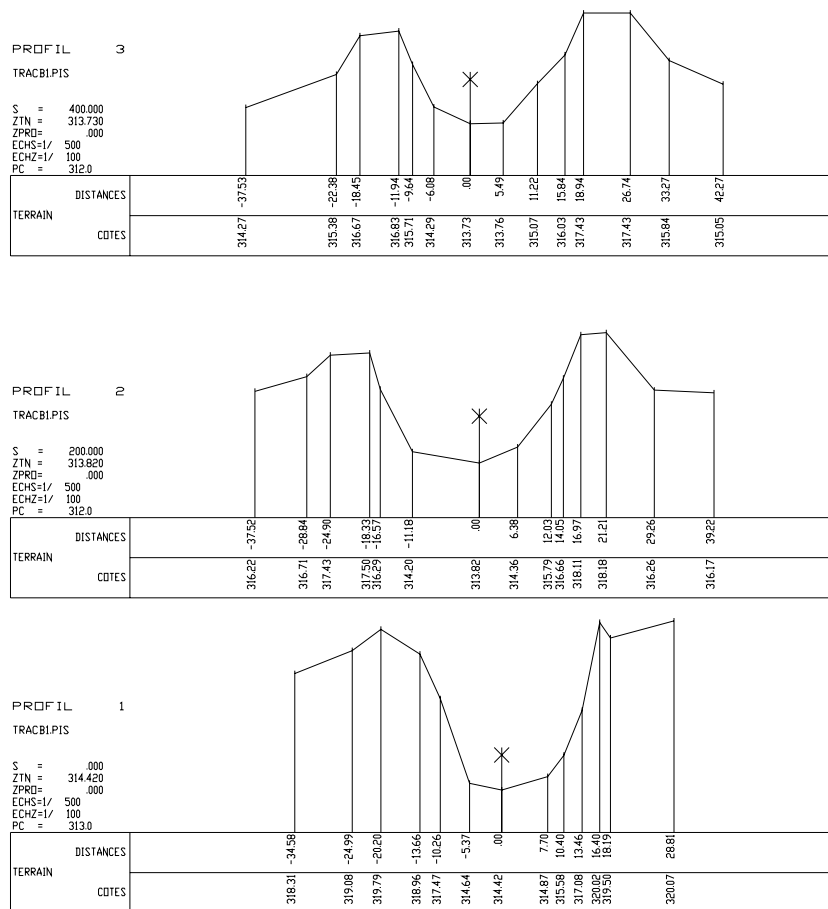


Figure 24: Example of cross sections on the main canal

- 2) An empty XS cutline “point theme” is created. Then, a specific extension called **Vertex.avx** is applied to the polylines (Geocommunity-Downloads). This tool converts the polylines vertices into graphic points that were copied and pasted in the XS cutline point theme. In this way, a topographic point theme was prepared, cutting the main canal and the secondary canal centrelines. It should be noticed that “Convert vertex to point” *does not work along with an image present in the table of content of a view*. The picture must be removed first.
- 3) In the topographic “point theme”, the attribute table was opened and the altitudes Z values were introduced in a new field. Since the points were already located on the map, the X,Y values were not required. However, in order to insert the coordinates values in the attribute tables, they were computed using another extension called NVTools.avx (Morefield, 2006). This extension comprises several useful tools to compute, for example, lengths of lines, areas and perimeters of polygons and points coordinates which were used.

Additional topographic points at the boundary of the irrigated land (Figure 25) were created. The altitudes, approximate, are read from Google Earth.

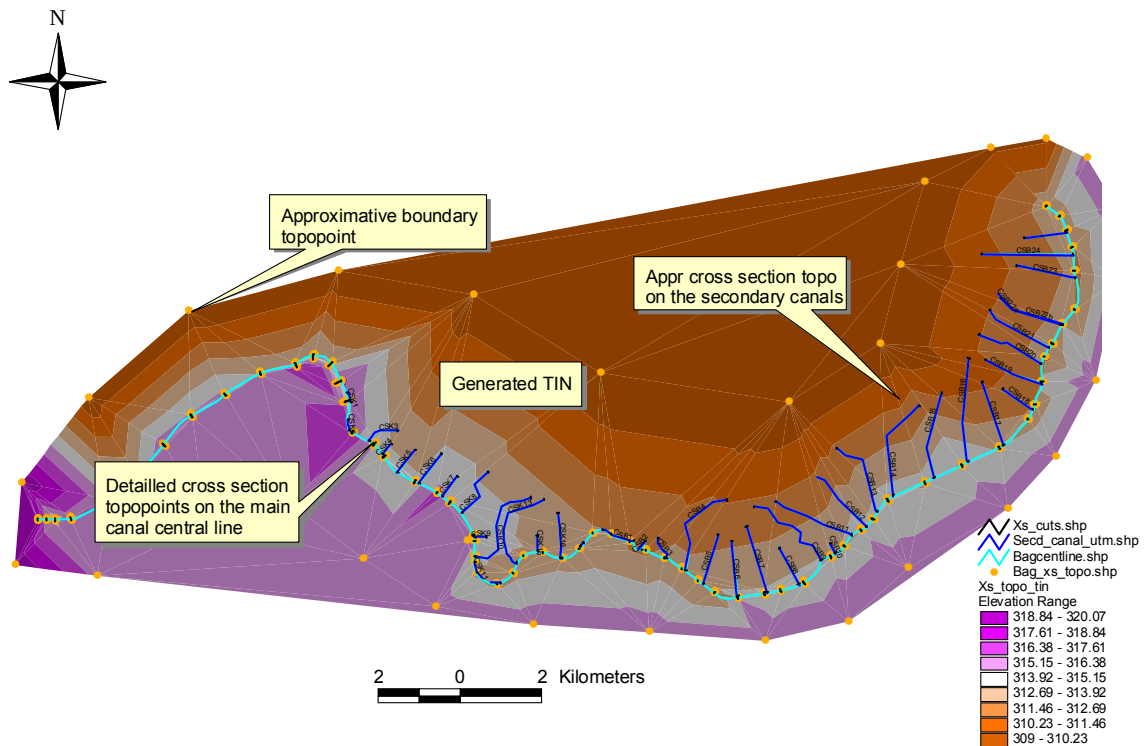


Figure 25: TIN Digital Terrain Model of Baguineda crop land and canal network

- 4) At this level the Arcview extension Projection Utility Wizard has been used (ESRI, 1992-2002). This wizard is applied to retro-project all the themes present in the view into Mercator projection system (or UTM – Universal Transverse Mercator; see Figure 14).

Once the topographic point theme is created, with its attributes table, it becomes possible to generate the terrain TIN⁵ using the “Surface menu/Create TIN” (Figure 25). As previously mentioned; the TIN is an Arcview 3D analyst extension created object. Before its creation, some precautions were required.

Whereas the points were in geographic coordinates (hence not projected), the TIN had to be projected to make it possible for the GIS functions to handle it properly. If not projected, the TIN creates also the difficulty to overlap the cross section cut lines theme since they appear at different geographic locations in the GIS display. A perfect overlapping of the cross section cut lines, the main canal

⁵ TIN is one of the objects used by Arcview 3D Analyst extension (the second is GRID) to represent a surface. TIN partitions a surface into a set of contiguous, non-overlapping triangles. A height value is recorded for each triangle node. Heights between nodes can be interpolated thus allowing for the definition of a continuous surface. TINs can accommodate irregularly distributed as well as selective data sets. This makes it possible to represent a complex and irregular surface with a small data set. Source : Arcview GIS 3.3 program help.

centreline themes and the TIN was required for intersecting the layers and make an integrated analysis.

After performing these steps, 3 basic features become available : i) the TIN incorporating a detailed topographic description of the main canal location, ii) the canal network centrelines comprising the main canal and the secondary canals and iii) the cross section cutlines (XS cuts). The next step was to generate the canal network geometry using GeoRAS.

2.9.2 Canal network geometry generation with GeoRAS

Hydraulic structures and flow parameters are not built in the GIS environment. Only the basic canal network geometry was produced. The different steps (HEC [1], 2002) to reach this objective are summarized on Figure 26.

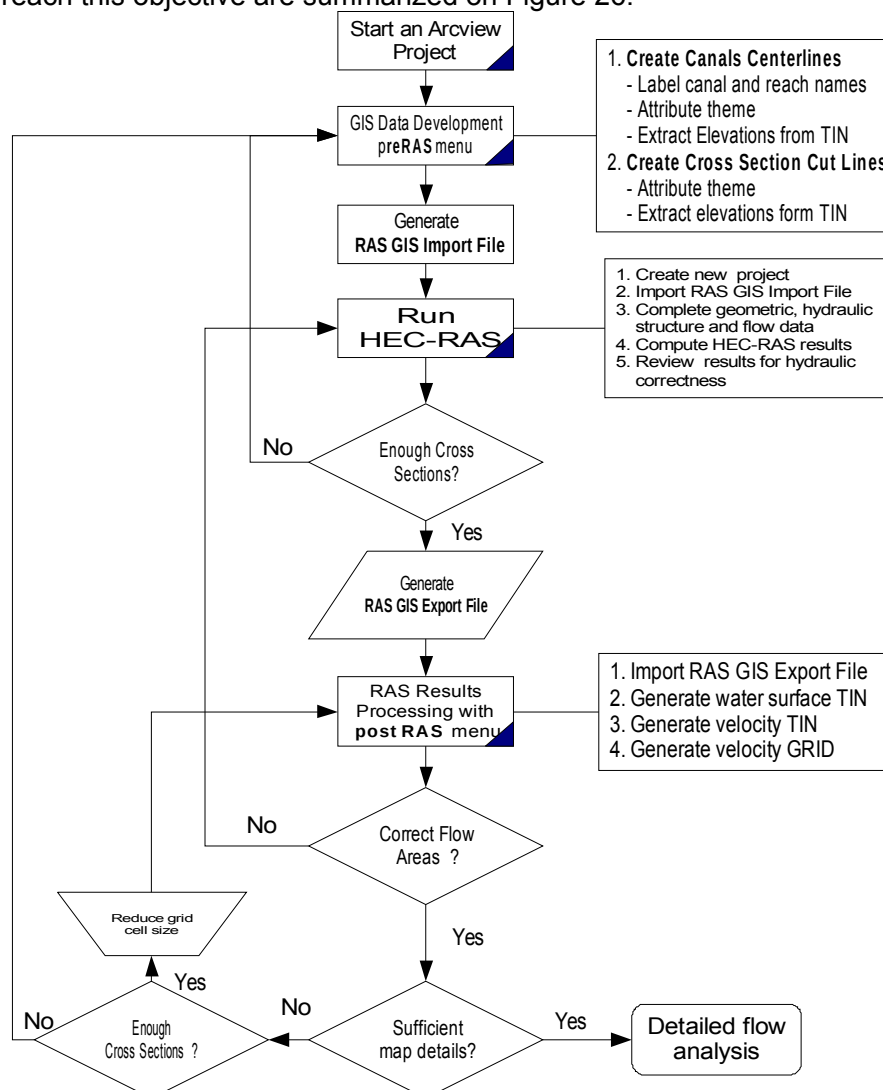


Figure 26: Process diagram applying Geo-RAS to model the canal network

Source : adapted from (HEC [1], 2002)

On this figure, the black triangles indicate programs or extension menus. In the original HEC flow diagram there are more *optional* steps for other analyses. Here are the required essential ones (Figure 26):

- Start an *Arcview project*. This is related to the process for the generation of the TIN as explained in the previous section
- GIS Data Development *preRAS menu*. This menu is available in Arcview once GeoRAS extension is loaded. Its processing had generated the GIS Import File comprising the canal geometry and topography.
- Run *HEC-RAS*. This was running the simulation program after providing the i) geometry complements, ii) hydraulic structure dimensions, and iii) flow data. It produces simulation results such as water levels, discharges, velocity and so forth.

The results of the flow computations were analyzed using HEC-RAS environment, which is enough for a canal system. Therefore, the RAS GIS export file was not needed.

In the following sections are explained the geometry completion process within HEC-RAS and the flow data settings for the simulation.

2.9.3 HEC-RAS running preparation

Canal Flow Modelling with HEC-RAS

The Arcview/Geo-RAS generated geometry was imported in the HEC-RAS environment for the entire irrigation network. This was done using Edit/Geometric Data/File/Import Geometry Data/GIS Format of menu the program. The system network is received in UTM (Mercator projection coordinates).

The schematic is shown on Figure 27 where are present:

- the canal network schematic
- the cross section cut line
- the labels

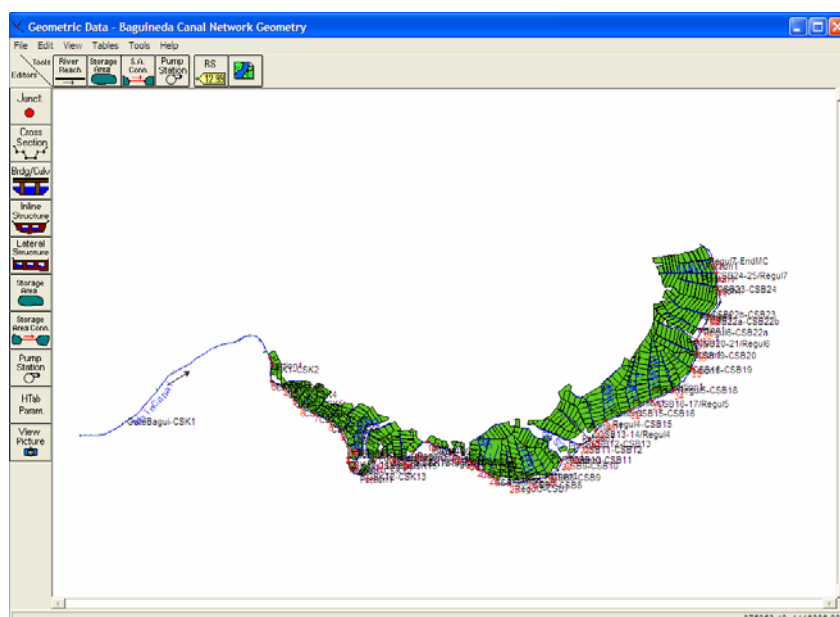


Figure 27: Baguineda entire network imported in HEC-RAS

Each cross section received in HEC-RAS was checked to ensure its conformity with the measured one. For example, the cross section at station 7416.06 located in the crocodile lake extracted from the digital terrain model is conform to its image in HEC-RAS as it can be seen on Figure 28.

Modelling the entire network would be an interesting issue. But the dimensions and elevations of secondary intakes vertical gates were not available. Furthermore, more cross section will be required. Therefore, it was decided to model the area of the network regulated by the regulator R1. This subsystem runs from the headwork double gate to the secondary canal CSK11 and command an area of 415 ha (Figure 29). The modelling principle is replicable for the entire scheme.

The interest in this area resides in the inclusion of:

- the headwork double gate at the most upstream end of the system; the gate openings can be changed at any time in the model
- a 15 km of not lined canal portion, from the headwork of Sotuba to CSK11; which allows the investigation of head canal seepage impact on the water levels and on the discharges. The presence of grass in the canal impacts on the roughness coefficient which can be changed in the model
- the “difficult” area called “crocodile lake”, of 2.2 km length (GIS measurement) where the canal cross section expands on more than 150 m width and looks like a river reach (Figure 28). An ineffective flow area is present and can be modeled in HEC-RAS

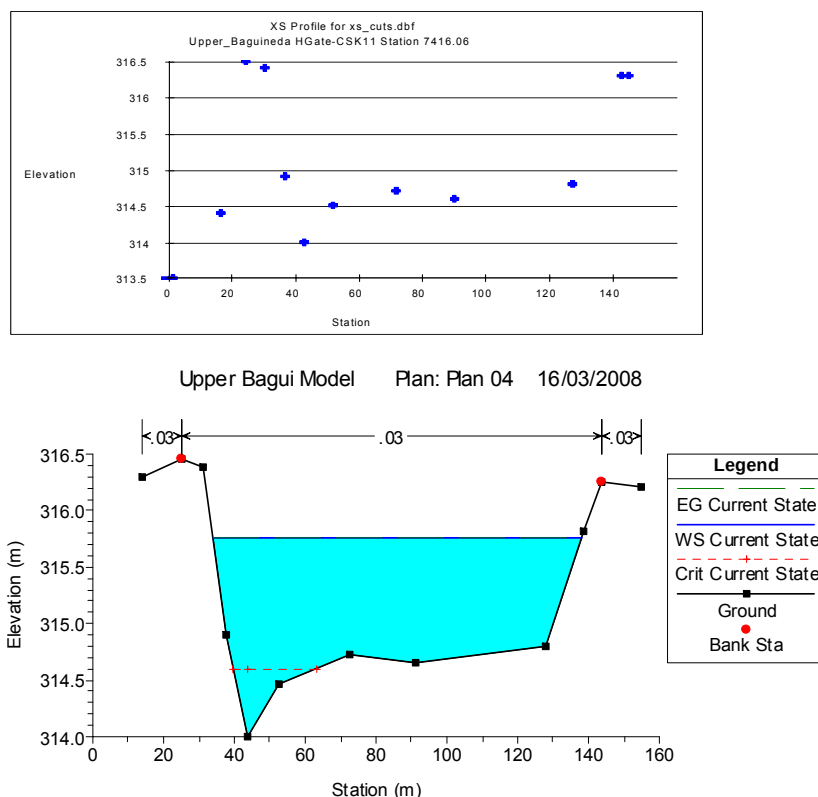


Figure 28: Cross sections in Arcview GIS and in the flow simulation software HEC-RAS

- secondary blocks among which CSK8 with 103.63 ha is the biggest and CSK11 with 5.23 ha is the smallest offering a representative range of the blocks (the maximum block size is 200.47 ha in CSB14 for the hole scheme). The average block size of the modelled area is 37.7 ha.
- a typical water level regulator, namely R1, is designed to maintain water level for 11 secondary intakes. Modelling this regulator offers a replicable process for the 6 others downstream (R2 to R7).

Although interesting, all the above mentioned influences were not investigated in this report. Were mainly considered:

- a comparison between the water level measured on November 28th 2007 at regulator R1 and the water level provided by the model. This shows the start of a calibration method
- the impact on water levels of the Manning roughness reduction from 0.027 (not lined canal) to 0.015 (*modern lined canal*) (Giles, 1983), combined with a drop in seepage from 0.22 m³/km to 0.10 m³/km

Area modeled with HEC-RAS in Baguineda

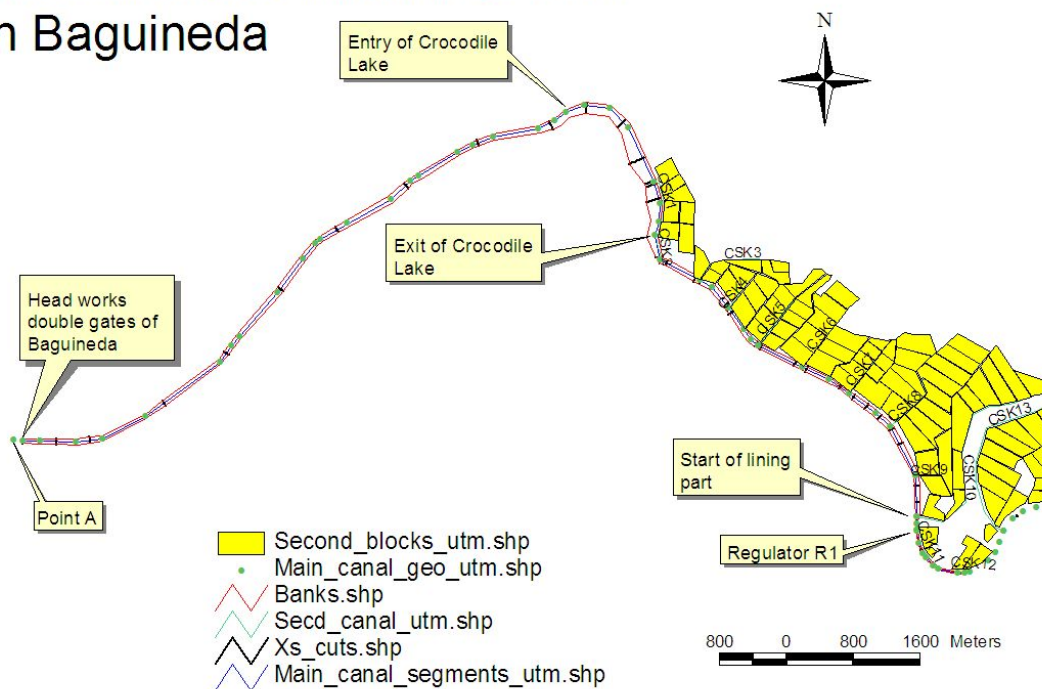


Figure 29: Headwork to CSK1 area modeled

The details of the cross sections data for the studied subsystem are provided in Appendix IV.

The modelling was conducted in 3 basic steps : i) finishing the construction of the subsystem network geometry, ii) choosing observation cross sections and iii) running the subsystem under steady flow conditions in order to determine the available water levels and discharges .

2.9.4 Completing the canal geometry and flow data structure

Built with Arcview/Geo-RAS extension, the canal basic geometry of the modeled area was constructed. The entire canal from headwork double gate to downstream CSK11, defined in Arcview as only one river – “Upper Baguineda” – and one reach “HGate-CSK11” was brought in HEC-RAS environment using the menu Geometric data/File/Import Geometry data/GIS Format. Some 45 cross original cross sections were hence available.

The geometry finalization involved 2 aspects : i) supplementary cross sections and ii) the gated weirs insertion.

Cross sections

The cross sections were completed for the location of the headwork gates by making an interpolation between two measured cross sections. This is accomplished through the menu Geometric data/Tools/XS interpolation/between 2 XS's in HEC-RAS.

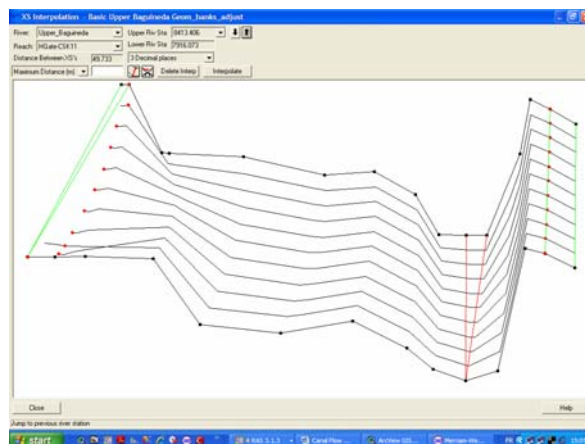


Figure 30 : Cross section interpolation

On the example of Figure 30, the 2 extreme cross sections are those measured by the topographic survey. In between are the 9 interpolated cross sections in the area of Crocodile Lake. Supplementary cords joining the points were not required to make “user guided interpolation” in this area. But the cross sections generated near CSK11 were guided by using supplementary cords.

When the cross section includes over bank station points elevations lower than the main canal bed, HEC-RAS splits water coming from upstream and convey a part in the low over bank side. This over bank flow does not exist in the case of the irrigation canal of Baguineda. Therefore, the main canal over bank elevations were increased enough above the canal bed to avoid the flow splitting.

Finally, the canal segment in between 2 secondary intakes is created with at least 2 cross sections at its extremities and 1 cross section inside. The cross section inside the segment is used to withdraw seepage water. The downstream cross section always corresponds to what is the location of a secondary canal intake, where the nominal discharge will be taken.

Weirs and Gates

At the headwork, there are 2 vertical gates. Downstream on the secondary canal CSK11's intake, there is the regulator R1 composed of a weir and two vertical gates in each side. The dimensions of the headwork gates were measured and those of the R1 read from KOEI documents

Gates and weirs were entered in the software as "inline structures". This was done using the sequence Geometric data/Inline structure (button)/weir-embankment or gate. In both cases - headwork and regulator R1 with their double vertical gates - a weir is entered first. Next, the double gate is inputted as a "1 group"⁶ of 2 gate openings in each case.

The following conditions were observed:

- given that there is no weir at the headwork, the weir inputted is only required to make the vertical gates. The weir was high enough to obstruct the main canal. Then, the double gates are lodged in the lower part of the weir. The construction obtained is called "gated spillway" in HEC-RAS
- since the length of regulator R1 – 13.36 m – is longer than the canal top width (the weir is an arc), HEC-RAS would cut it to the exact the dimension of the canal top width (HEC [2], 2002). Therefore, the regulator cross section was widened to the length of the weir, 13.36 m.

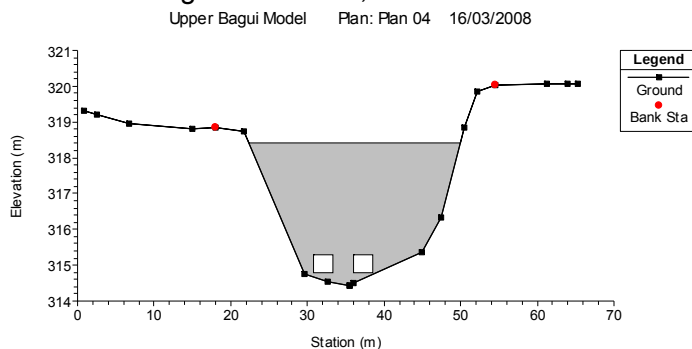


Figure 31 : Headwork double gate modeled by a "Gated Spillway" in HEC-RAS

The small 2 rectangles represent the gates dimensions. The top line is the top of a weir closing the canal and forcing water to pass through the gates when opened. This model is also valid for the regulators of the main canal comprising always a double gate and a weir.

Observation cross sections

Water levels are observed at 4 cross sections located:

- downstream the headwork
- at crocodile lake (6504 m upstream R1); a possible effect of the ineffective flow area is investigated
- near upstream CSK1 (5624 m upstream R1), which is supposed to be the remotest intake regulated by R1
- at the regulator R1 (cross section 6 m upstream R1): the reference water level for the CSK1-CSK11 secondary canal intakes is obtained here

⁶ Terminology of HEC-RAS

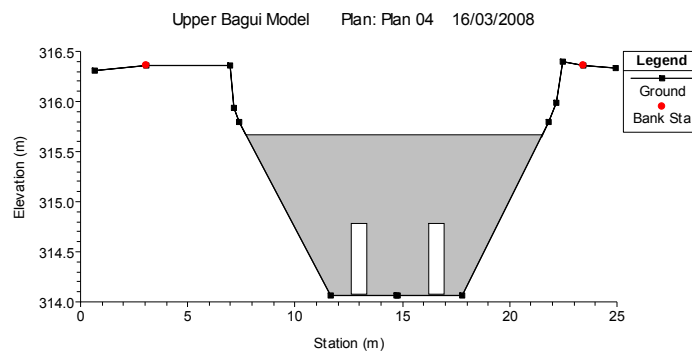


Figure 32 : Regulator R1 and its double gates

The small 2 rectangles represent the gates which are normally closed, except when rotating irrigation is practiced during water scarcity of the dry season. The canal was widened at the top part to allow the insertion of the 13.36 m length of the weir; otherwise, HEC-RAS shortens the weir to fit the actual width of the canal. In the case of the 7 regulators of Baguineda, the weir is not high varies from 1.51 to 1.64 and water passes above it when functioning.

The parameters inputted in the program are given in Figure 31, Figure 32 and Table 4 below.

Table 4 : Weir and gate parameters at the headwork and at regulator R1

Characteristics of the headwork gates		
o weir : distance to upstream cross section	:	6 m
width (wall thickness)	:	0.40 m
coefficient	:	1.7
stations [dist. x from left bank (m), elevation z(m)]	:	(20,318.4) and (55,318.4)
Type :	:	broad crested
o gate : height	:	0.5 m
width	:	2.5 m
invert elevation	:	314.78 m
discharge coefficient	:	0.52
weir coefficient (while working as a weir)	:	2.7
stations [dist. x from left bank]	:	13.0 and 16.6 m
Characteristics of regulator R1		
o weir : distance to upstream cross section	:	6 m
width (wall thickness)	:	0.20 m
coefficient	:	1.7
stations [dist. x from left bank (m), elevation z(m)]	:	(7.7, 315.67) and (21.5, 315.67)
Type :	:	broad crested
o gate : height	:	0.7 m
width	:	0.7 m
invert elevation	:	314.08
discharge coefficient	:	0.52
weir coefficient (while working as a weir)	:	2.7
stations [dist. x from left bank]	:	32.0 and 37.2 m

Setting the flow conditions

The network is checked for 2 scenarios called current and modern respectively:

- *current scenario* assumes:
 - o average loss by seepage measured in 2001 in the main canal equals to $0.22 \text{ m}^3/\text{s}/\text{km}$ (BCEOM 2002)
 - o Manning roughness coefficient of 0.027 upstream Crocodile Lake, 0.030 in the crocodile lake, and 0.015 in the short lined portion downstream R1.
- *The modern scenario* :
 - o assumes the main canal is lined with seepage of $0.10 \text{ m}^3/\text{s}/\text{km}$
 - o Manning coefficient value of 0.015 all along the canal

The Manning roughness coefficients are actually inputted with the system geometry.

In order to run the simulation under steady flow conditions, two groups of settings were required : i) the indication of the flow change values (discharges) and locations and ii) the boundary conditions in terms of water levels (normal, critical, known or rating curve).

In case of supercritical flow, the boundary condition in a reach is required at its upstream end for the program to start computations. In case of subcritical flow, the boundary condition is required at the downstream end the reach.

The ineffective flow area located in the “crocodile lake” is delineated in the canal geometry input of HEC-RAS. Flow in the right side of the cross sections located in this area is not conveyed. Although the ineffective flow areas are determined after an accurate field measurement, they were estimated in this study after visual inspection in the field. An example of ineffective flow area is shown on Figure 33. The hachured area contains water that is not conveyed.

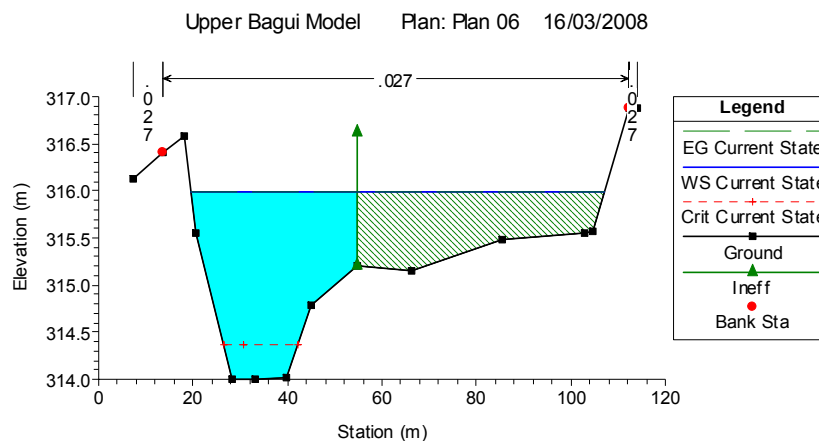


Figure 33 : Ineffective flow area cross section in Crocodile Lake

2.10 Irrigation water requirements calculation process

The software *Cropwat for Windows* is available for Crop water requirements, irrigation water requirements and scheduling (Clarke, 1998). Most of common crops are considered in the program, except rice (Smith, 1991). A major production in Baguineda is rice. Therefore, a proper algorithm to address the *CWR* computation is needed.

On Figure 34 are explained the different steps used to compute the irrigation water requirement in Baguineda. The preparatory steps are the determination of the:

- crops coefficients K_c which are function of the type of crops and their growing stages (de Laat, 2006)
- Penman-Monteith reference evapotranspiration ET_o for the climatic zone . The value of ET_o is read from Climwat, the FAO database The values depend on the climate but also on the month considered. Therefore, the cropping pattern (type of crop, planting and harvesting dates) must be integrated in the calculation (Clarke, 1998).
- collection of the total precipitation P (mm/month) or the effective rainfall Pe (mm/month) if available in the area
- total growing area A (ha)
- growing area percentage $A_{\%}$ per crop

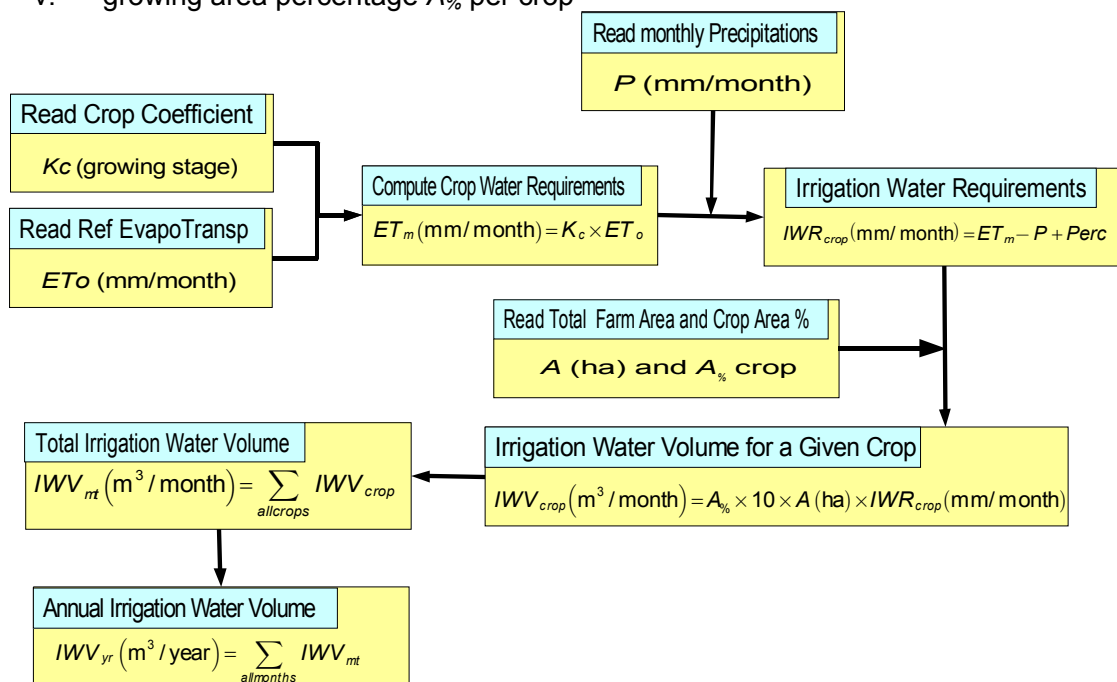


Figure 34: Irrigation water requirements computation process

With these five parameters are computed for each crop and per month:

- crop water requirement ET_m (mm/month)
- irrigation water requirement IWR_{crop} (mm/month) ;
 $IWR_{crop} = ET_m$; if $P = 0$ and $Perc = 0$. With rice, percolation $Perc$ is not zero⁷.
- irrigation water volume IWW_{crop} (m³/month)

When the preceding 3 quantities are available for all crops grown, the totals are computed to obtain the:

- monthly total irrigation water volume IWW_{mt} (m³/month)

⁷ The percolation value of Baguineda was taken 2 mm/day (Clay Loam).

- yearly total irrigation water volume $IWV_{yr} (m^3 / year)$

These volumes are converted afterwards into discharges to be compared with the nominal discharges used in the area for diagnosis purpose.

2.11 Deficit irrigation computation process

“Deficit irrigation” implies that the crop, for some reasons, will not be irrigated with required amount of water. Hence, it will not grow with the maximum evapotranspiration. The readily available moisture – that depends on the soil, the plant and the climate (through ET_m) - will not always be filled during the total growing period. The consequence is: a yield reduction but less water used.

The following reasons may lead to adopt a deficit irrigation approach:

- a protective irrigation is decided: the maximum possible of farms (families) will receive less than needed amount of water. That could be applied in Baguineda
- a drought happens in a system designed on a *no yield reduction* approach, that is ET_m is targeted. The water available is hence less than expected.

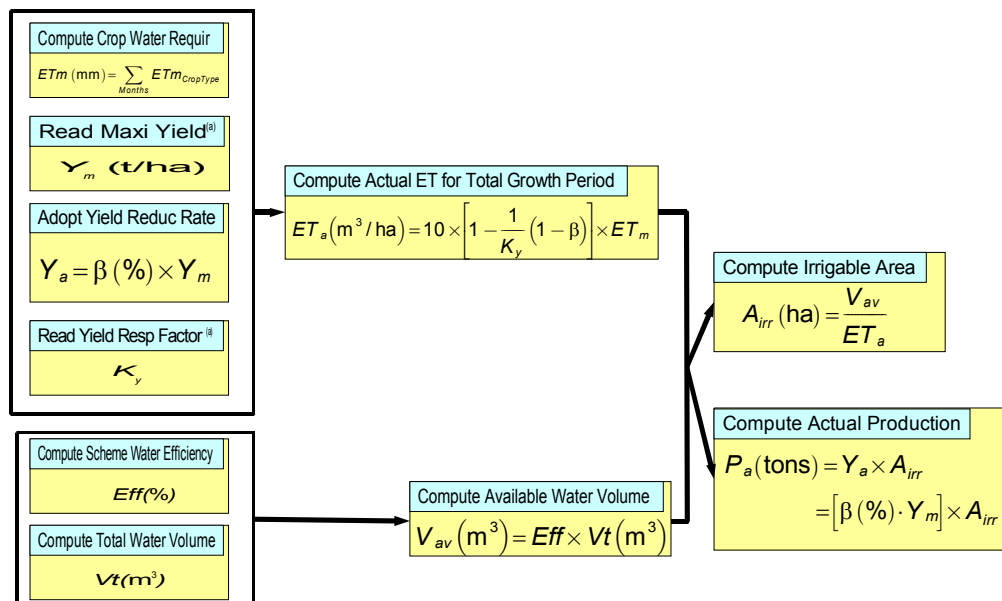


Figure 35: Deficit irrigation computation process

(a) the Y_m and the K_y values are given respectively in Table 5 and Table 6

The approach used to compute the irrigable area, given a yield reduction rate, is explained on Figure 35. The major assumptions are:

- the water deficit $ET_m - ET_a$ is spread over the entire crop growing period
- the yield response factor (Table 6) corresponding to the entire growing period of **rice** is $k_y = (1.2 + 2.4 + 0.3) / 3 = 1.3$

The values to input are the:

- maximum evapotranspiration ET_m (mm) over the total growing period
- maximum crop yield in tons/ha according to the climate read on Table 5

- adopted yield reduction rate $\beta (\%) = \frac{Y_a(t/ha)}{Y_m(t/ha)}$, where Y_a is the actual crop yield and Y_m the maximum one ; e.g. 80%
- yield response factor K_y read from Table 6
- total water efficiency of the irrigation scheme $Eff (\%)$
- total water volume from the resource infrastructure $Vt(m^3)$

The computation is performed using an Excel Sheet. At the end of the process, the irrigable area A_{irr} (ha) under deficit condition and the actual production P_a (tons) are obtained.

Table 5: Good crop yields Y_m (t/ha) as function of climatic conditions when an adequate water supply and high agricultural inputs are assured.

Crop	Product	Moisture content	Climatic regions					
			Tropics		Subtropics		Temperate	
			<20oC	>20oC	<20oC	>20oC	<20oC	>20oC
Alfalfa	hay	10-15	15		25		10	
Beans	grain	10	1.5-2.5		1.5-2.5		1.5-2.5	
Cotton	seed	10		3-4		3-4.5		
Maize	grain	10-13	7-9	6-8	9-10	7-9		4-6
Potato	tuber	70-75	15-20		25-35		30-40	
Rice	paddy	15-20		6-8		5-7		4-6
Sorghum	grain	12-15	3-4	3.5-5	3-4	3.5-5		2-3
Soybean	grain	6-10	2.5-3.5		2.5-3.5			
Sugar beet	beet	80-85			40-60		35-55	
Sugarcane	cane	80		110-150		100-140		
Tomato	fruit	80-90	45-65		55-75		45-65	
Wheat	grain	12-15	4-6		4-6		4-6	
			Semi-arid and arid areas only		Summer and winter rainfall areas		Oceanic and continental areas	

Source: (de Laat, 2006)

Table 6: Yield response factor k_y

Crop	Vegetative period	Flowering period	Yield formation	Ripening	Total growing period
Alfalfa					0.7-1.1
Beans	0.2	1.1	0.75	0.2	1.15
Cotton	0.2	0.5		0.25	0.85
Maize	0.4	1.5	0.5	0.2	1.25
Potato	0.45-0.8		0.7	0.2	1.1
Rice ¹	1.2	2.4	0.3		
Sorghum	0.2	0.55	0.45	0.2	0.9
Soybean	0.2	0.8	1.0		0.85
Sugarbeet					0.7-1.1
Sugar cane	0.75		0.5	0.1	1.2
Tomato	0.4	1.1	0.8	0.4	1.05
Wheat(spring)	0.2	0.65	0.55		1.15

¹ the k_y -values for rice are applicable to ET_a and ET_m taken over the total growing period

Source : After FAO-ID33, 1979 quoted by (de Laat, 2006)

2.12 Overall objective of an irrigation scheme

Due to a possible mutation in the overall objective of a project during its lifespan, it is not always obvious to determine its overall objective. To help finding out the objective of an irrigation system, Ankum proposed a useful classification method (Ankum, 2004).

To explain the classification proposed by the author, one can use the terminology of mathematical analysis about *functions of several variables*. One can assume the *overall objective* of an irrigation system is a function of 2 variables :

- the first is the specific discharge q which dimension is l/s/ha but is function of 2 possible seasons, *wet* or *dry*. This is expressed by $q = q(\text{wet})$ or $q = q(\text{dry})$
- the second is the supply nature, that can be named sn . The supply nature takes also 2 possible values, i.e. $sn = sn(\text{equitable})$ or $sn = sn(\text{flexible})$.

In other words, a system can be designed with a specific discharge based on the *wet* or the *dry* season. The same system, on the other hand, may be designed to allow an *equitable* or a *flexible* water distribution. In an equitable system, farmers are supposed to have the same rights on irrigation water. A flexible system design allows giving priority to specific areas or crops within the irrigation system.

Therefore, there are two possible options for the overall objective of an irrigation system:

- i. system with $\left\{ \begin{array}{l} q = q(\text{dry}) \text{ or } q = q(\text{wet}) \\ sn = sn(\text{flexible}) \end{array} \right\} \Rightarrow \text{Overall objective} = \text{Productive irrigation}$
- ii. system with $\left\{ \begin{array}{l} q = q(\text{wet}) \\ sn = sn(\text{equitable}) \end{array} \right\} \Rightarrow \text{Overall objective} = \text{Protective irrigation}$

As mentioned by Ankum, it appears that a *productive irrigation* may be designed for the *wet season* with in mind to provide a supplementary irrigation to random rainfall. It can be also noticed that the more logical basis for *productive irrigation* design is the dry season.

The specific discharges based on the dry season are higher than those based on the wet season.

This classification method of Ankum is used to determine the overall objective of the irrigation system of Baguineda.

3 Results

3.1 Organization

The Operation and Maintenance agency OPIB⁸ is composed of one General Direction and three "Divisions" + one Cell (BETICO-BCEOM, 2005):

- Division Administration and Finance (DAF)
- Division Rural Advise and Vulgarization (DCRVA)
- Division of Works (DT)
- Planning and Follow Up Cell

Particularly, the DT has in charge:

- evaluation of works to be implemented
- water management in the whole irrigated system
- maintenance of the infrastructures, buildings and materials (auto park and electricity generator)

As explained in section 1.3; the irrigation system is divided into 4 geographical sectors each of which is supervised by a "Chief Sector". The 4 sectors are:

- Kobala-Coura : CSK1-CSK17 secondary canals
- Baguineda Camp : CSB1-CSB12
- Sébéla : CSB13-CSB18
- Tanima : CSB19-CSB25 , CST1 to CST6 and CSS1 to CSS4

It should be noticed that the secondary canals of Tanima (CST) and those of Sienkoro (CSS) further downstream are not represented on the maps produced during this research.

The irrigation and maintenance are implemented, in principle, on a basis of co-management (Figure 36) implicating OPIB DT agents and farmers. The work is managed as follows:

- at the level of each of the 421 tertiary canals, the irrigation is implemented by a Water Users Group (GUE);
- a Irrigation and Maintenance Committee (CIE) has in charge the management of each of the 42 secondary canals;
- the representatives of all the CIEs in a sector (geographical group of secondary canals and dominated blocks) composed the Parity Commission of Irrigation and Maintenance (CPIE). The CPIE manages at the sector level (4 sectors);

⁸ OPIB (Office du Périmètre Irrigué de Baguineda) is a mixed organization composed by national officers and contractual agents. Some 87% of the water fees paid by farmers are used for maintenance of secondary canals. The remaining 13% is a contribution to OPIB's functioning. The total annual functioning budget of OPIB is assessed to be 122,200 €/yr. For 2007 rainy season, the water fees perceived from the 3,000 farmers amounted to € 103,815 (Source: OPIB' administration). Some 98% of the farmers pay the water fee.

- the Parity Commission for Exploitation and Maintenance or CPEE coordinates all the CPIEs at the whole irrigation system level. It resides at OPIB and the president is the Deputy Director of OPIB.

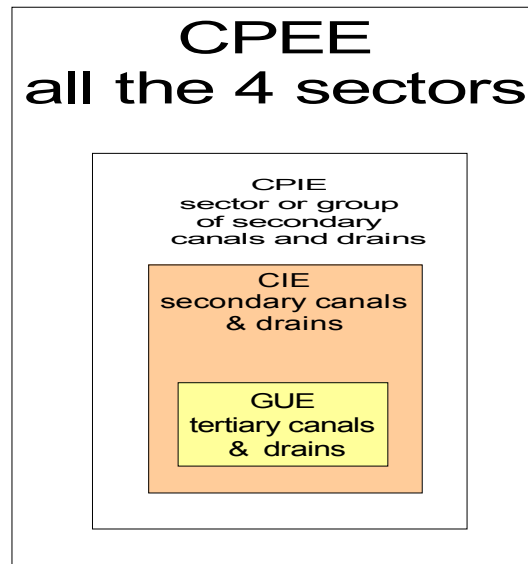


Figure 36 : Management organizations

The GUE and the CIEs sensitize and inform their members, gather information about irrigation and the maintenance needs. They work together with the OPIB sector agents. (BETICO-BCEOM, 2005)

The CPIEs prepare the detailed annual program cropping activities and maintenance at the sector level. They record also farms which have difficulties and supervise the cropping and maintenance activities.

The CPEE is the institution that *makes decisions*. It has in charge:

- annual program elaboration, execution, schedule and prospective budget of works
- proposal of the list of farmers exempted from water fee payment or expelled from the crop land
- revise periodically the water fee amount to adjust to the secondary canals and drains maintenance needs⁹
- participation to market elaboration, attribution and implementation supervision
- approval of progress reports of maintenance implementation using water fees

The meetings of the GUEs are *informal*, as well as their irrigation programs. The other institutions have regular formal monthly meetings with reports.

⁹ The primary canal and drain maintenance is supported by a contribution from the Malian National Budget. These amounts were estimated for 2008 to respectively 157 000 and 96 000 euros. Source : OPIB administration.

Individually a farmer makes a contract called "Contrat d'exploitation agricole" or CEA that is signed by the farmer and by the General Director of OPIB. The contract is continued automatically during 3 cropping seasons. After a period of 3 years without any failure, the CEA is replaced by a "Permis d'exploitation agricole" or PEA. The validity period of a PEA is 5 cropping seasons¹⁰ (5 years). (OPIB [7], 2001)

The water fee is 48.8 euros/ha in the rainy season. In the dry season, 10% of this amount is collected. Therefore, the main contribution comes from the rainy season fees. In the 2007 rainy season campaign, 98% of the water fees were paid to OPIB.

The basic contract links the Ministry of Agriculture, OPIB and farmers through one representative. Since *farmers are not organized in Federation*, their representative person is designated by farmers with OPIB's assistance. The basic contract is called "Contrat Plan". The current "Contrat Plan" embraces the period 2006-2008. It describes the role and contribution of each actor.

3.1.1 Water distribution during the rainy season (May to October)

No rotation is prescribed on the main canal. All regulator gates are closed and water passes above the central sill of the regulators, ensuring the designed water level to the secondary canals intakes.

All the 42 secondary canals receive water. Except during rare dry periods, there is no rotation along a secondary canal. There is enough water.

3.1.2 Water distribution rules during the dry season (November to April)

During the water penury period irrigation is organized by rotation on the main canal, on the secondary canals and on the tertiary canals.

The rotation on the *main canal* for the 2007 the dry season was by the General Direction of OPIB as follows(OPIB [1], 2007):

- 2) a "tour d'eau" or rotation is introduced for dry-season in Baguineda according the Table 7
- 3) the regulator gates are manipulated by the chief sectors in collaboration with the "DT", starting at 8 am
- 4) adaptive measures may be introduced if necessary
- 5) the farms irrigation will end on April 30th 2007
- 6) the divisions DT and CRVA are responsible for the application of the service note in their respective competence area.

An example of regulator gate is presented in Figure 45.

During the dry season, there water scarcity. Thus irrigation is rationed has shown in Table 7.

¹⁰ Season apparently indicates here a rainy season. Therefore 5 cropping seasons are 5 years.

Table 7: Rotation on main canal during the dry Season from January to April

Part	Reach of Main Canal	Part Irrigation Day	Secondary Canals addressed	Regulator Gates Handling Positions
I	From Sotuba Gate to Regulator N°4 or Regulator of Tieman	Monday Tuesday Wednesday	From CSK1 to CSB14 included	R 1: the 2 gates totally open R 2: one gate is closed R 3: one gate is closed R4: the 2 gates closed (water passing above the central sill) R 5*: (the 2 gates) totally open R 6*: one gate is closed R 7: the 2 gates closed
II	From Regulator N°4 to Regulator N°7 of Mofa Regulator	Thursday Friday Saturday Sunday	From CSB 15 to CSB 25 included	R .1: the 2 gates totally open R 2: one gate is closed R 3: the 2 gates totally open R 4: the 2 gates totally open R 5: one gate is closed R 6: one gate is closed R 7: the 2 gates closed

Source : Translated from (OPIB [1], 2007)

* **Remark:** One gate is closed on R 6 in order to handle the supplement water coming from R 4 to solve the irrigation difficulties on CSB18 and CSB 19. Meanwhile, no water will be retained at R 5

3.2 Baguineda farm system characteristics

3.2.1 Soil map

BCEOM realized a pedologic study (BCEOM, 1992) on the irrigated land of Baguineda in 1992. A soil map was produced in 4 different hard sheets each one at scale 1:2,000. This study described 4 groups of soils according to their agronomical aptitudes based on physico-chemical properties. The corresponding areas of the soils were computed using an electronic planimeter:

In the BCEOM's map, the following symbols are used:

- the numbers in the code combination indicate layer thickness or depths counted from soil surface
- S is sand
- L is loam
- A is clay
- N is water table

For example, a soil class SL20/L/N<80 means "soil with top Sandy Loam of 20 cm thickness laying upon a Loam layer and a water table located less than 80 cm". A soil class SL20/SA/N>80 means "soil with top Sandy Loam of 20 cm thickness laying upon a Sandy Clay layer and a water table located more than 80 cm".

To compute the Readily Available Moisture (RAM) BCEOM's study [(BCEOM, 1992); pp31-32] adopted a soil depletion factor of $p = 2/3$ ¹¹ for all crops. An average root depth $Z_{\text{root}} = 0.50$ m was also assumed. The study used the RAM formula version based on the

¹¹ In principle, p is a function of the crop group and ET_m (mm/d). (de Laat, 2006)

gravimetric moisture content $w(\%)$ and the soil dry bulk density $D_b(\text{kg/m}^3)$ that can be turned into the more common Anglo-Saxon expression as it follows :

$$RAM(\text{mm}) = \text{Fraction} \times AM = (2/3) \cdot \left[Z_{\text{root}}(\text{m}) \cdot D_b(\text{kg/m}^3) \cdot [w_{FC}(\%) - w_{WP}(\%)] \right]$$

$$\text{But } w(\%) = 1000 \times \frac{\theta(\%)}{D_b(\text{kg/m}^3)} \Rightarrow$$

$$RAM(\text{mm}) = (2/3) \times \left[Z_{\text{root}}(\text{mm}) \cdot [\theta_{FC}(\%) - \theta_{WP}(\%)] \right]$$

Where

$w_{FC}(\%)$ = gravimetric soil moisture content at field capacity

$w_{WP}(\%)$ = gravimetric soil moisture content at wilting point

$\theta_{FC}(\%)$ = volumetric soil moisture content at field capacity

$\theta_{WP}(\%)$ = volumetric soil moisture content at wilting point

$Z_{\text{root}}(\text{mm})$ = crop root depth

$2/3$ = adopted soil depletion factor p

L20/LA

In other words, the Anglo-Saxon expression is based on volumetric moisture contents.

Using this setting, BCEOM provided (Table 8) the available readily moisture for all the inventoried soils.

Table 8 : Soil Types and the readily available soil moistures

Soil Class	RAM(mm)
SL20/L/N<80	15.0
SL20/SA/N>80	12.0
SL20/LA-AL	16.0
SL20/LA/N>100	14.0
LS20/L/N<80	24.0
LS20/LA-AL/N<80	19.0
LS20-30/LA-AL/N>80	15.0
LS20/LA-AL	14.5
LS15/SL50/LA	17.5
LS20/L40/LA-AL	21.0
L20/LA	20.5
L20/LA/N<80	21.5
L20/AL-LA/N>80	27.0
L/N<80	19.5
LA-AL/AL-LA	20.0

Source : (BCEOM, 1992)

Finally, the soils were gathered into classes according to their agronomic suitability for crop growing.

These areas comprise the location of the roads, farm separation embankment, etc. From Table 9 it can be observed:

- the major soil 2R – with 1,900 ha representing $1,895 / (858 + 2,209) \equiv 62\%$ – is very good for only rice in the rainy season
- the soils 1P and 2P with a total area of $225 + 207 + 230 + 12 \approx 674 \text{ ha} \equiv 22\%$ are very good for maize and vegetables production in both seasons

- the soil 1R with $195 + 303 \approx 500ha \equiv 16\%$ is very good for rice in both seasons and remains very good only for maize and vegetables only in the dry season

Table 9 : Soil classes and their agronomic aptitudes

Soil Type	Soil Class	Size & Location		Agronomic Aptitude
		CSK	CSB	
L20/LA L20/LA/N<80 L20/AL-LA/N>80 L/N<80 LA-AL/AL-LA	1R	195.0 ha	303.0 ha	• Very good for rice in both rainy and the dry season. • Very good for maize in the dry season
LS20/L/N<80 LS20/LA-AL/N<80 LS20-30/LA-AL/N>80 LS20/LA-AL	2R	208.0 ha	1,687.0 ha	• Very good for rice in the rainy season • Almost good for rice in the dry season if drainage reduction measures are assured • Almost good for maize and polycrops (maize, vegetables)
SL20/L/N<80 SL20/SA/N>80 SL20/LA-AL SL20/LA/N>100	1P	225.0 ha	207.0 ha	• Very good for maize in the rainy season • Very good for polycrops in the dry season (maize, vegetables, potatoes)
LS15/SL50/LA LS20/L40/LA-AL	2P	230.0 ha	12.0 ha	• Almost good for maize in the rainy season • Very good for vegetables and potatoes in the dry season
Totals		858.0 ha	2,209.0 ha	

Source : Adapted from (BCEOM, 1992)

Note: "R" stands for Rice while "P" stands for Poly crops (maize and vegetables)

In other words:

- In the rainy season : $62\% + 16\% = 78\%$ of the soils are *very good* for rice while 22% are *very good* for maize or vegetables
- In the dry season : $22\% + (16\%) = 38\%$ of the soils are very good for maize and vegetables
- In the dry season : the same previous 16% are also very good for rice
- In the dry season $100\% - 38\% = 62\%$ of the soils are only almost good for rice, maize or vegetables

The four sheet hard copies – each one at scale 1:2,000 – of the soil map were digitized with GPS/GIS using the same technique exposed in section 2.3. The map is georeferenced and linked to a table of attributes. Every click on an area of the map in GIS displays the following information (Table 10):

- each soil type area is computed and the "Hectares" and the "Perimeters" provided
- each soil class information and size is provided such as "K20/LA"
- the Readily Available Soil Moisture information is provided according to the location

- an agronomic advice is given, e.g. very “good for rice in the rainy season” (RS=VGd rice)

Table 10: Information provided by clicking on an area of the GIS soil map

Identify Results	
1: Soil_agro_map.shp - 46	
Hectares	129.346
Perimeter Meters	8002.690
Pedo Code	L20/LA
Readily Available Moisture (mm)	20.5
Agro Aptitude Code	1R
Agonomic Advice	RS=VGd rice ; DS=VGd maize
creator	Amadou Keita
agency	UNESCO-IHE/OPIB
date	20080118
hour	20
model	GPSMap 60 CSx

Note: RS= Rainy season, DS= dry season; VGd= very good

The soil map is presented on Figure 37 .It was provided to the Infrastructure Division and Land Reclamation Division of OPIB as a modern management tools.

The accuracy of the areas processed by GIS can be appreciated by comparison with those offered by BCEOM using an electronic planimeter for each soil class. This comparison is shown on Table 11 and Figure 38.

The main features are:

- the total soil surface by planimetry is 3,067 ha while GIS rough is 3,456 ha and GIS neat is 2,833 ha
- planimetric area result is 389 ha smaller that GIS rough and 233 ha greater than GIS neat
- GIS neat of 2,833 ha is the most in agreement with to the total secondary blocks total area of 2,846 ha computed.

The average of the GIS two values is 3,145 ha (relative error of 2% when compared to BCEOM's value).

Table 11: Soil class areas by planimeter (BCEOM) and by GPS/GIS

	Soil Map Areas (ha)					Differences			
Soil Class		1R	2R	1P	2P	Totals	b-a	a-c	b-c
BCEOM 1992	a	498	1,895	432	242	3,067	389	234	623
GPS/GIS 2008 with embankments, canal sites and roads	b	576	2,240	370	270	3,456			
GPS/GIS 2008 without embankments canal sites and roads	c	415	1,907	285	226	2,833			

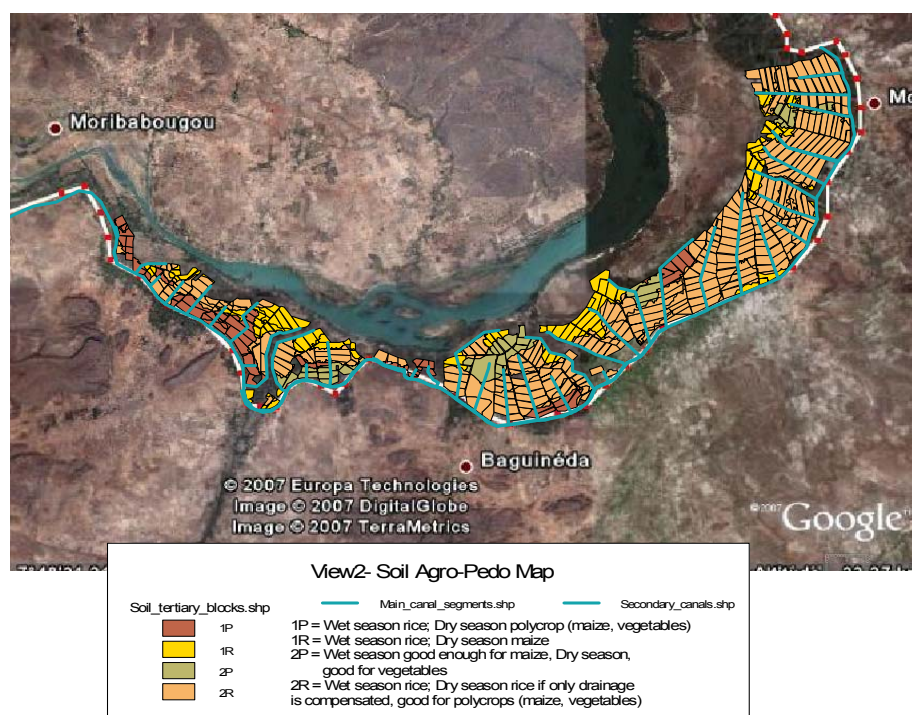


Figure 37: Soil map of Baguinéda irrigation scheme

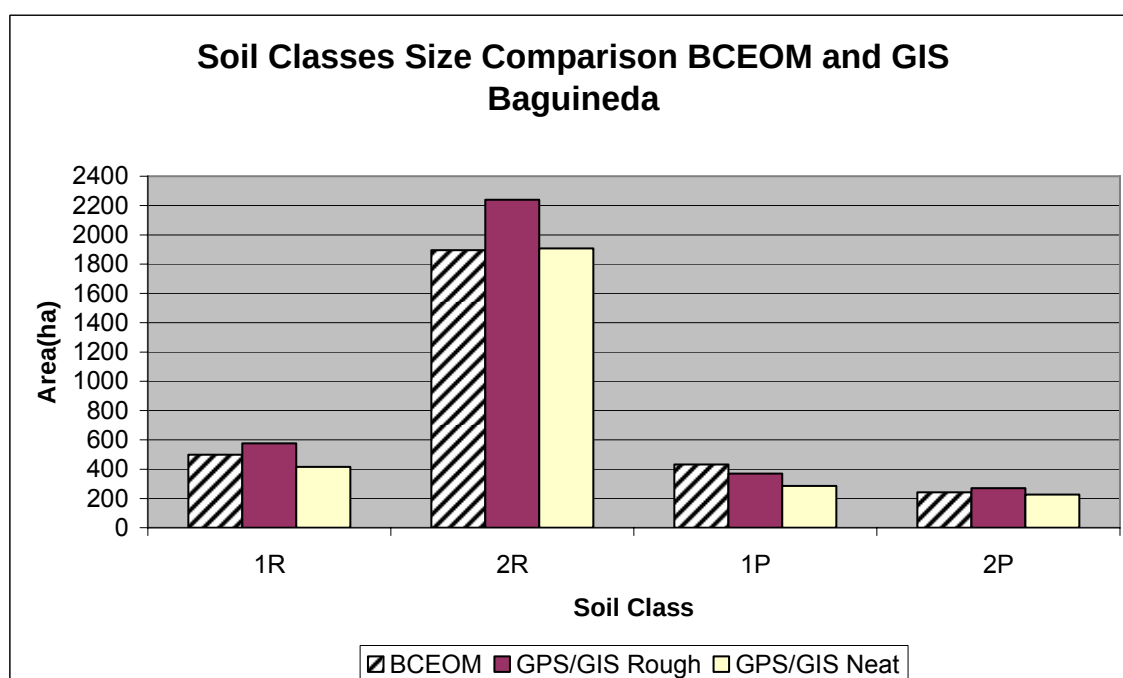


Figure 38: Soil class sizes comparison BCEOM/planimeter and GPS/GIS computations

3.2.2 Water delivery system

The GIS processing resulted in the digitization and the creation of a database of all the secondary and tertiary canals. The canal lengths and locations were determined. The statistical computation produced e.g. i) mean length, ii) lengths confidence intervals; iii) minimum and maximum lengths and iv) dispersion assessment parameters such as variance and standard deviation.

In the GIS environment, a simple click on a secondary or tertiary canal renders its characteristics recorded in the associated database. The geographic coordinates – longitude and latitude – are also indicated on the screen.

The main properties of the secondary and tertiary canals, followed by secondary drains are described below. The Appendix II provides further details.

Secondary canals

The statistics of the 42 secondary canals are presented in Table 12. The total length is 54 km and the average is 1.30 km. The standard deviation is more than 770 m, auguring a quite important dispersion of the canal lengths around the mean. A typical secondary canal cross section is 2 m wide and 40 cm deep (see Figure 39).

The nominal discharges of the 42 secondary canals were also included in the database.

Table 12: Statistics for the 42 secondary canal lengths (m)

Mean: 1279.24 Lower 90% Conf. Limit: 1078.76 Upper 90% Conf. Limit: 1479.73 Minimum: 148.98 Maximum: 2580.80 Variance: 596071.27 Standard Deviation: 772.05 Total Records: 42 Number of Null Values: 0 Sum: 53728.40	
---	--

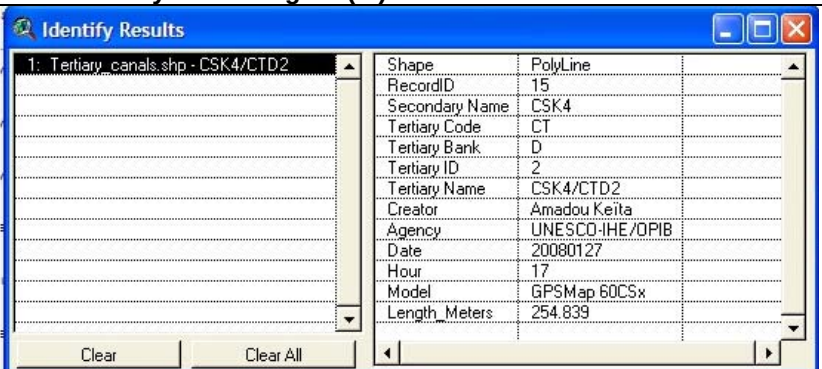
Figure 39: A typical secondary canal is the CSB5.

Tertiary canals

The average length is 345 m and the total of all the canals laying in the farming area from the Headwork to the drain N°13K (the end of the main canal) is 145 km.

A typical information slide is shown below Table 13, reproducing what is obtained when a click is done on the canal feature.

Table 13: Statistics for the 421 tertiary canal lengths (m)

Mean: 345.49		
Lower 90% Conf. Limit: 331.51		
Upper 90% Conf. Limit: 359.48		
Minimum: 46.20		
Maximum: 2287.025		
Variance: 30285.18		
Standard Deviation: 174.02		
Total Records: 421		
Number of Null Values: 0		
Sum: 145454.88		

In this GIS information window are presented the followings:

- “Shape” is the geometry shape of the canal : polylines or line composed of several segments
- “Record ID” is the record tag of the canal in the database
- “Secondary Name” is the name of the secondary canal that delivers water to the tertiary canal
- “Tertiary Code” provides the code of the tertiary canal (CT or tertiary canal)
- “Tertiary Bank” indicates the bank side on which is located the tertiary canal. “D” corresponds to right bank (or “droite” in French)
- “Tertiary ID” is the order of the canal when counting toward downstream; in this case it is the second tertiary canal on the right bank
- “Tertiary name” is the full name of the canal. CSK4/CTD2 reads in French “2^e Canal Tertiaire situé à Droite sur le 4^e Canal Secondaire de Kobala”. The english translation is “2nd Tertiary Canal on the Right bank of the 4th Secondary Canal of Kobala”
- “Creator “ field is filled with the name of the author of the database
- “Agency” field corresponds to the name of the company which carried out the work
- “Date” 20080127 means January 27th, 2008 and indicates the date of creation of the information
- “Hour” is the hour of creation; at 17:00 in this example
- “Model” field deals with the type of GPS used to collect the data; here it is Garmin GPS Map 60 CSx
- “Length_Meters” indicates the length of the canal measured in meters using the GIS tools; in this example, the tertiary canal length is 255 m.

Similar attributes were created for the secondary canals, the secondary and tertiary blocks of Baguineda.

3.2.3 Crop land

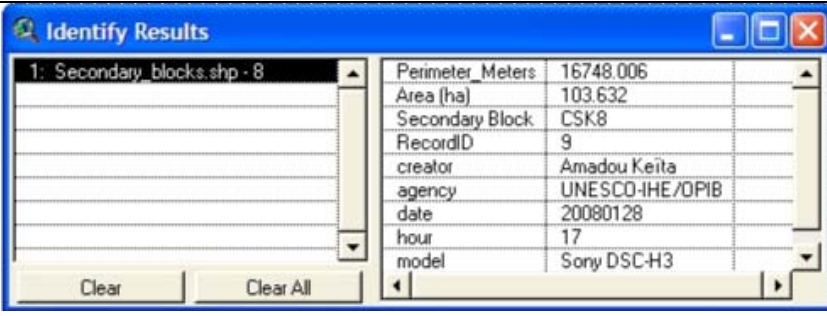
A Sony DSC-H3 digital camera was used to scan the hard copy of the crop land map before GIS processing. The detailed values of the secondary and tertiary blocks are presented in Appendix III.

Secondary blocks

The 42 secondary blocks (Figure 40) have an average value of 67.77 ha while the total area of the crop land is 2,846 ha. This figure does not contain the dead areas examined separately below.

A typical information slide is shown in Table 14, reproducing what is obtained when clicking on the canal feature in the GIS program.

Table 14: Statistics for the 42 secondary block areas

Mean: 67.77 Lower 90% Conf. Limit: 54.76 Upper 90% Conf. Limit: 80.78 Minimum: 5.28 Maximum: 200.47 Variance: 2510.09 Standard Deviation: 50.10 Total Records: 42 Sum: 2846.36	
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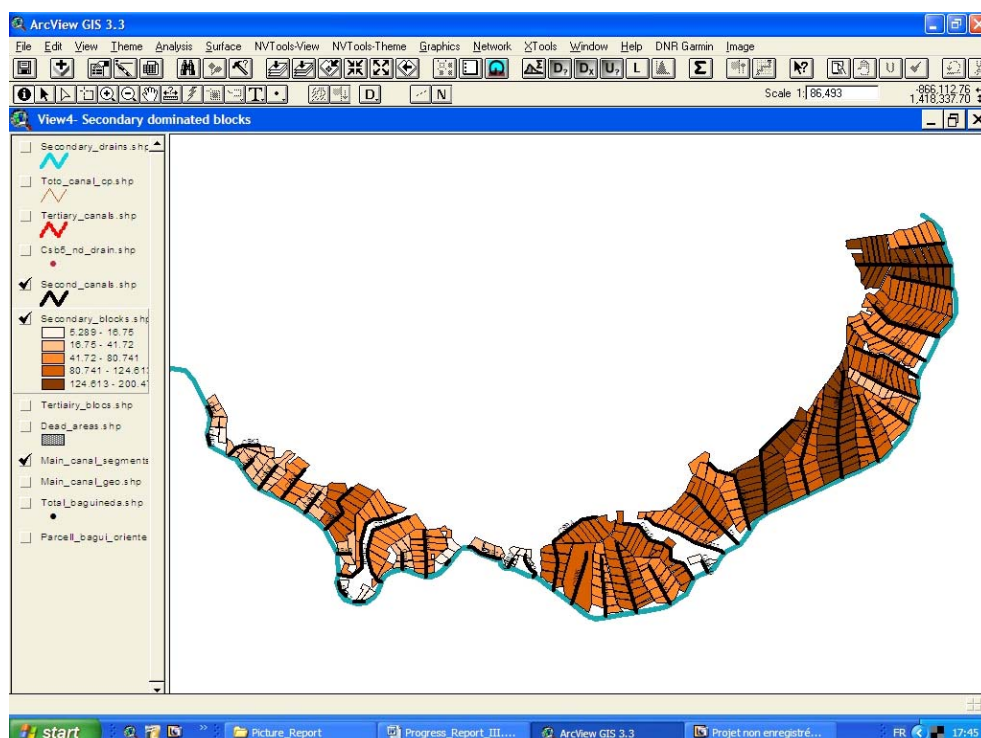


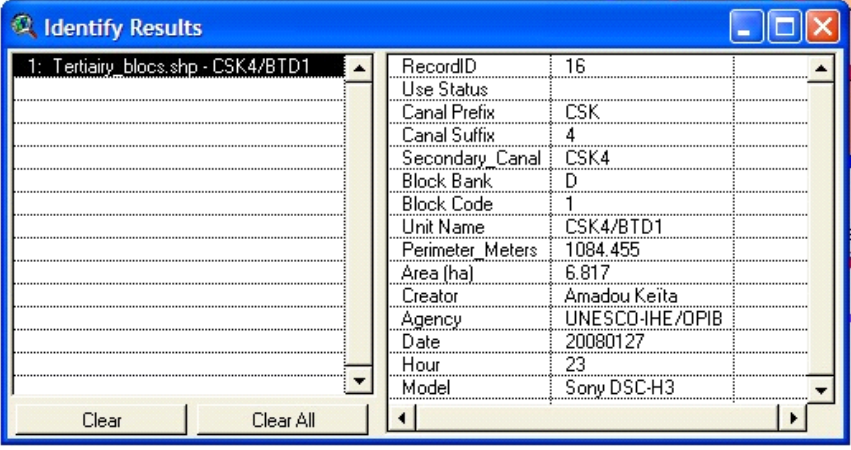
Figure 40: Secondary blocks irrigation area

Tertiary blocks

A typical information slide is shown below Table 15, reproducing what is obtained when a click is done on the canal feature.

The average block size is 6.76 ha and 90% of them have a size between 6.37 and 7.15 ha. The total farm land, except the dead areas is 2,848 ha, which is 2 ha more than the total area of the secondary blocks. The relative error is 0.07%.

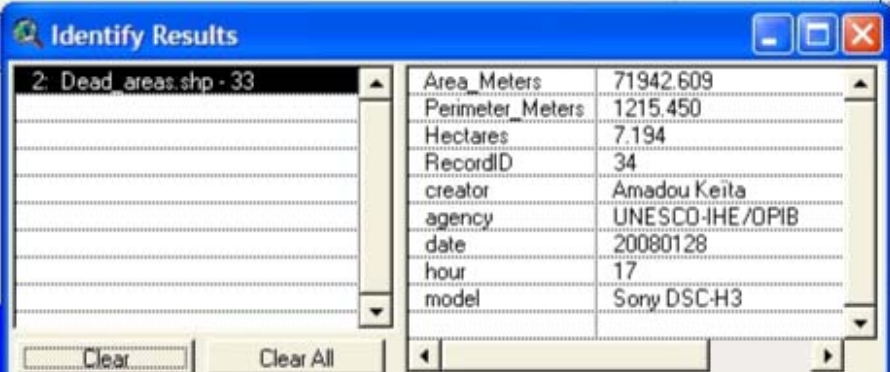
Table 15: Statistics for the 421 tertiary block areas (ha)

Mean: 6.76 Lower 90% Conf. Limit: 6.37 Upper 90% Conf. Limit: 7.15 Minimum: 0.95 Maximum: 91.67 Variance: 23.11 Standard Deviation: 4.80 Total Records: 421 Number of Null Values: 0 Sum: 2848.47	 <table border="1"> <thead> <tr> <th>Field</th> <th>Value</th> </tr> </thead> <tbody> <tr><td>RecordID</td><td>16</td></tr> <tr><td>Use Status</td><td></td></tr> <tr><td>Canal Prefix</td><td>CSK</td></tr> <tr><td>Canal Suffix</td><td>4</td></tr> <tr><td>Secondary Canal</td><td>CSK4</td></tr> <tr><td>Block Bank</td><td>D</td></tr> <tr><td>Block Code</td><td>1</td></tr> <tr><td>Unit Name</td><td>CSK4/BTD1</td></tr> <tr><td>Perimeter_Meters</td><td>1084.455</td></tr> <tr><td>Area (ha)</td><td>6.817</td></tr> <tr><td>Creator</td><td>Amadou Keita</td></tr> <tr><td>Agency</td><td>UNESCO-IHE/DPIB</td></tr> <tr><td>Date</td><td>20080127</td></tr> <tr><td>Hour</td><td>23</td></tr> <tr><td>Model</td><td>Sony DSC-H3</td></tr> </tbody> </table>	Field	Value	RecordID	16	Use Status		Canal Prefix	CSK	Canal Suffix	4	Secondary Canal	CSK4	Block Bank	D	Block Code	1	Unit Name	CSK4/BTD1	Perimeter_Meters	1084.455	Area (ha)	6.817	Creator	Amadou Keita	Agency	UNESCO-IHE/DPIB	Date	20080127	Hour	23	Model	Sony DSC-H3
Field	Value																																
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Canal Suffix	4																																
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Agency	UNESCO-IHE/DPIB																																
Date	20080127																																
Hour	23																																
Model	Sony DSC-H3																																

The Dead Area

These are the ones not cultivated in rice, maize or vegetables for different reasons. The dead areas were also mapped. Typical information got when clicking on a dead area is Table 16. The total area computed is 145 ha.

Table 16: Statistics for the 145 ha dead areas

Mean: 4.02 Lower 90% Conf. Limit: 2.91 Upper 90% Conf. Limit: 5.13 Minimum: 0.41 Maximum: 18.027 Variance: 15.53 Standard Deviation: 3.94 Total Records: 36 Sum: 145.00	 <table border="1"> <thead> <tr> <th>Field</th> <th>Value</th> </tr> </thead> <tbody> <tr><td>Area_Meters</td><td>71942.609</td></tr> <tr><td>Perimeter_Meters</td><td>1215.450</td></tr> <tr><td>Hectares</td><td>7.194</td></tr> <tr><td>RecordID</td><td>34</td></tr> <tr><td>creator</td><td>Amadou Keita</td></tr> <tr><td>agency</td><td>UNESCO-IHE/DPIB</td></tr> <tr><td>date</td><td>20080128</td></tr> <tr><td>hour</td><td>17</td></tr> <tr><td>model</td><td>Sony DSC-H3</td></tr> </tbody> </table>	Field	Value	Area_Meters	71942.609	Perimeter_Meters	1215.450	Hectares	7.194	RecordID	34	creator	Amadou Keita	agency	UNESCO-IHE/DPIB	date	20080128	hour	17	model	Sony DSC-H3
Field	Value																				
Area_Meters	71942.609																				
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Hectares	7.194																				
RecordID	34																				
creator	Amadou Keita																				
agency	UNESCO-IHE/DPIB																				
date	20080128																				
hour	17																				
model	Sony DSC-H3																				

3.2.4 Drainage system

The secondary drains

The 43 secondary drains were named according to the names in use at Baguineda and were processed by GIS. The secondary drains yield a total length of about 70 km. Typical information when clicking in a drain renders the following:

- shape of the feature : polylines
- ID : the tag number in the records
- Full_Name : the name used by OPIB
- Length_Meters : the length of the drain in meters

It should be noticed, actually, that these drains comprise the main drains as well. The Full_Name identifier not followed by a letter indicates a main drain in the database (Table 16). The details are reported in Appendix II.

Table 17: Statistics for the 70 km of secondary drains

Summary Statistics for Length			

Mean:	1622.423		
Lower 90% Conf. Limit:	1395.719		
Upper 90% Conf. Limit:	1849.127		
Minimum:	239.979		
Maximum:	4202.352		
Variance:	781193.177		
Standard Deviation:	883.851		
Total Records:	43		
Sum:	69764.203		

 Identify Results

1: Secondary_drains.shp

Shape	PolyLine
ID	30
Full Name	N*13a
Length_Meters	4202.352

The tertiary drains

There are 460 tertiary drains in Baguineda. The average or mean length is 375 m and the maximum and minimum are respectively 56 and 827 m. For commodity of the size of this report, the details of the tertiary drains are not listed in the Appendix. However, they were provided in the file to OPIB.

A typical information on a tertiary drain is presented in Table 18.

Table 18: Statistics for the 172 km tertiary drains

Table 16: Statistics for the 172 km tertiary drains			
Mean:	374.673		
Lower 90% Conf. Limit:	363.211		
Upper 90% Conf. Limit:	386.134		
Minimum:	55.648		
Maximum:	826.758		
Variance:	22244.183		
Standard Deviation:	149.144		
Total Records:	460		
Sum:	172349.607		

 Identify Results

2: Tertiary_drains.shp - 15

<

3.2.5 Nomenclature

Baguineda canal and drain system possessed a nomenclature in use by OPIB. This nomenclature is about the:

- secondary canals, the tertiary gates (offtake from secondary canals)
- main and secondary drains.

The nomenclature did not cover:

- the tertiary blocks irrigated by tertiary canals
- the tertiary canals

This study, following as close as possible the existing hard copy nomenclature, has completed the missing elements in a digitized map of the whole system. The results are shown on Figure 41.

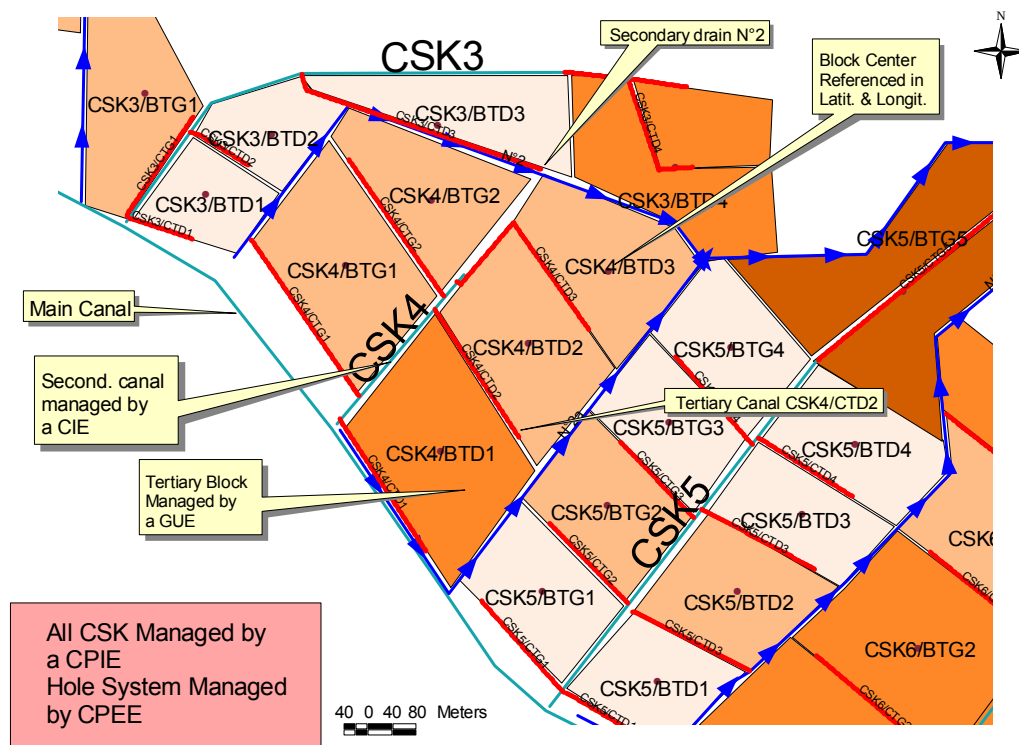


Figure 41: Proposed nomenclature for OPIB and organization groups

As shown on this figure:

- a secondary canal such as CSK4 is the 4th secondary canal of the sector of Kobala
- CSK4/CTD3 stands for the 3rd Tertiary Canal on the Right (D) bank of the 4th Secondary Canal of Kobala
- CSK4/BTD3 indicates the 3rd Tertiary Bloc on the Right (D) bank of the 4th Secondary Canal of Kobala
- the point in the middle of the area is georeferenced so that any agent with a GPS can navigate until the centre of the block

As explained in section 3.1 about the organization i) a tertiary block is managed by a GUE or Water Users Group, ii) a secondary canal by a CIE (Irrigation and Maintenance Committee), iii) a sector or group of secondary canal by a CPEI (Parity Commission of Irrigation and Maintenance) and iv) the whole system by the CPEE (Parity Commission for Exploitation and Maintenance).

The secondary roads lengths were also produced and given to OPIB at Baguineda.

3.3 Overall and operational objectives

Baguineda Irrigation System main canal starts with a headwork made of 2 vertical gates called headwork of Sotuba. Along this main canal are constructed 7 regulators with a mean length of 13 meters each one. A regulator is composed of a central weir and two lateral vertical gates. It is not known whether the lateral gates were constructed for flushing or as irrigation flexibility equipment. These regulators maintain water level around a targeted elevation for the 42 official secondary canal intakes.

Each of the secondary canal intakes is equipped with vertical gate located on the main canal and followed by a weir at the most upstream site of the secondary canal. The purpose of these weirs is to keep the gates under submerged flow conditions. Therefore, the system was built on a regulation principle of *upstream control*.

The whole system is lined over 12.8 km in the main canal that is 37 km long from the headwork to the intake of Tanima canal.

3.3.1 Overall objective

The irrigation scheme of Baguineda was designed – before hydro-plant competition for water- with 10 m³/s for 3,000 ha. That corresponds to a specific discharge of $q = 3.3 \text{ l/s/ha}$. Furthermore, the flexibility provided by vertical gates installed at the intakes of the secondary canals and the one the sides of the regulators indicates the ability to adapt to water demand changes. Therefore, the system was designed for the dry season and the overall objective was a “*Productive irrigation*” (see section 2.12). This is confirmed by the existence at a certain period of the history of a tomato transformation factory in Baguineda called SOCAM.

However, the main water fee contribution – because of water shortage in the dry season¹² – is collected from the rainy season cropping. Furthermore, OPIB is practicing currently a rotation along the main canal during the dry season on an “equitable basis”. Therefore, there is an ongoing effort to set a “*Protective irrigation*” as overall objective of the system.

The potential consequences of the change in the overall objective will be analyzed in the discussion chapter of this report

3.3.2 Operational objectives

In the rainy season, the gates are open and there is no rotation. Currently, water distribution is a *rotation* among secondary canals in the dry season. Each secondary canal is equipped with a lock, handled by the chief sector of OPIB. The flow is

¹² Hydro power station discharge withdrawals and seepage in the main canal are the basis of the shortage.

intermittent and the rotation period is 3 or 4 days. Therefore, the water distribution method is a **rotational flow**. (Ankum, 2004)

3.4 Discharge values

Although the unsteady flow condition makes it difficult to use the computed values as actual flow transferred to farmers, they provide a mean to check certain water levels obtained by simulation on the main canal at the same locations. Discharge measurements are performed at locations of regulator weirs. The discharge Q is a univocal function of the water levels when critical flow occurs. That is obtained by design on weirs on the network. Therefore, water level measurements are a mean to obtain instant discharge values in the canal.

The discharge measurements results are presented in Table 19. The determination process is explained below for the vertical slide gate of the headwork and 4 of the 7 regulator weirs on the main canal.

Table 19: Discharge measured on the main canal

Structure	Measured Length (m)	Gate opening w or weir height p P (m)	Discharge parameter (m)	Q (m ³ /s) computed	Duration t (hh:mn)	Date
Headwork Vertical Slide Gate (submerged sluice) of <i>Sotuba</i>	L=2x2.5 (gate width)	0.50	$y_1 = 2.00$	8.140		27/11/2007
Regulator R1 Weir	B=13.36	1.62	$h=0.035$	0.240	2:00	28/11/2007
Regulator R2 Weir	B=13.44	1.52	$h=0.06$	0.543	01:45	29/11/07
Regulator R3 Weir	B=13.34	1.51	$h=0.059$	0.526	01:45	29/11/07
Regulator R4 Weir	B=13.43	1.64	-	-	02:30	30/11/07

Note:

- Each regulator has also two gates that were closed during the measurements. These gates could not be closed for R4, hence it was not possible to measure Q above the weir.
- The metric dimensions were measured by tape and by ultrasound measurer
- The sill heights and the head losses were measured by SPK (Single Point Laser Kit). The head loss is calculated taking the weir top level minus the water level 6-10 m (3 to 4 times water depth) upstream the weir. The canal bottom level - also measured - minus the weir top level provided the weir heights. The water depth is obtained by the difference between bottom level and water level. The weir heights provided by the constructor Nippon Koei are $P(R1)=1.53$; $P(R2)=1.53$ and $P(R3)=1.63$

3.4.1 Measuring at the headwork

The flow type at the headwork during the measurement is described on Figure 44. This is a "closed conveyance-flow" (Ankum, 2004). In this type, flow under the gate is subcritical ($Fr < 1$) and is largely influenced by the tailwater level. The general formula used for a sluice with N parallel gates is:

$$Q \text{ (m}^3/\text{s)} = \sum_{i=1}^N \left[C d_i A_i \sqrt{2gy_1} \right] = \sum_{i=1}^N \left[C d_i (B_i w_i) \sqrt{2gy_1} \right]$$

Where : N = number of gate ; $C d_i$ = discharge factor of gate i ; B_i (m) = width of gate i , ; w_i (m) = gate i opening and y_1 (m) = upstream water depth.

The main problem resides in the discharge factor C_d . The ideal would be to make a local calibration to find the discharge factor. In absence, the factor is determined using a graph (Ankum, 2004) in which $C_d = f\left(\frac{y_1}{w}, \frac{y_3}{w}\right)$.

In this case (Figure 42): $C_d = f\left(\frac{2}{0.5}, \frac{1.25}{0.5}\right) = f(4, 2.5) \approx 0.52$

Hence, the discharge value is

$$Q_{gate} (\text{m}^3/\text{s}) = 2 \times (0.52 \times 2.5 \times 0.5 \times \sqrt{2 \times 9.81 \times 2}) = 8.14 \text{ m}^3/\text{s}$$

$$Q_{gate} = 8.14 \text{ m}^3/\text{s}$$

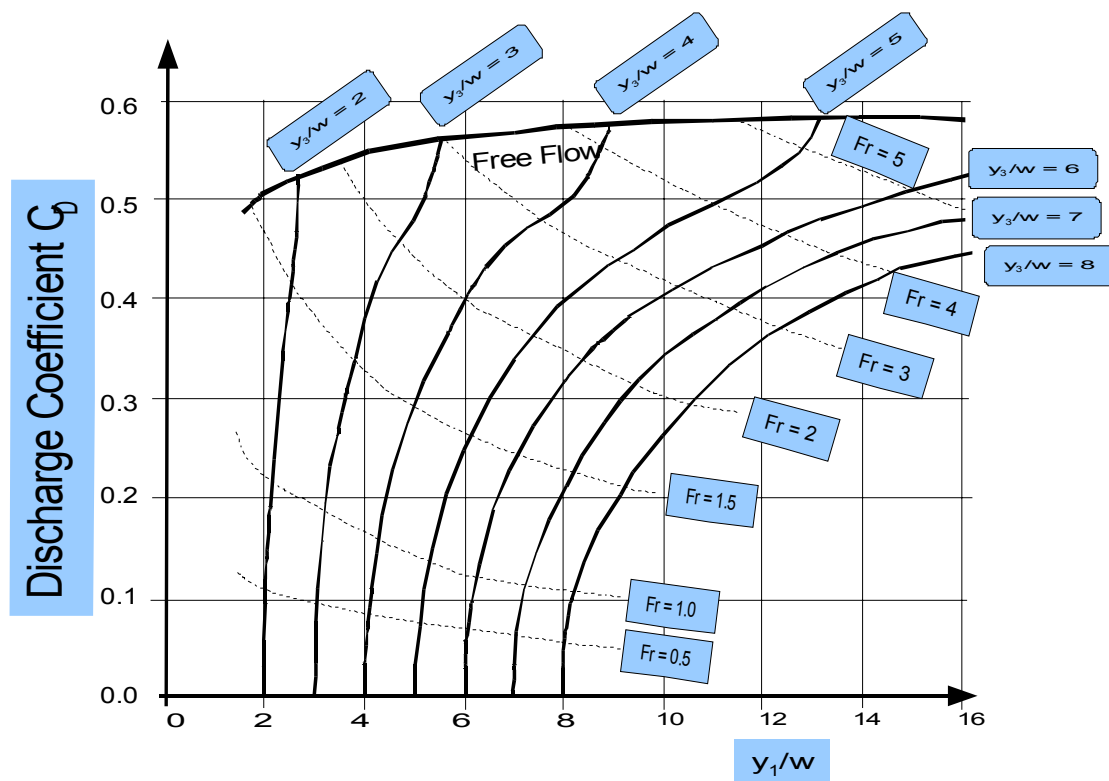


Figure 42: Discharge coefficients for submerged and free flow under vertical gates

Source : Adapted from (Ankum, 2004)

Applying the method exposed on rod-float which announced an accuracy of 3 to 5%, a discharge measurement was performed with at the headwork double gate. The following value was obtained:

$$Q_{float} = \bar{V} \times A = \frac{Dist (m)}{\Delta t (s)} \times W (m) \times y_1 (m) = \frac{18.80}{33.22} \times 7.55 \times 2 \approx 8.54 \text{ m}^3/\text{s}$$

$$Q_{float} = 8.54 \text{ m}^3/\text{s}$$

The canal forms a gorge upstream the headwork double gate. The measurement with a tape was rather difficult. The canal width 7.55 m was measured by ultrasound meter and

compared with a tape extended over the gorge. The ultrasound meter provides measurements with a deviation of ± 1 cm. An iron was attached to a tape's extremity and put in the flow to measure the water depth of 2 m. Five (5) measurements were averaged to provide final values.

The discharge was measured at the headwork gate on 2007, November 27th, while the water depth in the canal on the upstream side was 2.0 m.

The relative error between the two results can be computed by :

$$\Delta Q (\%) = \frac{Q_{float} - Q_{gate}}{Q_{gate}} = \frac{8.54 - 8.14}{8.14} \approx 5\%$$

$$\Delta Q (\%) \approx 5\%$$

The manipulation of these headwork gates is made only after agreement between OPIB and the Hydropower Central of Sotuba, which uses also the derived water that is split at Point A. Hence, it can be considered that the 8.14 m³/s remained constant during the measurements performed in the week at other locations on the canal network.

3.4.2 Measuring at the regulators

As seen in section 2.7, the following formula provides the discharge values on the regulators weir (Ankum, 2004):

$$Q (\text{m}^3/\text{s}) = c \cdot B \cdot h^{3/2} = \left(\frac{2}{3} \cdot \sqrt{\frac{2}{3}} g \cdot c_d \right) \times B \times h^{3/2} = (1.71 \cdot c_d) \cdot B \cdot h^{3/2}$$

Where c (m^{1/2}/s) = weir coefficient, c_d = discharge factor, B (m) = length of the weir and h (m) = energy head above the crest (generally measured upstream at a distance = 3-4 times the weir height).

This general formula leads to 2 types of formula :

- for the **broad crested weirs** : $Q (\text{m}^3/\text{s}) = 1.7 \cdot B \cdot h^{3/2}$; with $h < \frac{1}{2} \cdot L_{weir}$
- for **sharp crested weirs** : $Q (\text{m}^3/\text{s}) = 1.9 \cdot B \cdot h^{3/2}$; with $h > \frac{1}{2} \cdot L_{weir}$

In which L_{weir} (m) = weir wall thickness.

In the case of Baguineda, $L_{weir} = 0.20$ m for all the weirs and the maximum value of h measured is $h=0.06$ m (see Table 19). Hence it comes that

$$[h = 6 \text{ cm}] < \left[\left(\frac{L}{2} = \frac{20}{2} = 10 \text{ cm} \right) \right] \Rightarrow \text{Broad crested weir formula is applied}.$$

For example, at regulator R1, it comes:

$$Q = 1.7 \cdot B \cdot h^{3/2} = 1.7 \times 1.62 \times 13.36 \times 0.035^{3/2} = 0.240 \text{ m}^3/\text{s}$$

$$Q = 240 \text{ (l/s)}$$

Applying these formulas leads to the results in Table 19.

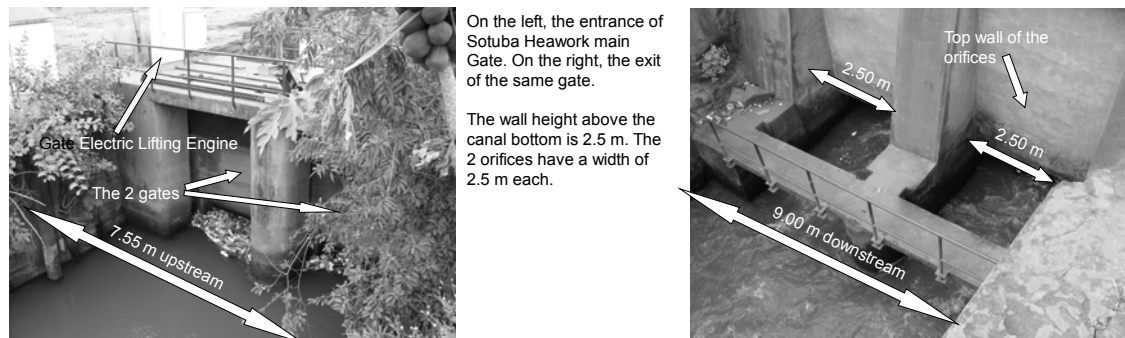


Figure 43: Dimensions of the headwork double gate

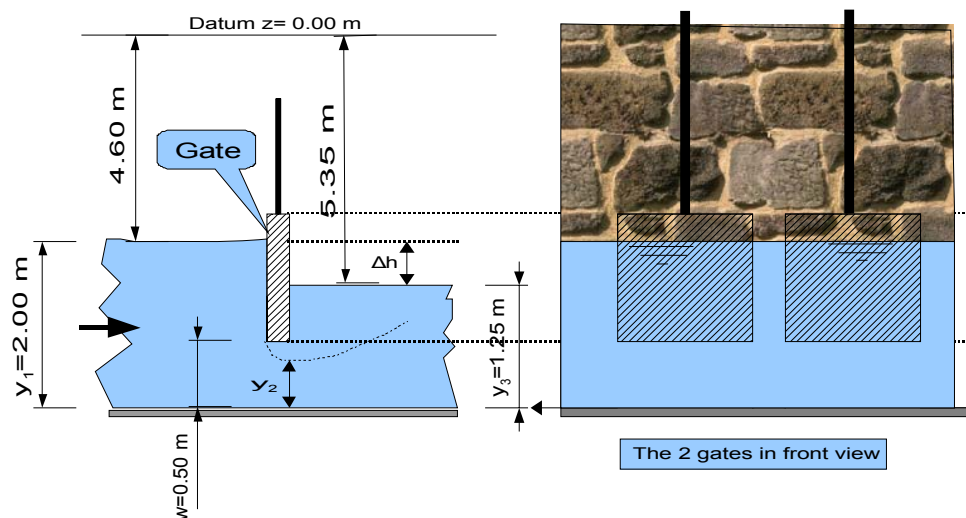


Figure 44: Measurement conditions at the headwork of Sotuba in 27/11/2007

The value of the head loss $\Delta h = 5.35 - 4.60 = 0.75 \text{ m}$. The 2 gates were completely open. The flow is type "Closed Conveyance Flow" or totally submerged.



Figure 45: Dimensions of the regulator weirs

The regulator R2 on the main canal of Baguineda

There are seven regulators like this one. The water level regulation is assured by a structure composed of two side or lateral gates and a central weir. When the gates are totally closed, water passes above the central weir.

The sector responsible manipulates the gates during the dry season to implement a rotation along the main canal and among groups of secondary canals.

3.5 Modelling the main canal system with HEC-RAS

3.5.1 Boundary conditions

Although the measured discharge at the headwork gates provides a realistic simulation value of 8.14 m³/s, the discharges used are based on BETICO's measurements (BETICO/BCEOM 2005):

- current scenario : the discharge used is $Q = 8.0 \text{ m}^3/\text{s}$ with a water surface elevation of 316.17 m¹³
- modern scenario : the discharge used is $Q = 9.5 \text{ m}^3/\text{s}$ with a water surface elevation of 316.20 m.

These conditions were introduced upstream the main canal reach, while downstream the regulator R1, the normal depth was set as boundary condition through a canal slope of 0.0002.

3.5.2 Flow change values and locations

The flow change locations are i) the cross sections set for seepage intake and ii) those for nominal discharge intakes of the secondary canals. The flow changes occur at specific cross sections for 2 reasons: either seepage or secondary canal intakes. For both *current* and *modern scenarios*, the values are summarized in Figure 46 and Figure 47. The detailed values are provided in Appendix V.

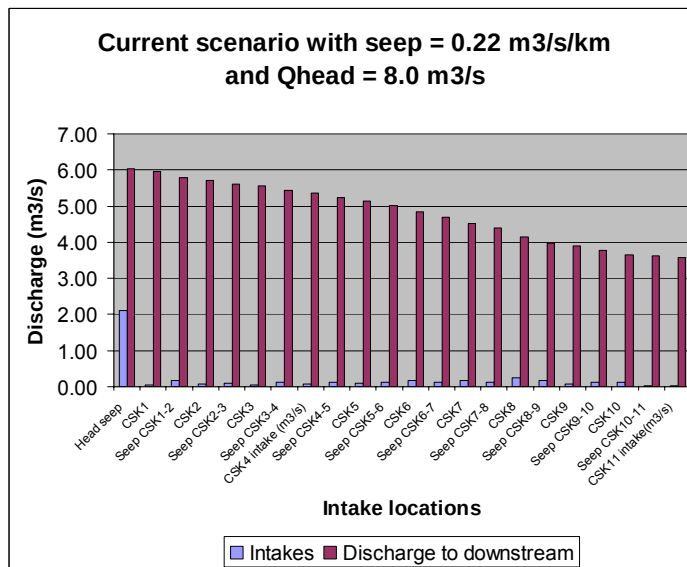


Figure 46 : Flow changes in current scenario

¹³ The company calculated for an elevation $Z=316.60$ a discharge of $Q=120 \text{ m}^3/\text{s}$ in the feeder canal of the Aigrettes, and for $Z=316.70$, a $Q=125 \text{ m}^3/\text{s}$. This corresponds to a specific linear fluctuation value of $x=10\text{cm}/(5\text{m}^3/\text{s})=2(\text{cm}/\text{m}^3/\text{s})$. At the elevation $Z=316.60$ in the feeder canal corresponds a $Z=316.20\text{m}$ and a discharge of $9.5 \text{ m}^3/\text{s}$ at the headwork double gates of Baguineda. Therefore, the discharge in the Baguineda head gates of 8.0 is estimated to be at $Z=316.17$.

On Figure 46, the discharge released from the headwork double gate is $8 \text{ m}^3/\text{s}$ and the seepage along the canal till regulator R1 equals an average value of $0.22 \text{ m}^3/\text{s}/\text{km}$. The seepage and the secondary canal intakes are reported as “intakes” on the figure.

It can be noticed that the flow in the main canal, of course, decreases from upstream to downstream. From the initial value of $8 \text{ m}^3/\text{s}$ it drops to $3.58 \text{ m}^3/\text{s}$ after the regulator R1.

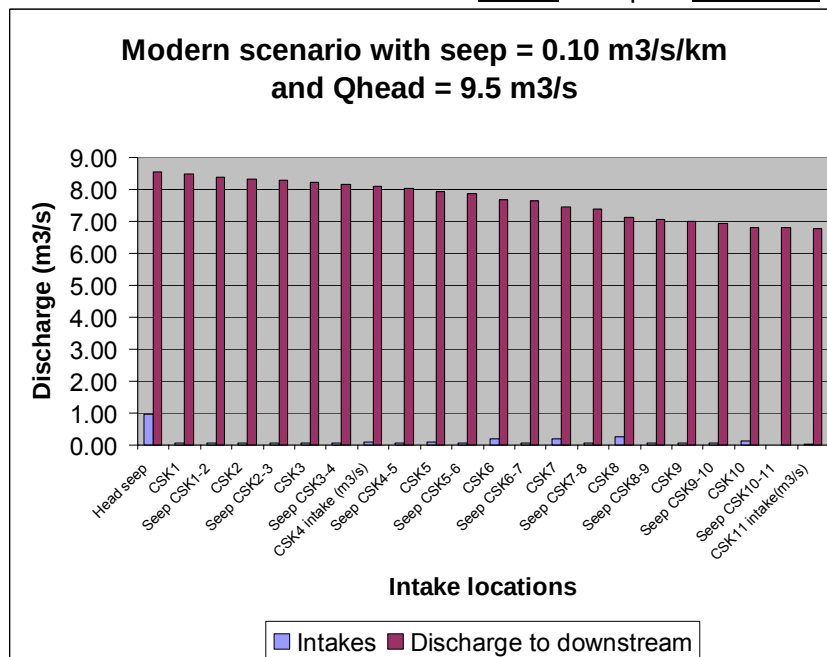


Figure 47 : flow changes in modern scenario

On Figure 47, the modern scenario is considered with a discharge of $9.5 \text{ m}^3/\text{s}$ released from the headwork gate. This discharge is what is currently under negotiation between OPIB and the hydro power plant authorities of Sotuba.

In the modern scenario of lined canal with a seepage of $0.10 \text{ m}^3/\text{s}/\text{km}$, the discharge transferred downstream R1 is $6.76 \text{ m}^3/\text{s}$.

In Table 20, the results of flow configurations are summarized. It appears that in:

- **current scenario** : with an available cropping land downstream of 4,660 ha, the specific discharge $q = 0.8 \text{ l/s/ha}$ which is lower than the required 3 l/s/ha computed as crop irrigation requirements in the dry season with secondary canals conveyance efficiency of 60%. In this scenario 415 ha upstream R1 receive a normal amount of water with $q = 3 \text{ l/s/ha}$.

It should be noticed that (Table 20) $3.33 \text{ m}^3/\text{s}$ were lost per seepage on the first 15 km. Some 12 km downstream R1 are lined. The loss over the remaining not lined 10 km on the main canal will absorb the $3 \text{ m}^3/\text{s}$ from the $3.58 \text{ m}^3/\text{s}$ going downstream R1.

- **modern scenario** : with a reduced cropping land of 2,200 ha downstream R1 and a normal land area of 415 ha upstream R1, the specific discharge obtained

is $q = 3 \text{ l/s/ha}$. Taking into account some $2 \text{ m}^3/\text{s}^{14}$ as seepage in the main canal downstream R1, the irrigable area with $4.76 \text{ m}^3/\text{s}$ would be 1,600 ha to meet $q = 3 \text{ l/s/ha}$. Therefore the total irrigable land would be 2,000 ha.

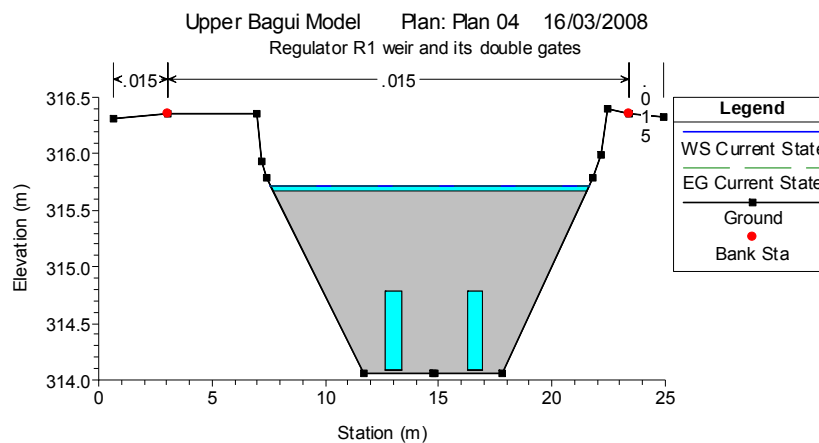
Table 20 : Flow allocation configuration upstream and downstream regulator R1

	Current scen seepage rate $=0.22(\text{m}^3/\text{s}/\text{km})$	Current Scen discharge at the headwork $= 8.0 (\text{m}^3/\text{s})$	Modern scen seepage rate $= 0.10$ $(\text{m}^3/\text{s}/\text{km})$	Modern Scen discharge at the headwork $= 9.50 (\text{m}^3/\text{s})$
Total CSK intakes (m^3/s)		1.22		1.22
Total seepage (m^3/s)		3.33		1.51
Discharge to downstream R1		3.58		6.76
Total area upstream R1 in ha		415.0		415.0
Specific discharge available for the blocks upstream R1 : $q(\text{l/s/ha})$		2.9		2.9
Total area (available and possible) downstream R1 in ha		4,657.9		2,200.0
Specific discharge available for the blocks downstream R1 : $q (\text{l/s/ha})$		0.8		3.1

3.5.3 Checking the water level measured on R1

The measured flow transferred downstream the weir of regulator R1 was $0.240 \text{ m}^3/\text{s}$ at the date of November 27th, 2007. The 2 vertical gates were closed.

The water surface elevation obtained just upstream the weir or R1 is 315.72 m while the weir crest elevation is 314.06 m. The difference between these two values provides the water charge on the weir: $h_{\text{HEC}-\text{RAS}} = 315.72 - 315.67 = 0.05 \text{ m} \equiv h_{\text{measurement}} \approx 0.04 \text{ m}$ (see section 3.4.2) with a weir coefficient of 1.7 adopted in the program.



¹⁴ On the first 15 km upstream R1, $1.5 \text{ m}^3/\text{s}$ were lost per seepage. It is reasonable to assume that on the remaining $37-15=22 \text{ km}$ some $2 \text{ m}^3/\text{s}$ will be lost in the main canal.

Figure 48 : Water level above regulator R1 is in agreement with the measurement

3.5.4 Current scenario HEC-RAS water levels

(n Manning = 0.30, 0.27 and 0.15, seepage 0.22 m³/s/km)

Current scenario with the double gates of R1 are closed

The results are shown in Figure 49 and the detailed table is provided in Appendix V.

From this figure, it can be noticed:

- the canal bed goes down and up, resulting in an average very low slope
- from downstream the head work double gate to regulator R1 (15 km) the flow is subcritical everywhere
- from downstream the headwork double gate to regulator R1 the water surface drops according to $Z_{wat} (m) = Z_{wat, headworks} - Z_{wat, R1} = 316.08 - 315.95 = 0.13$
- there is no noticeable phenomenon at Crocodile Lake
- from CSK1 intake (5.6 km upstream R1) to R1, the water level change is $Z_{wat} (m) = Z_{wat, CSK1} - Z_{wat, R1} = 315.97 - 315.95 = 0.02$
- the drop of water upstream and downstream R1 is $Z_{wat} (m) = Z_{wat, ups} - Z_{wat, dws} = 315.95 - 314.50 = 1.45$
- the drop in the canal bed at regulator R1 is $Z_{bed} (m) = Z_{bed, ups} - Z_{bed, dwn} = 314.06 - 313.67 = 0.39$

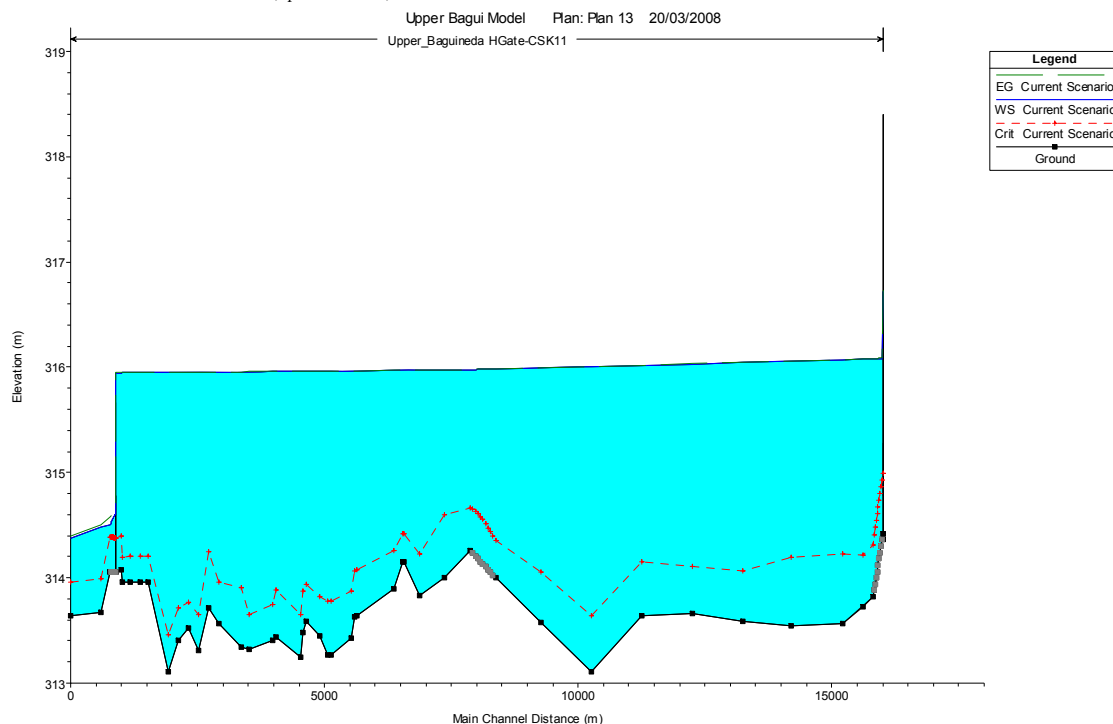


Figure 49 : Water surface profile over 15 km, from headwork to regulator R1

The double gates of R1 are closed

Current scenario with the double gates of R1 totally opened

The results are shown in Figure 50 and Table 21. The computations details are provided in Appendix V.2.

From the figure and the table, it can be seen:

- from downstream the headwork double gate to regulator R1 the water surface drops according to $Z_{wat} (m) = Z_{wat, headworks} - Z_{wat, R1} = 315.95 - 315.76 = 0.19$, value greater than the 0.13 m when the gates were closed.
The water level upstream R1 is also 0.19 m lower than in the previous situation with gates closed
- there is no noticeable phenomenon at Crocodile Lake
- from CSK1 intake (5.6 km upstream R1) to R1, the water level change is $Z_{wat} (m) = Z_{wat, CSK1} - Z_{wat, R1} = 315.79 - 315.76 = 0.03$
- the $3.58 \text{ m}^3/\text{s}$ arriving at R1 are split and $0.66 \text{ m}^3/\text{s}$ passes above the weir while $2.92 \text{ m}^3/\text{s}$ enter into the 2 gates. This last value represents 80%.

Table 21: Discharge values at the headwork gates and the regulator R1

Reach	Canal Station		Water Surface Elevation (m)	Q Total (m^3/s)	Q Weir (m^3/s)	Q Gates (m^3/s)
HGate-CSK11	16029.8	Headwork	316.71	8.00		8.00
HGate-CSK11	926.990	Regulator R1	315.76	3.58	0.66	2.92

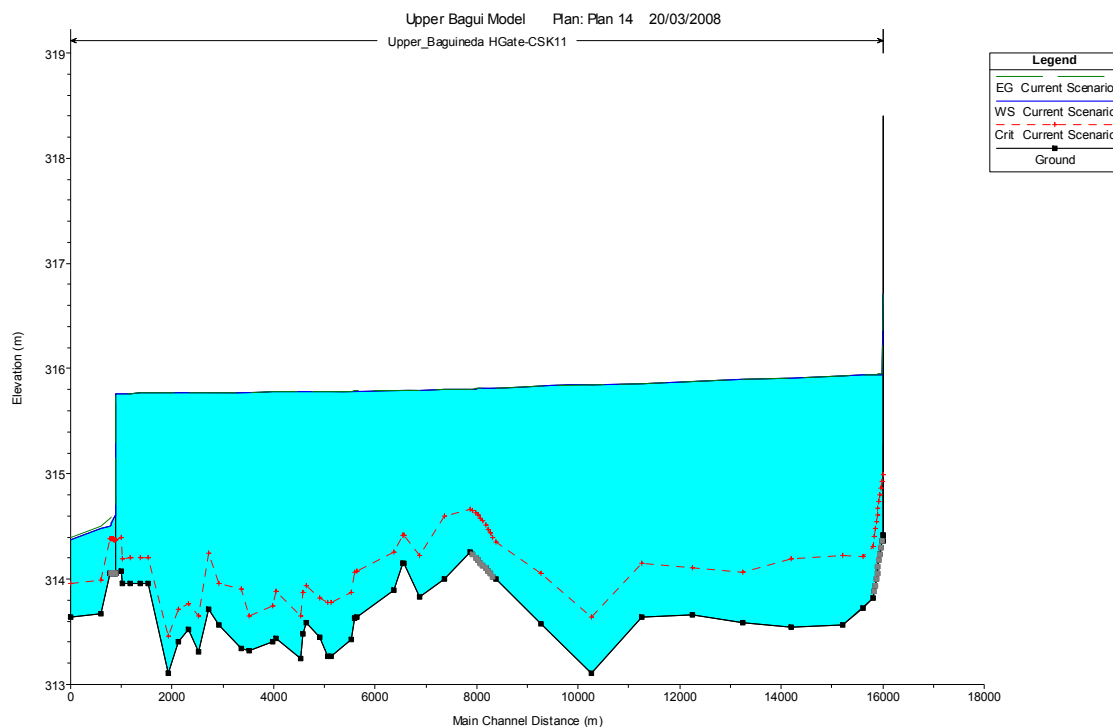


Figure 50 : Current scenario water surface from headwork to regulator R1

The double gates of R1 are full 0.70 m opened

On Figure 51 the drop in water level near regulator R1 is mainly due to the opening of the 2 vertical gates

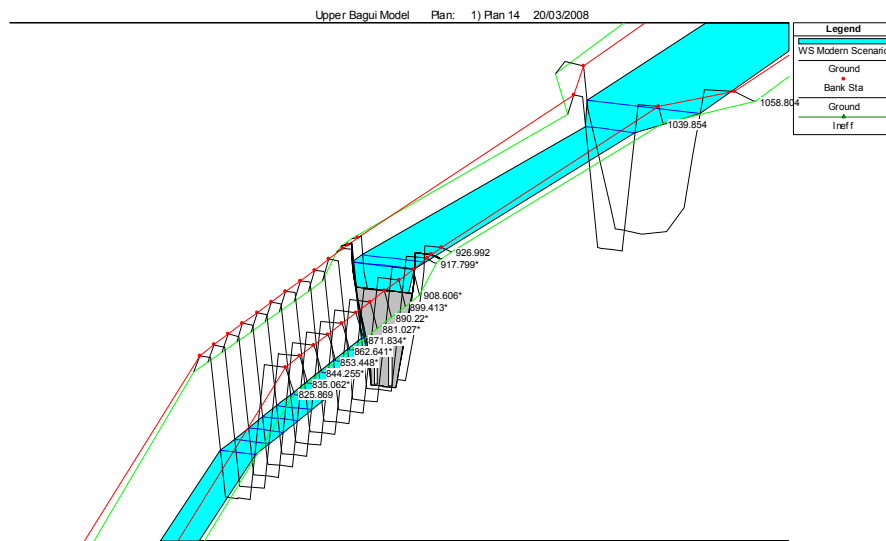


Figure 51 : Current scenario water level drop near R1 due to gate openings
The double gates of R1 are full 0.70 m opened

3.5.5 Water levels in modern scenario with lined canal

(n Manning = 0.015, seepage 0.10 m³/s/km)

Case the double gates of R1 are closed

Gates closed conditions are the only one considered here. The drops in water level are less, as it can be noticed of Figure 52. The details are provided in Appendix V.3.

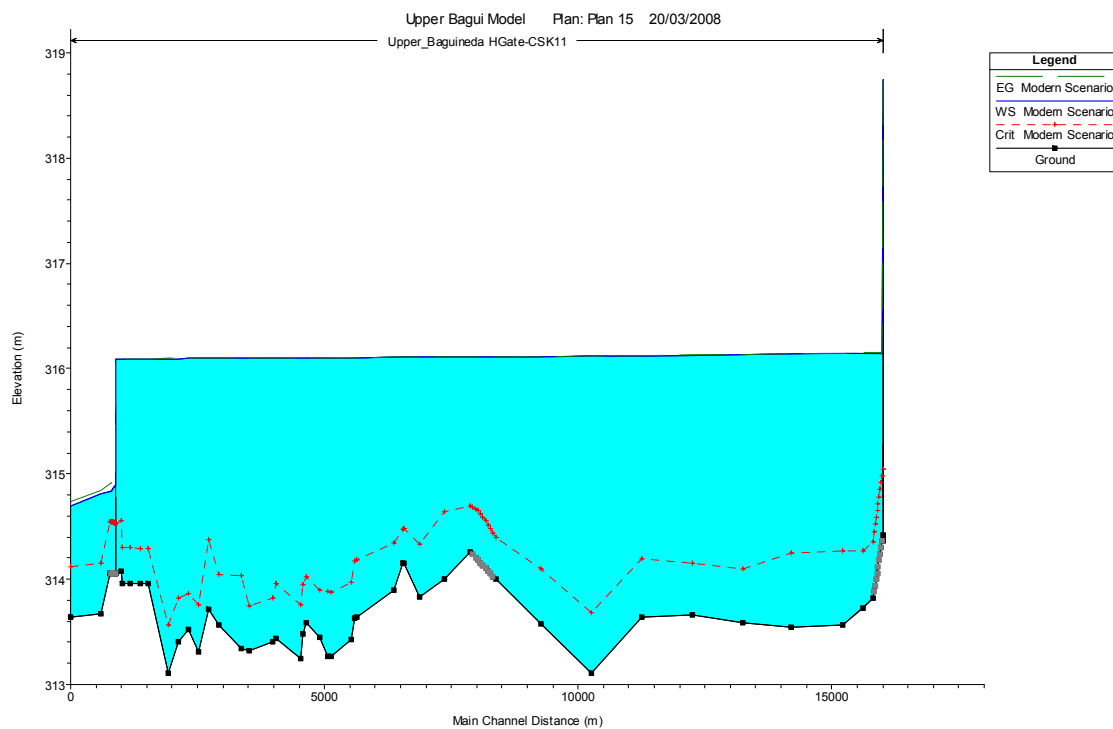


Figure 52 : Modern scenario water surface profile from headwork to regulator R1
The double gates of R1 are closed

The main results are:

- from downstream the headwork double gate to regulator R1 (15 km) the flow is subcritical everywhere
- from downstream the headwork double gate to regulator R1 the water surface drops according to $Z_{\text{wat}}(\text{m}) = Z_{\text{wat,headworks}} - Z_{\text{wat,R1}} = 316.15 - 316.09 = 0.07$, value smaller than the 0.13 m of the current scenario

The water level upstream R1 is

$$Z_{\text{wat,R1,modern}} - Z_{\text{wat,R1,current}} = 316.09 - 315.95 = 0.14 \text{ m}$$

- there is no noticeable phenomenon at Crocodile Lake
- from CSK1 intake (5.6 km upstream R1) to R1, the water level change is

$$Z_{\text{wat}}(\text{m}) = Z_{\text{wat,CSK1}} - Z_{\text{wat,R1}} = 316.11 - 316.09 = 0.02$$

equal to the value in current situation with gates closed.

3.6 Crop water and irrigation requirements

3.6.1 Current cropping pattern and yields

The Climate in Baguineda is “Sudanese” type (Niambele, 2007) with a dry season from November to April (6 months) and a rainy season from May to October (6 months). The rainy season concentrates the total precipitation events with 755 mm¹⁵ (OPIB[2], 2007). This value stands also for the annual rainfall.

As computed by GIS application, the total area developed for irrigation is 2846 ha, not including the extension of Sienkoro and Tanima.

The cropping seasons overlap these 2 climatic divisions. The rice growing preparation starts in April 1st with organic matter input and ends in October with the harvest. The dry season starts in the second half of November (OPIB [3], 2007). Rice transplantation extends from June 20th to July 5th. The harvest of rice starts from October 25th till November 30th. The dry season growing starts from December and ends in April.

A total of 677.21 ha are cultivated in the dry season whereas 3930 ha are used in the rainy season. Furthermore, taking into account the cultivated areas, it appears from Table 22 that the main crops are:

- in the dry season $\text{rice}30\% + \text{maize}16\% + \text{okra}28\% + \text{tomato}14\% \equiv 88\% \text{area}$
- in the rainy season : $\text{rice}62\% + \text{sorghum}19\% + \text{maize}12\% \equiv 93\% \text{area}$

Thus, one can say that rice and maize, in the current Baguineda figure; are grown each season. In addition, are grown in the dry season okra and tomato while in the rainy season sorghum is grown. The crop water requirements consider these 5 crops.

OPIB had nominal and equipped discharge values at each secondary intake. It would be useful to compare those discharge values with the ones obtained by computing the IWR based on the actual cropping pattern.

¹⁵ Average of 31 years (1976-2006)

Table 22: Cropping main figures in 2007

		Cropping Area (ha)		Yield Ya(tons/ha)	Production(tons)
Dry Season	Crop Type	Acrop(ha)	%of Total Area		
	rice	205.73	30%	3.886	799.33
	maize	111.37	16%	1.393	155.17
	vegetables				
	tomatoes	95.38	14%	29.890	2,851.16
	onion	63.89	9%	21.000	1,342.18
	cabbage	9.24	1%	32.480	300.15
	okra	191.6	28%	7.920	1,517.68
	Total	677.21	100%		6,965.67
Rainy Season	rice	2433	62%	5.147	-
	<i>dry crops</i>				
	maize	477.63	12%	1.725	824.04
	millet	126.14	3%	0.825	104.09
	sorghum	765.73	19%	0.980	750.71
	groundnut	123.3	3%	0.104	128.70
	cotton	5	0%	0.197	0.98
	Total	3,930.8	100%		

Source : adapted from (OPIB [3], 2007).

3.6.2 Water requirements scenarios

Irrigation water requirements

The vegetative cycle of okra is 65 days (Delarbre, 1988) while tomato reaches 135 days (de Laat, 2006). Furthermore the crop coefficients k_c of tomato are higher than okra (Smith, 1991) (Ghawi.I, 1989). Therefore, tomato is taken as representative of vegetables in the dry season.

Since the nominal discharge on which the system was designed consider the full area as being cultivated, the following proportions can be adopted :

- in the dry season : $rice30\% + maize16\% + tomato54\% \equiv area100\%$
- the rainy season : $rice62\% + sorghum20\% + maize18\% \equiv area100\%$

The cropping calendar shown on Table 23 follows from rice transplanting dates. In this table, the transplanting and harvesting dates, although simplified, are in line with the recommendations of OPIB. The last column –“duration” values of the table (based on the actual values provided in Table 30 in the Appendix VIII) – allows the attribution of crop coefficient k_c to individual months.

By application of the method exposed in section 2.10, the IWR results (Table 24) are as follows:

- for the dry season :
 $rice \approx 1483 \text{ mm}; maize \approx 560 \text{ mm}; tomato \approx 630 \text{ mm}; (Total \approx 2675 \text{ mm})$

- for the rainy season:
rice ≈ 419 mm; *sorghum* ≈ 0 mm; *maize* ≈ 0 mm; (*Total* ≈ 419 mm)

Table 23: Cropping calendar and growing durations for water requirements

	Crop Type	Transplanting or sowing date	Harvest date	Durations in days for Water Req Computation
Dry Season	rice	1 st December	31 March	120
	maize	1 st December	31 March	120
	Tomato	1 st November	28 February	120
Rainy Season	rice	1 st July	30th October	120
	sorghum	1 st June	30th September	120
	maize	1 st June	30th September	120

These values multiply by 10 yield the requirements in m³/ha. On the other hand, it appears that the main water *constraints are concentrated in the dry season*, in which 2,675 mm of net IWR must be balanced. Only 419 mm are required in the rainy season. Hence, discharge simulations computation scenarios will *focus on the dry season*.

Required and nominal discharges at secondary canals intakes

OPIB had the nominal discharge values for each secondary canal. These discharges, rounded up, were the values used to realize the secondary intake gates¹⁶. The rounded discharges are called *module discharges*.

All the 42 secondary canals are equipped with vertical gates and are not lined. Their lengths run from 150 m for the shortest to 2,580 m for the longest one. On a clayey and ferruginous soil, it can be reasonably assumed that 40% of the upstream discharge are lost by seepage (Hayde, 2006).

A comparison between the “actual” discharges – deducted from the crops IWR – and the nominal discharges will make it possible to know if the system can satisfy or not crop needs. This supposes that there is no limitation in water delivery to the secondary intakes from the main canal and that there is no water scarcity.

¹⁶ For example, the nominal discharge 75.87 l/s of CSK2 is implemented with a vertical gate module of 80 l/s.

Table 24: Crop water requirements and net irrigation requirements in mm/month

	Precipitation	Rice		Maize		Sorghum		Tomato		Totals
Month	(mm/m)	Etm(mm/m)	IWR(mm/m)	Etm(mm/m)	IWR(mm/m)	Etm(mm/m)	IWR(mm/m)	Etm(mm/m)	IWR(mm/m)	IWR(mm/m)
May	51.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Jun	69.4	0.0	170.6	51.3	0.0	51.3	0.0	0.0	0.0	170.6
Jul	203	145.7	4.7	109.3	0.0	109.3	0.0	0.0	0.0	4.7
Aug	256.4	130.2	0.0	156.2	0.0	130.2	0.0	0.0	0.0	0.0
Sep	129.4	141.75	72.35	67.5	0.0	74.2	0.0	0.0	0.0	72.3
Oct	45.9	155	171.1	0.0	0.0	0.0	0.0	0.0	0.0	171.1
Nov	0.0	0.0	180	0.0	0.0	0.0	0.0	97.2	97.2	277.2
Dec	0.0	170.5	294.5	51.1	51.1	0.0	0.0	148.3	148.3	494.0
Jan	0.0	192.2	316.2	144.1	144.1	0.0	0.0	221.0	221.0	681.48
Feb	0.0	214.62	326.62	245.3	245.3	0.0	0.0	163.5	163.5	735.4
Mar	0.0	241.8	365.8	120.9	120.9	0.0	0.0	0.0	0.0	486.7
Apr	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	D. Season	819	1,483	561	561	0.0	0.0	630	630	
	R. Season	573	419	384	0.0	365	0.0	0.0	0.0	
	Year tot	1,392	1,902	946	561	365	0.0	630	630	
	Total the dry season and all crops									
	IWR(mm)	2,675								
	Total rainy season and all crops									
	IWR(mm)	419								

Note: the system water use efficiency is not incorporated in IWR

Thus, in the following simulation, 2 scenarios are considered:

- *scenario 1*: current situation. The secondary canals are not lined and their conveyance efficiency is 60%
- *scenario 2*: modernized situation. All the secondary canals are lined and the conveyance efficiency is 80%

The results are shown of Figure 53 through Figure 55 on which the entire scheme is exposed into 3 sets¹⁷: i) CSK1 to CSK17, ii) CSB1 to CSB14 and iii) CSB15 to CSB25 (see Appendix VI for the details). These settings are in line with the dry season sets for rotation. Furthermore, it should be noticed that CSK 14 does not exist in the field and that there two CSBs 22 (CSB22a and CSB22b).

The main features are:

- the pick IWR is located in January in all secondary blocks
- the IWR discharges range from i) 16 to 318 l/s on CSK1-17, ii) 20 to 616 l/s on CSB1-14 and iii) 120 to 616 l/s on CSB15-25

In the current scenario no lined canals:

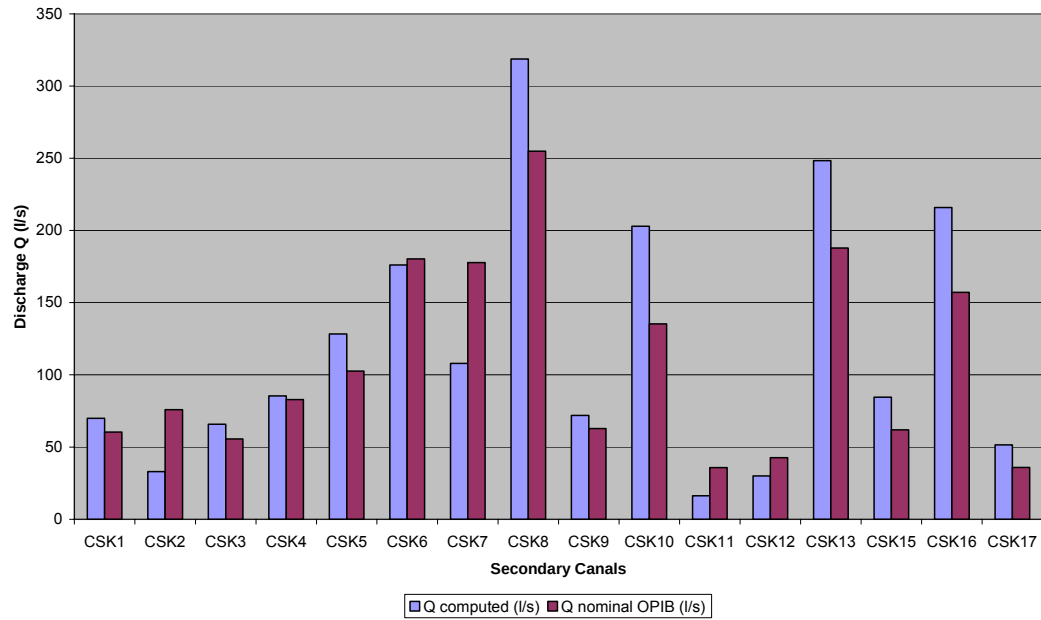
- on the first set CSK1-17, the required discharge computed from IWR is higher than nominal on: CSK8(103.63 ha), CSK10(65.97 ha), CSK13(80.74 ha) and CSK16(70.185 ha)
- on the second set CSB1-14, the required discharge computed from IWR is higher than nominal on: CSB4(111.74 ha), CSB7(108.19 ha), CSB12(112.73 ha) and CSB14(200.47 ha)
- on the third set CSB15-25, the required discharge computed from IWR is higher than nominal on: CSB15(124.61 ha), CSB20(102.67 ha), CSB22a(72.87 ha), CSB22b(89.04 ha), CSB24(186.63 ha) and CSB25(49.78 ha)
- the specific discharge within the secondary block is the same everywhere with *specific $q = 3$ (l/s/ha)*

In the modern scenario with all canals lined

- the required discharge computed from IWR is smaller or quite equal to nominal discharges everywhere (except CSB10)
- the specific discharge within the secondary block is the same everywhere with *specific $q = 2$ (l/s/ha)*

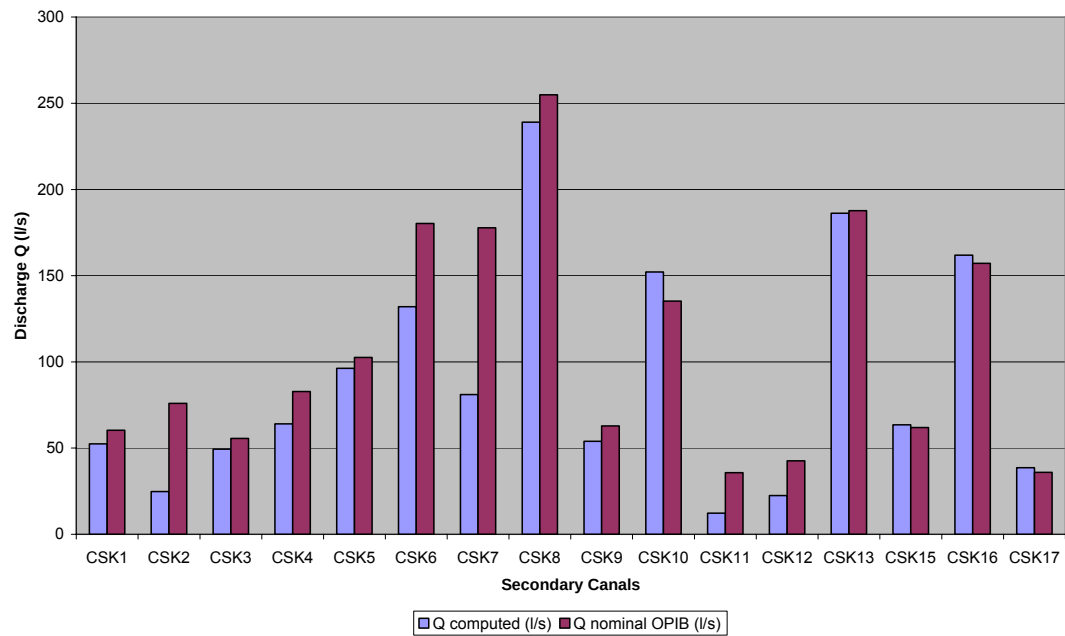
¹⁷ According to the gathering practice during dry season rotation among group of canals (water scarcity)

Comparison Pick Q (IWR) and Qnom OPIB
Current Secondary not Lined Scenario Eff=60%



(a)

Comparison Pick Q (IWR) and Qnom OPIB
Modern Secondary Lined Scenario Eff=80%



(b)

Figure 53 : Discharge satisfaction scenarios from CSK1-CSK17

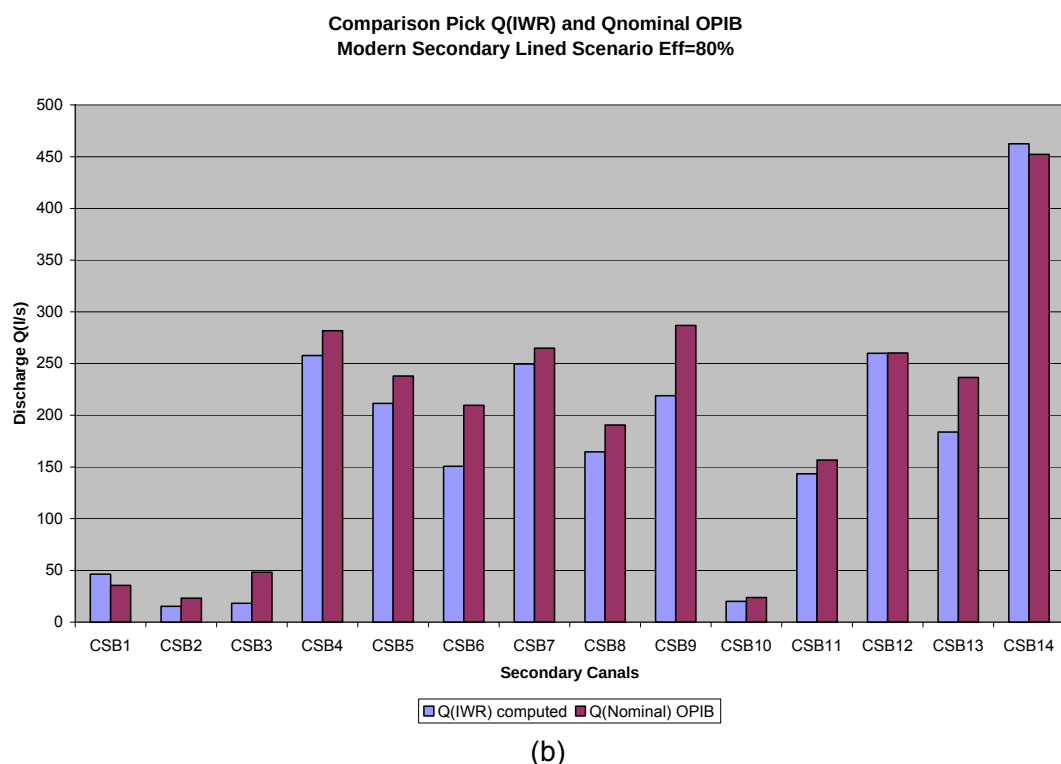
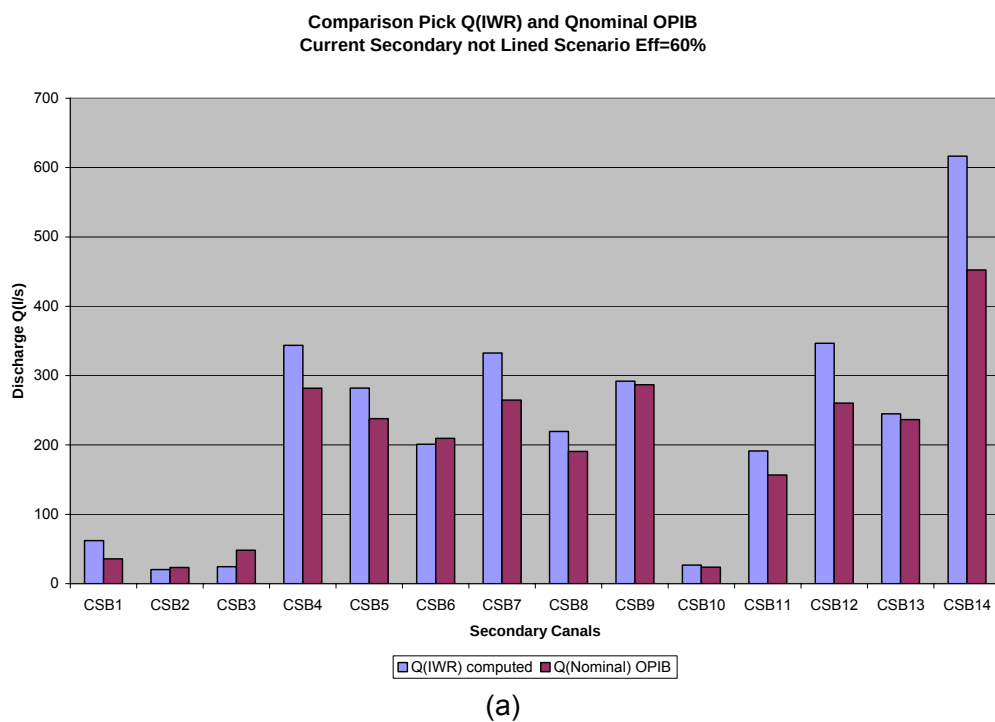
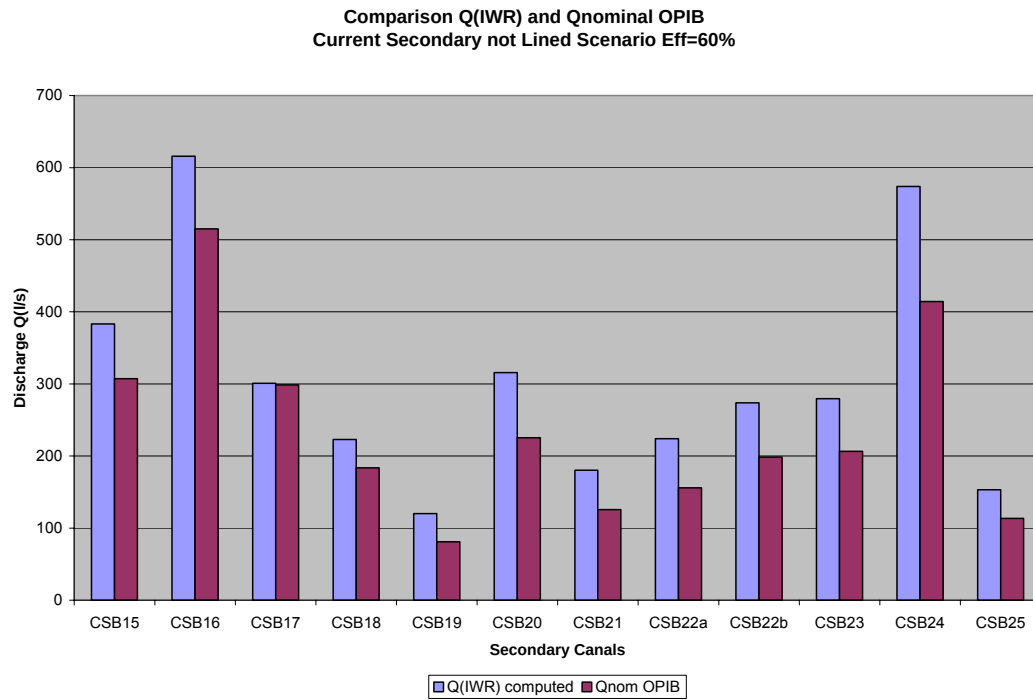
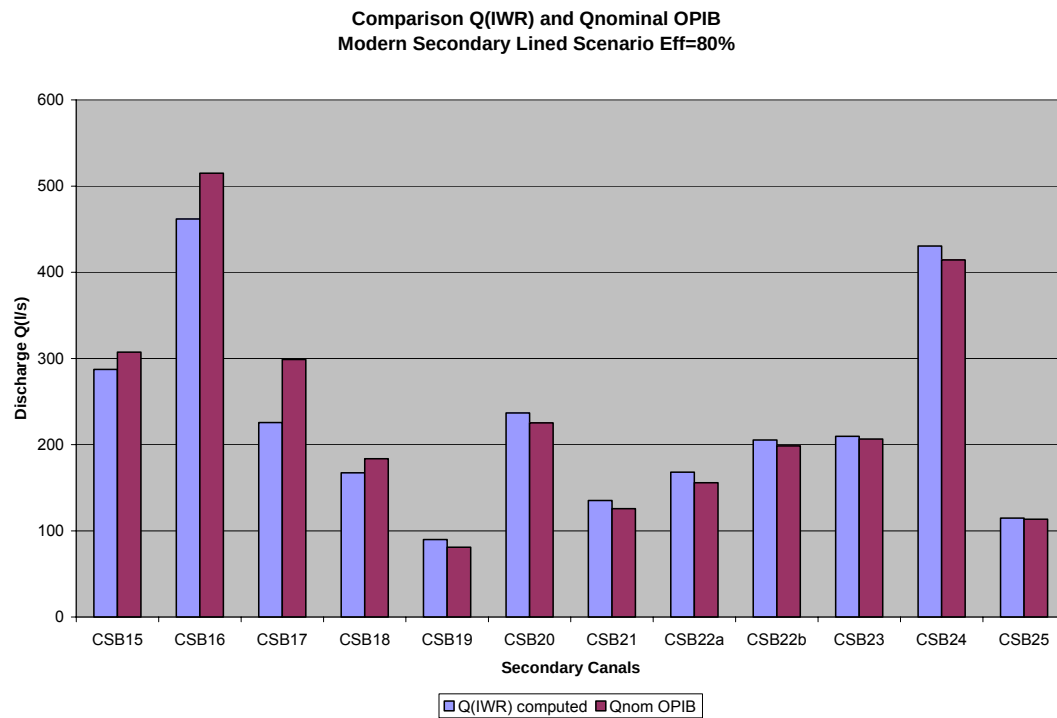


Figure 54 : Discharge satisfaction scenarios from CSB1-CSB17



(a)



(b)

Figure 55 : Discharge satisfaction scenarios from CSB15-CSB25

3.6.3 Deficit irrigation scenarios

Current scenario: 25% water available

The yields currently obtained in Baguineda (Table 22) in the dry season *are lower than the maximum yields found in the literature*. As reported in section 3.6.1, the main crop yield features in the dry season at Baguineda are respectively as it follows:

$$Y_{\text{rice, Baguin}} (\text{tons/ha}) \approx 4.0 ; Y_{m_{\text{literat}}} (\text{tons/ha}) = 6 - 8 \text{ with } a \text{ } Ky = 1.30$$

$$Y_{\text{maize, Baguin}} (\text{tons/ha}) \approx 1.4 ; Y_{m_{\text{literat}}} \approx 6 - 8 \text{ with } a \text{ } Ky = 1.25$$

$$Y_{\text{tomato, Baguin}} (\text{tons/ha}) \approx 30.0 ; Y_{m_{\text{literat}}} \approx 45 - 65 \text{ with } a \text{ } Ky = 1.05$$

Where Y is the yield and Ky is the yield response factor.

Deficit irrigation can not be applied to the actual yields obtained by farmers in Baguineda. Since deficit irrigation intentionally reduces the yield, it would mean lowering yields already low. Due to population growth and other water used pressure (hydro power); the trend is to increase the yields. (Schultz, 2006) Therefore; the deficit irrigation scenario analysis reference must be the maximum yield Ym, The maximum yield considered are 6 tons/ha for rice or maize and 45 tons/ha for tomato.

The computation process is the application of the method presented in section 2.11 to the 42 secondary blocks using a spreadsheet.

As a consequence of water scarcity (Table 22), the cropping area by farmers in the dry season is only 677.21 ha versus a total available (without the dead areas) of 2,846.36 ha¹⁸. This represents a ratio of $677.21/2846.36 \approx 25\%$ ¹⁹, the quarter of the area. Therefore, the total water volume available for the secondary blocks farms can be assumed as equal to:

$$V_{av_{crop}} (m^3) = 10 \cdot [25\% \times ETm_{crop} (mm/season)] \times A_{crop} (ha)$$

And the total volume Vt available for each crop at each secondary intake²⁰ must take into account the losses expressed through the efficiency:

$$V_{t_{crop}} (m^3) = \frac{V_{av_{crop}} (m^3)}{Eff (\%)} = 10 \cdot \left[\frac{25\% \times ETm_{crop} (mm/season)}{Eff (\%)} \right] \times A_{crop} (ha)$$

On the other hand, the actual evapotranspiration is given by:

$$ETa_{crop} (m^3/ha) = 10 \cdot \left[1 - \frac{1}{Ky} (1 - \beta) \right] \times ETm_{crop} (mm/season)$$

¹⁸ Values computed by the GIS

¹⁹ Hence; the current total dry season cropping area is rounded at 711.59 instead of 677.21

²⁰ When ETm is transferred from the farm level to the secondary intake, the value is increased by division by the conveyance efficiency of the canal.

Therefore, the actual (deficit managed) area corresponding to a particular crop is:

$$\begin{aligned}
 A_{crop,act}(ha) &= \frac{Vav_{crop}(m^3)}{ETa_{crop}(m^3/ha)} \\
 &= \frac{10 \cdot [25\% \times ETm_{crop}(mm/season)] \times A_{crop}(ha)}{10 \cdot \left[1 - \frac{1}{Ky}(1 - \beta)\right] \times ETm_{crop}(mm/season)} \\
 &= \frac{0.25 \times A_{crop}(ha)}{\left[1 - \frac{1}{Ky}(1 - \beta)\right]} \\
 &= \frac{0.25}{\left[1 - \frac{1}{Ky}(1 - \beta)\right]} \times A_{crop}(ha)
 \end{aligned}$$

Where

- $A_{crop,act}(ha)$ = actual area for the crop under deficit managed conditions
- $A_{crop}(ha)$ = the initial (before applying deficit irrigation) area of the block
- $ETm(mm/season)$ = maximum evapotranspiration of a particular crop
- $Eff(\%)$ = conveyance efficiency of the secondary canal in the block
- Ky = yield response factor (varies with rice, maize and tomato)
- β = yield reduction rate (80%)

For the long non lined secondary of Baguineda, the conveyance efficiency of $Eff=60\%$ is a good estimation (Hayde, 2006). The ETm values are those computed for each crop in section 3.6.2 while the yield response factor Ky is provided in Table 30 of the Appendix VIII. The area values for the 3 crops in a particular secondary block are added to get the deficit managed area of the block:

$$\begin{aligned}
 A_{block,act}(ha) &= \sum_{allcrops} A_{crop,act} \\
 &= A_{rice,act} + A_{maize,act} + A_{tomato,act}
 \end{aligned}$$

When applied to a worksheet, the main area increase figures are:

- in the 1st set CSK1-17:
small CSK11 : 1.32ha $\Rightarrow$ 1.62 ha
big CSK8 : 25.91ha $\Rightarrow$ 31.66 ha
- in the 2nd set CSB1-14:
small CSB2 : 1.65ha $\Rightarrow$ 2.02 ha
big CSB14 : 50.12ha $\Rightarrow$ 61.24 ha
- in the 3rd set CSB15-25:
small CSB19 : 9.75ha $\Rightarrow$ 11.91 ha
big CSB16 : 50.07ha $\Rightarrow$ 61.18 ha
- The total cropping area: 711.59 $\Rightarrow$ 869.47 ha an increase of 160 ha.

The results are shown on Figure 56 and detailed in Appendix VII

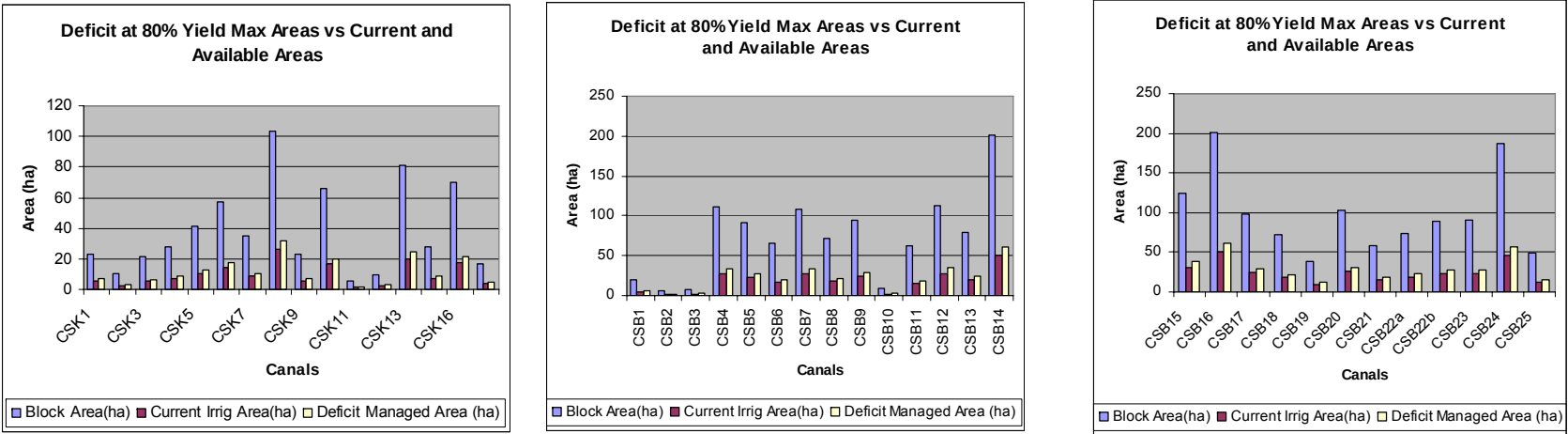


Figure 56: Area gained under deficit irrigation with 25% water available

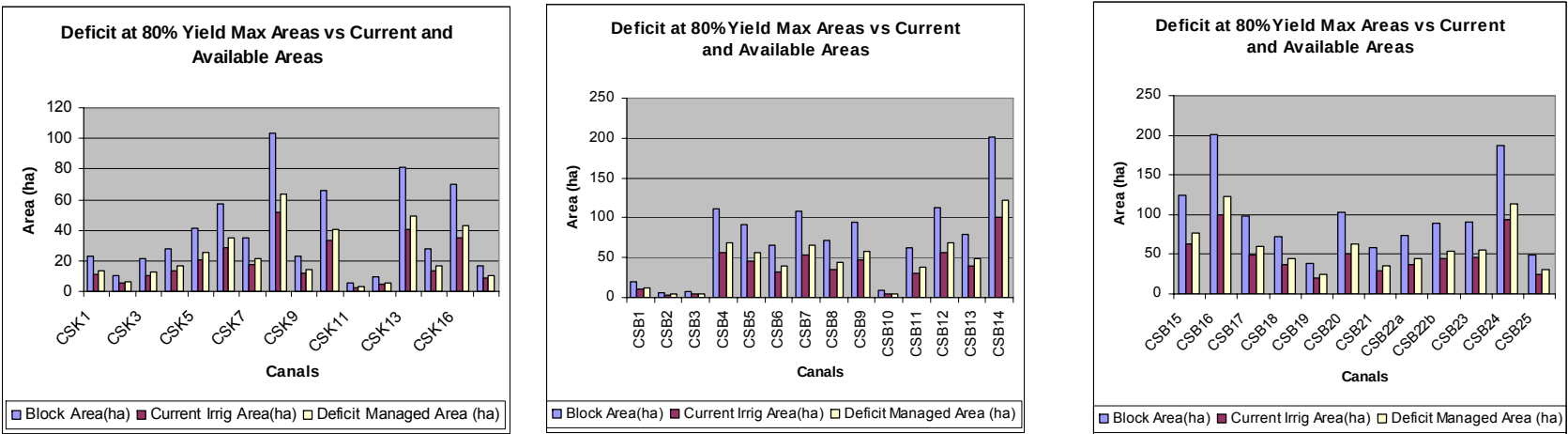


Figure 57: Area gained under deficit irrigation with 50% water available

Modern scenario: 50 % water available

This scenario assumes that the losses in the main canal and the secondary canals are now less. The on going rehabilitation will line parts of the main canal and contribute to loss reduction. Water scarcity, consequence of the competition with other needs (hydro power plant of Sotuba, river Niger flow reduction etc.) will still exist. However, it can be supposed that 25% more water are available. That is to say 50% of the total required water is available. In that case, what would be the area cultivable using deficit irrigation technique?

The worksheet computations yield the main following area increase figures:

- in the 1st set CSK1-17:
 small CSK11 : 2.64ha → 3.23 ha
 big CSK8 : 51.82ha → 63.31 ha
- in the 2nd set CSB1-14:
 small CSB2 : 3.30ha → 4.03 ha
 big CSB14 : 100.24ha → 122.48 ha
- in the 3rd set CSB15-25:
 small CSB19 : 19.50ha → 23.83 ha
 big CSB16 : 100.14ha → 122.36 ha
- The total cropping area : 1423.18 → 1738.93 ha, an increase of 315 ha

The details are also shown on Figure 57 and in section VII of the Appendix.

3.7 Farmer's economy: what crop to grow to face water fee

The farm budget computation for a typical farmer can be performed only on the base of cropping pattern assumptions.

As an indicative list of factors, the choice of the crops to grow will depend on:

- soil type
- water availability
- farmers skills to grow the type of crop
- farmers food dependency as regards the crop
- market price offered
- the agri-inputs costs
- advice provided by OPIB reflecting the authority viewpoint

The specific cropping objectives of the authorities of Mali in connection with Baguineda scheme are (BCEOM-BETICO, 2002) :

- increase cereal production (rice and maize)
- diversify crop growing during the dry season by developing vegetables mainly for the market of Bamako through securing completely the irrigation system

The soil map on agronomic suitability exposed in section 3.2.1 yielded the scenario:

- *the rainy season* : about 70% of the soils are very good for rice production while 22% are very good for polycrops (maize and vegetables)
- *the dry season* : 38% of the soils are very good for rice(16%), and polycrops (22%) while 62% are only almost good for rice and polycrops.

The 2007 actual cropping pattern was exposed in section 3.2.1 and it was deducted from it the following cropping scenario:

- the rainy season : $rice62\% + sorghum20\% + maize18\% \equiv area100\%$
- the dry season : $rice30\% + maize16\% + tomato54\% \equiv area100\%$

Although rice and maize are present each season, from these figures, it appears that the majority will grow rice in the rainy season while the majority will grow polycrops (maize and vegetables) in the dry season. Therefore the 3 following combinations can be considered for rainy season/dry season:

- rice/rice
- rice/maize
- rice/tomato (vegetables)

At ideal, the production charges and the prices in a farmer accounting would be based respectively on the costs of the inputs such as fertilizers, seeds, pesticides, water fees and the price offered by traders at the farm exit (Table 25). In absence of these costs for the specific site of Baguineda, the average production costs and producer prices (Ministère de l'Agriculture, 2005) can be used (Table 26). Such costs and producer prices per kilogram of fruit are shown on Figure 58 for twelve crops frequently grown in Mali: millet, sorghum, rice, maize, wheat, cotton, onion, tomato, potato, green beans, sweet pea and mango.

From this graph it appears that:

- rice; onion and potatoes have the most important profit margin and maize the least one
- in Baguineda, 80% of the rice produced is for self consumption
- green beans and sweet pea have the highest both production and producer sell price
- the production cost of mango is almost nil (€ 0.01)

Table 25: Main agri-inputs of rice, maize and tomato

Rice		Maize		Tomato	
Fertilizer		Fertilizer		Fertilizer	
DAP (amoniac phosphate)	10	Complex NPK (kg/ha)	100	Complex NPK 10-10-20 (kg/ha)	30
Organic Matter (kg/ha)	500	Organic Matter(kg/ha)	*	Organic Matter (kg/ha)	30,000
Urea (kg/ha)	250	Urea (kg/ha)	50	Urea (kg/ha)	*
Seed (nursery) (kg/ha)	60	Seed (kg/ha)	20	Seed (kg/ha)	0.30
Herbicide	*	Pesticides	*	Pesticides	*
e.g. BasagranPL2 (liters/ha)	6	Yield (tons/ha)	6	Yield (Roma VF=25)(tons/ha)	20
Yield (Gambiaka Suruni) (tons/ha)	6	Cycle (days)		Cycle (days)	120
Cycle (days)		"Niéléni"	80-90		
"Télimani"	95	"Sotubaka"	115-120		
"Wassa"	120				
Remarks:					
Mali produced 800 000 tons of rice in 2001 which is 10% of the total rice production in West Africa Mali imports yearly 250 000 tons of rice Total rice production in Baguineda is 6572.22 tons. Total rice self-consumption in Baguineda is 5394.72 (82%) Water fee is not mentioned in the above charges in case of irrigation Annual production of Maize in Mali is 500 000 tons with an average yield of 2 tons/ha *** = data not available				Sources : BCEOM 2002; Delarbre 1998, (OPIB [3], 2007)	

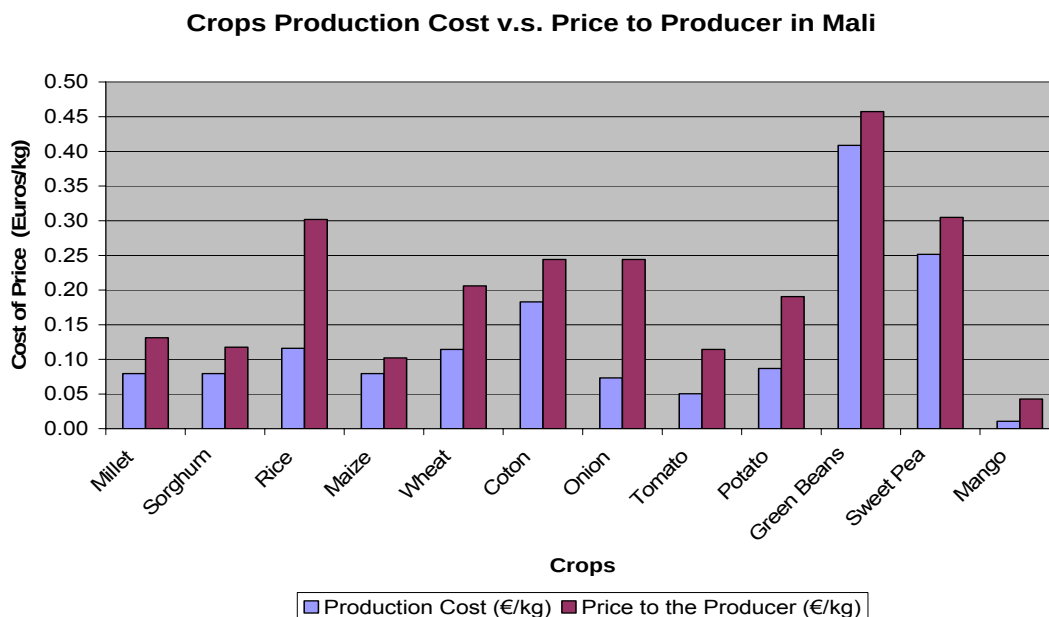


Figure 58: Profit margins for 12 crops in Mali

Among these 12 crops, the attention is focused on rice, maize and tomato in the case of Baguineda in order to see how so far a farmer can afford the water fee. Two scenarios are considered:

- *current scenario* : not lined main and secondary canals with water infiltration losses and actual yields
- *modern scenario* : main and secondary canals are all lined resulting in less infiltration losses and high yield under proper cropping practices

On Table 27 and Figure 59, are presented first the profit margins for a 1ha farm size. Keeping in mind that the production for 1 ha – and not per unit mass 1 kg – is involved here, it appears:

- whereas rice had the most important profit margin per unit mass of fruit, tomato with a much higher tonnage (30 tons/ha) possesses the most important profit margin per hectare
- tomato margin – with an expected yield 45 tons/ha – reaches 2880 euros in modern scenario while it is 1920 euros currently
- maize has the least important profit margin per hectare in both the dry and the rainy seasons

On Figure 60, the analysis is extended to the currently practiced water fees. The ratio $(Water\ Fee) / (Profit\ Margin)$ is an indicator of the farmer's ability to pay the water fee and of the type of crop preferable to be grown. The less is this ratio, the more a farmer can face the water fee. It appears from this figure that :

- currently growing only maize on 1 ha yields a ratio $(Water\ Fee) / (Profit\ Margin) = 125\%$ in the rainy season (and the rainy season IWR of maize was computed to be nil in section 3.6.2). However, this ratio will fall

down to 15% in the dry season in which water fee practiced in Baguineda is 10% of the rainy season fee²¹ for all crops

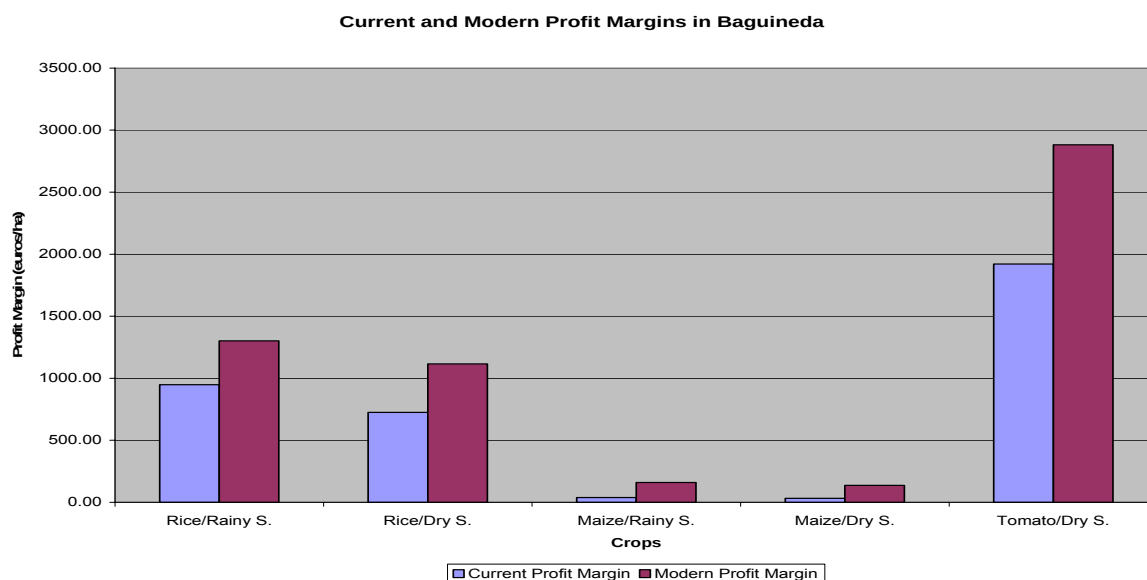


Figure 59: Current and modern scenarios profit margins of rice, maize and tomato

- even in modern scenario, the $(Water\ Fee) / (Profit\ Margin)$ is still 30% for maize
- the ratio for rice is almost nil in both rainy and the dry season
- the ratio is nil for tomato in the dry season

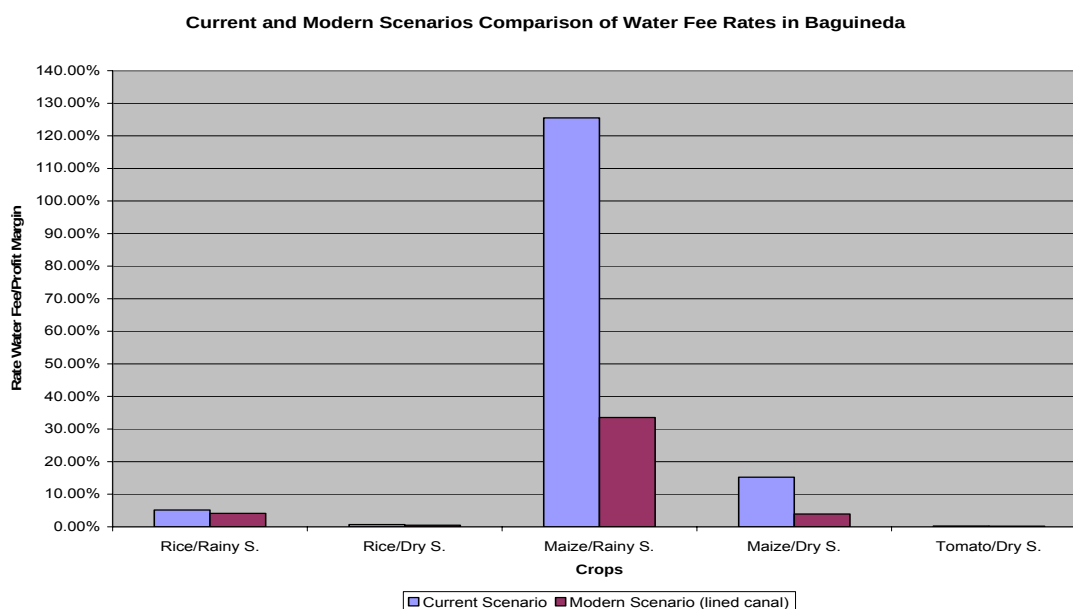


Figure 60: Water fee over profit margin in Baguineda

²¹ Mainly due to water scarcity and distribution problems

4 Discussions

4.1 Scientific and technical contributions

4.1.1 GPS/GIS use in irrigation systems

The population growth and the increasing competition of hydro power plant in Baguineda have induced an important pressure on the water resource derived from river Niger. Although water available is enough in the rainy season, the dry season crop production faces a rapid change from year to year in the size and location of the cultivated lands. More spontaneous installations and water withdrawal points are visible.

In the past decade, the accuracy of affordable GPS – less than € 500 – working in *absolute mode* was often more than 100 m (Boiten, 2003). The *differential* working mode required a much more expensive GPS (more than € 25,000) but yields a positioning accuracy better than ± 1 cm. GPS was used when the targeted areas were several hundred thousands hectares or in forestry (Freycon V., 1998). The accuracy exigency of irrigated land did not allow the use of affordable GPS to create geographic and hydraulic information.

In this study, a Garmin GPSMap 60 CSx coupled with a Sony DSC-H3 8 megapixels digital camera were used to generate reliable data of the irrigation farms and canal network. Although the GPS had the ability to work in differential mode, the absence of local reading correction providers in Bamako led to use it in absolute mode. The average positioning accuracy of more than 200 measurements was less than 6 m.

Satellite remote sensing and aerial pictures have been often used to follow up in GIS applications the rapid change in land use in cities and towns (Weng, 2002). However; they are not enough accurate to delineate small crop lands of some 100 ha to 5 000 hectares. Hence, the digital camera and a topographic hard copy map (scale 1:10,000 and 1:2000) were used in the case of Baguineda. The resulting GIS map, developed in Arcview GIS 3.3, has a relative error of less than 5% as obtained with the soil Map computations.

4.1.2 GPS insight

Some insight was gained in GPS utilization as explained on Figure 63. The Garmin GPSMap 60 CSx was used in absolute mode to produce the basic data analyzed in this report. Most of the time, at least 6 or 7 satellites were “visible” on the screen of the GPS.

However, when preparing for measurements, the following points must be kept in mind:

- when the sky is very cloudy, it is better to wait till the sky is clear again
- the best satellite configuration on the GPS screen is the situation in which at least 4 satellites are on the inner and the outer circles. In that situation a positioning accuracy of ± 2 meters is obtained after less than 10 minutes
- when obstacles such as trees or hills form a barrier against the signal, a solution can be found by attaching the GPS to a 1 to 2 m rod that will be lifted up. The signals may be improved

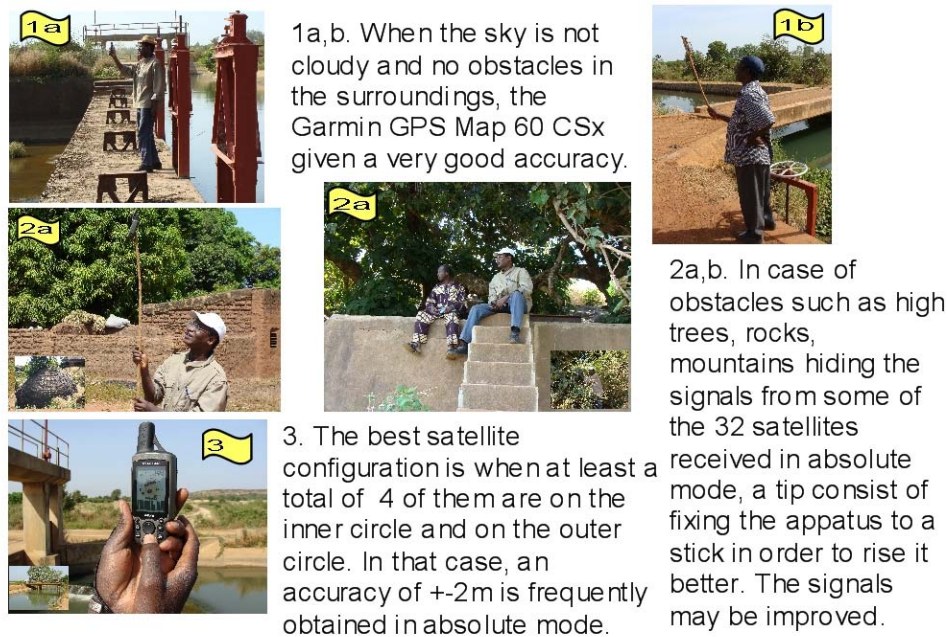


Figure 61: Hints for using Garmin GPSMap 60 CSx

The average accuracy obtained in Baguineda was $\pm 6\text{ m}$. Very often the position of the operator was fixed with an accuracy of $\pm 2\text{ m}$.

4.1.3 Ultrasound distance measurement insight

A Stanley ultrasound apparatus was used to measure the width of the feeder canal just upstream the headwork double gate (Figure 62). At the beginning, there was no reflection received by the sensor when an incident sound was sent to the rocky wall of the canyon.

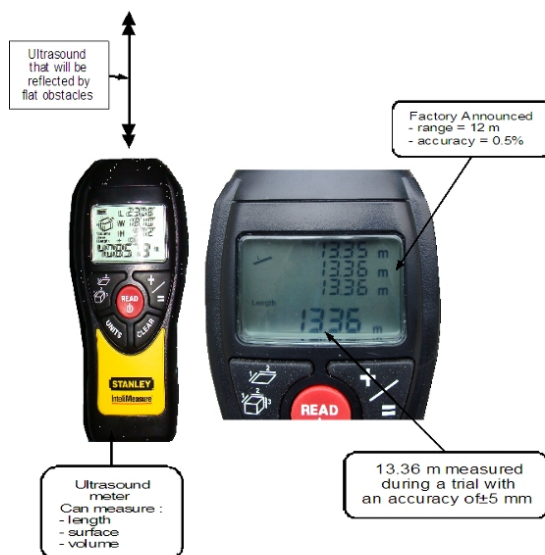
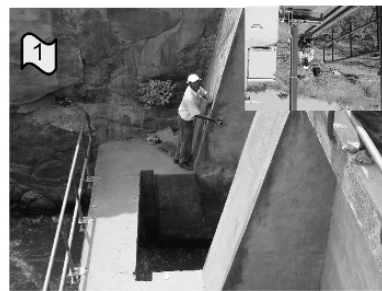
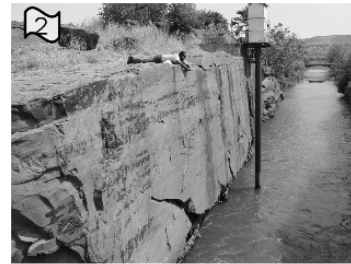


Figure 62: Stanley ultrasound meter



1. In areas difficult to reach, such as gate walls, ultrasound measuring is very suitable.



2. Measuring by ultrasound is an advantage when no partner to pull the tape over a canyon like this headwork canal of Baguinéda (Mali). The ultrasound is reflected by the rock when moved around an « exploration » area.



3. When the surface is irregular, like on this rock, the sound is spread out and the measurement may be difficult. The solution is to press and hold the read button and explore the target area till a number appears on the screen. That works.

Figure 63: Hints on ultrasound distance measurement

Later, making some trials on facades in a hilly area (Figure 63); it was discovered that the irregular surface of the wall caused a dispersion of the incident sound. Therefore the reflected sound was not received by the apparatus and the ultrasound meter could not compute and display the distance. What solution was found to this problem?

Fortunately, the Stanley apparatus allows “continuous” sound emission when the button is pressed and hold. The sound flow strikes continuously the irregular surface and when the operator at the same time moves the emission direction, the incident sound will fall upon a perfect perpendicular sheet. The sound reflected by that sheet will be received by the apparatus and the distance is displayed.

4.1.4 Scenario analyses in irrigation structures

Scenarios analyses have considerably developed along side with a modelling software. Although often a “vision”, scenarios analyses have been used to anticipate potential hardship in food management in Sub-Saharan Africa (Ararso et al., 2006). In this research were developed 4 pairs of scenarios.

The *first pair* focused on the potential water gain in changing from not lined to lined complex secondary canal network of 54 km. A spreadsheet based on climate, crops and canals characteristics was realized.

Hydraulic modelling considered a *second pair* of scenarios. In current and modern scenarios the impact of non lined main canal (with important seepage) and lined main canal (with less seepage and roughness) on the discharge transfers trough the system and the water levels were studied.

The *third pair* of scenarios analyzed the impact crop land increase using deficit irrigation method for rice, maize and tomato. A computation algorithm was proposed and introduced in a worksheet. The first situation considered 25% only of the required water available whereas the second situation was computed with a hypothesis of 50% water available.

Finally, the *fourth pair* of scenarios focused on the affordability of water fee by a farmer and the research of the most appropriated crops to produce. The 2 scenarios considered were respectively a non lined canal network (low crop yield) and a lined canal network (high crop yield).

A flow simulation software, the HEC-Rivers Analysis System (HEC-RAS) was used to model the hydraulic behaviour of 15 km on main irrigation canal. Although modelling may become a barrier to understanding unusual values of certain components of a system (Klemės, 1986), it can be the only way to analyze flow evolution in a complex irrigation system (William & Honton, 1987). The complex non prismatic cross section of the main canal was modelled as well as the headwork double vertical gate and a typical gated spillway regulator used in the system.

Due to its importance on the reliability of flow distribution in the system (Malaterre & Baume, 1998), the regulation effectiveness of a long weir (13 m) as far as 5.6 km upstream and the Manning roughness coefficient influence were also investigated.

4.1.5 Discharge measurements

Flow measurement is important and delicate on most of the gravity irrigation structures. Some authors such as Boiten (Boiten, 2003) or Troskolanski (Troskolanski, 1960) mentioned among discharge measurement techniques the use of “rod-float” as an accurate one. Long time ago, Professor Unwin wrote that by making rod-float measurement along 2 streamlines located each one at one third of the canal breadth, it was possible to measure approximately the average velocity of a stream (Cunningham & Unwin, 1883). In the case of Baguineda, 5 measurements were performed along the stream centreline of the headwork with a rod-float. The length of the rod was $h_{rod} = 0.8 \times h_{water} = 0.9 \times 2 = 1.8$ m. The resulting discharge was 8.54 m³/s with 5% as relative error of. This confirms that rod-float velocity measurement can be used in complement to other methods or even alone to assess the discharge in a stream. However, one should keep in mind that the canal cross section must be accurately measured as well.

4.2 Research questions

4.2.1 Overall objective of the system and operational roles in the dry season

Overall objective

Baguineda Irrigation System has a specific discharged $q = 3.0$ l/s/ha designed on the basis of the dry season. The system is constructed offering a great flexibility in water

allocation to secondary blocks. In fact, there are on the main canal 7 regulation weirs each of which has 2 lateral vertical gates in order to convey water when downstream needs more. Each of the 42 secondary canal intakes is equipped with a vertical gate with a weir some 10 m downstream to maintain a submerged flow. Every tertiary block intake is made of a vertical gate. Besides, a tomato factory called SOCAM²² used to buy and transform tomato production of Baguineda crop land. Therefore, it can be said that after the rehabilitation of the end of 1990s – that brought the infrastructure to its current configuration – the overall objective planned for the irrigation scheme was *productive irrigation*.

Once the overall objective of an irrigation system is decided, the structure is designed and implemented to respond to this objective. (Ankum, 2004). *Protective irrigation* will logically lead to *equitable* water supply through fixed water division structures such as division weirs or boxes. Protective irrigation aims famine relief or food security. The specific discharge used is lower than in productive irrigation. In addition, protective irrigation is extensive and *supply-based* (Hussain & Deeptha, 2004), in other words, *water allocation decision* is taken by O&M Agency.

It is most of the time impossible to turn a protective irrigation infrastructure to productive irrigation. At the opposite, it is “possible” to render a “protective” service with a productive irrigation system. The *price to pay* is the operational *complexity* that will result and a usually *non-equitable* water delivery. Therefore, this mutation tends to incite to *unauthorized water withdrawals* from the main canal.

Under the pressure of population crop-land requests and water scarcity due to seepage and hydro power water use, the *productive* irrigation system of Baguineda is now working on the “*protective option*”. During the GPS measurements implemented, three unofficial pumping points were located between the headwork and CSK1. This is also confirmed by BETICO-BCEOM’s study (BETICO-BCEOM, 2005) that reported more than 10 unofficial intake locations.

Amazingly, all the water level scales that were installed at the secondary intakes disappeared. Several weirs are broken by farmers because considered as “blocking” water flow to farms.

Operational rules during water scarcity

During the dry season in which water is scarce (February to May), a rotation is introduced along the main canal by OPIB. Rotation is practiced also along secondary canals and along tertiary canal.

Along the main canal, the scheme is divided into 2 parts: from CSK1 to the intake CSB14 is the first group, and from CSB15 to CSB 25 is the second group. The first group receives water Monday, Tuesday and Wednesday. Water is supplied to the second group in the 4 remaining days of the week. Therefore, the flow in secondary canals is *intermittent*. This *rotation* is formal and written down. At the opposite, the

²² That factory no more exists.

rotation along the secondary canals and the one along the tertiary canals are *informal*, made by *consensus* among farmers.

The *operational complexity* of the system in the dry season emerges from the rotation program described earlier. The lateral gates of the 7 regulators can have at least 3 configurations: i) the 2 gates are closed, ii) the 2 gates are open and iii) only one gate is open. That varies from a regulator to another. The manipulation of the gates is a rather *hard physical job* as it was noticed during the Fieldwork. This role is devoted to the chief sectors, agents of OPIB who have the lock of the gates.

Even lining the main will not solve this threat of spontaneous water pumping. A *strong reliable water service* based on *priority cropping* areas must be offered by OPIB (productive irrigation). This will require the installation of – for example – long-throated flumes downstream each secondary intake in order to know what amount of water is provided to each secondary block. This kind of flume can be efficiently designed using the software Winflume. (USBR et al., 2001)

4.2.2 Decision making process for water allocation to farmers

As described in the organization and nomenclature (section 3.2), farmers are organized at several levels. Within the tertiary block they are organized in GUE²³ for irrigation and maintenance. The members of a GUE are only farmers. At the secondary block, farmers are organized in CIE²⁴ for irrigation and maintenance. These 2 organizational levels worked with OPIB's chief sectors as *partners*.

A *sector* is composed of a group of CIE. The corresponding organization is the CPIE²⁵ for irrigation and maintenance. Therefore, the CPIE manages a set of secondary canals and the related command area. The letter “P” stands for “parity” and accordingly, the chief sector, an OPIB agent, is member of the organization. The CPIE schedules and supervises the yearly cropping activities and maintenance within the sector. It is at this level that farms having water or soil problems are also recorded for a possible water fee exemption.

All the CPIE in the irrigation scheme join together, through their representatives, in the CPEE²⁶. Again the “P” stands for “parity”, thus OPIB agents are formally involved in this organization. This is *the structure that makes decisions*.

Whereas OPIB is not formally involved in the GUE and the CIE, it is in the CPIE and the CEE. At the secondary canal intake from the main canal, the farmers' organization dealing with water is the CIE. During the dry season, water is delivered to the CIE on a *rotational basis*. There is no discharge measurement at the intake and there is no contract between OPIB and the CIE. The existing 2 types of contract are: i) the contract between OPIB and the individual farmer and ii) the contract shared by Ministry of Agriculture, OPIB and all farmers' Representative (there is no federation).

²³ In French : Groupe d'Utilisateurs de l'Eau

²⁴ Comité d'Irrigation et d'Entretien.

²⁵ Comité Paritaire d'Irrigation et d'Entretien

²⁶ Commission Paritaire d'Exploitation et d'Entretien.

As experienced for example in the Fayoum irrigation system in Egypt (de Veer et al., 1993), the main risk of *rotation* is the *lack of equity*. This is particularly true in extended irrigation systems where intermittent flow means also unsteady flow most of the time. Hence discharge and water levels are not stable and may significantly deviate from the target or promised value to farmers' organizations.

For the *improvement of the cropland productivity*, a contract is suitable between OPIB and the CIE. But this supposes OPIB's ability to deliver a reliable water service (Perry, 1995). Therefore, at least the *main canal*²⁷ and the *secondary canals should be lined* and discharge measurement structures installed the main canal downstream each secondary intake. At the very junction where water from managed by OPIB turns into managed by farmers, the water delivery should be permanent and measurable. It is preferable that inequity is handled within a farmer's organization than between farmers and OPIB in case a contract is signed.

4.2.3 Existing flow control structures and discharges

Flow control structures

The flow is controlled through the main canal mainly by 7 regulators. Each regulator is composed of a central weir of 13 m long and two 0.70x0.70 m² lateral vertical gates. Each of the 42 secondary canals intakes is made of a vertical gate associated downstream with a weir to maintain submerged flow conditions.

Transferred discharges reliability

In the rainy season – with an irrigation need of 420 mm – water level is regulated in the main canal by the seven regulators and flows permanently. Hence, the flow control method is *upstream control*.

During the dry season in which the irrigation need is 2680 mm and seepage and hydropower withdrawals cause water scarcity, the flow control method turns to be mixed: *partially upstream control*, *partially manually controlled* to meet downstream demands. This can be called *simultaneous control* (Ankum, 2004) Flow occurs both above the regulator weir and through the lateral gates. In fact, as the HEC-RAS simulations showed for the current scenario, 80% of the flow passes through the gates when regulator R1 works in this mixed condition. Furthermore, as the simulations predict (section 3.5.4), water level drops some 20 cm upstream the regulator R1.

Although the extent to which the *discharge decreases through the 11 secondary intakes upstream R1* is not known, *there will be reduction* as a consequence of the 20 cm drop. More investigation, using the exact geometry and elevations of the secondary intakes is required in order to know the real discharge delivered to the secondary blocks.

²⁷ The beginning of partial lining of the main canal is planned for 2008

In case of *modern scenario* HEC-RAS simulation in which the 2 lateral gates were closed, water level upstream regulator R1 is 14 cm higher than in *current scenario*. This may ensure the target nominal discharge to the secondary canals located upstream R1.

A long weir can be called a *water level stabilizer*²⁸ since water charge above the weir $h \sim \left(Q/L_{\text{weir}}\right)^{(2/3 = 0.66)}$. An important variation of Q will result in little variation of h. This is particularly true when the weir is long. In fact, upstream control concept is built to ensure stable water level *upstream*. Therefore, upstream control privileges upstream instead of downstream. It is difficult to satisfy farmers located downstream in case of water scarcity. To overcome the difficulty, a strong water operation centre with installed discharge measurement flumes or automation may be solutions (Mandavia, 1998).

In a nutshell, OPIB does not know in the dry season the actual discharges transferred neither upstream nor downstream the regulators in its water scarcity program. This certainly explains also why the dry season water fee is only 10% (in fact 5 €/ha) of the rainy season fee.

What area can be cultivated in the dry season?

In the current scenario simulation presented in section 3.5.2, it appeared that the 8 m³/s released from the headwork drop to 3.6 m³/s after regulator R1 located 15 km downstream. This drop is caused by the 11 secondary intakes and seepage. Seepage represented 3.30 m³/s whereas the intakes summed up to 1.22 m³/s. Seepage is twice higher than the intakes. In fact the 3.6 m³/s yielded a specific discharge of $q = 1.5 \text{ l/s/ha}$ for the 2430 ha located downstream R1. This *discharge is insufficient* for that cropland since the normal value computed from IWR is $q = 3 \text{ l/s/ha}$.

Keeping in mind that some 3 m³/s will be lost by seepage along 10 km not lined canal downstream, only 0.6 m³/s will be available. That corresponds to $A(\text{ha}) = (600 \text{ l}) / (3 \text{ l/s/ha}) = 200 \text{ ha}$ as cultivable land downstream R1. To summarize, in the current scenario of the dry season, only a total of $A_{\text{tot,dry season}} = 415 + 200 = 615 \text{ ha}$ are cultivable. This number is confirmed by the actual practice that was 677 ha in 2007 (section 3.6.1)

This result stresses the need for lining the whole main canal comprising also the 10 km dead head canal²⁹.

In the modern scenario (with *full lined main canal and seepage reduced to 0.10 m³/s/km* and a headwork discharge of 9.5 m³/s as proposed by BETICO/BCEOM) shows that only 2,000 ha out of 3,000 ha will be cultivable in the dry season³⁰. This does not take

²⁸ At the opposite, a gate can be called a *discharge stabilizer*, since $Q \sim h_{\text{gate}}^{0.5}$ means an important variation of h will result in little variation of Q.

²⁹ The ongoing lining project includes only 5 km upstream regulator R1 plus the not lined portions downstream R1. 10 km of the dead head canal will remain not lined.

³⁰ The secondary canals are not lined and have a conveyance efficiency of 60%. This corresponds to a $q = 3 \text{ l/s/ha}$ in the secondary blocks.

into account the extension areas of Tanima and Sienkoro (460ha) not analyzed in this research. Therefore, even with full lined main canal, *not more than 2,000 ha can be cultivated*. Interestingly, this results is the same than the 2000 ha announced by BETICO/BCEOM (BETICO-BCEOM, 2005), though with lined portions.

A Possible solution for *increasing* the area is to improve the *conveyance efficiency of the secondary canals* by lining.

Another, but more difficult solution is to increase the discharge at the headwork by reducing the hydropower plant discharge and constructing additional gates. This solution is being applied with 9.5 m³/s in the ongoing OPIB project. Hence, to increase more the head discharge again is unlikely to happen...

4.2.4 Irrigation water requirements and crop yields

The irrigation water requirements at the intake of secondary canals were determined in section 3.6.2:

- for both current and modern scenarios the *net irrigation water requirements* yielded : i) in the dry season IWR = 2,680 mm and ii) in the rainy season 420 mm
- for the current scenario with secondary canal of 60% efficiency, the specific discharge is 3 l/s/ha
- for the modern scenario with secondary canal of 80% efficiency, the specific discharge is 2 l/s/ha

Theses values seems high compared to those from southern Asian countries (Ankum, 2004) . But it is helpful to keep in mind that Baguineda was firstly designed with 9 m³/s for 3000ha, which corresponds to 3l/s/ha. Furthermore, the system is designed for the dry season in which evapotranspiration is high (more than 190 mm/month in January, February and March) and the efficiency of the canals are low.

Most of the irrigation systems built in the 1970's in the Malian neighbouring country Burkina FASO by SOGREAH³¹ were based on 3l/s/ha, while those constructed in the 1980's used 5l/s/ha. These last irrigation systems assume a rice production during the dry season.

4.2.5 Practicing deficit irrigation

Deficit irrigation in the dry season was applied to a current scenario with 25% of the required water available and a modern scenario with 50% of the required water available (section 3.6.3). In both cases, 80% of maximum yield reduction was expected. Furthermore, it was assumed that farmers were already producing high yields (6 tons/ha for rice and maize and 45 tons/ha for tomato).

With these hypotheses, in the:

- *current scenario* : 160 ha can be cultivated in addition to 700 ha being used
- *modern scenario* : 315 ha can be cultivated in addition to 1,420 ha used

³¹ Société Générale de Recherche et d'Etude Hydro-Agricole. France.

The gained in area size is more important with the biggest secondary blocks.

Actually, the dry season yields in Baguineda were for rice, maize and tomato respectively 4; 1.4 and 30 tons/ha in 2007. *Therefore, although the gains in area are substantial, it would be difficult to put in practice deficit irrigation in Baguineda in a near future.* The question may arise: and if due to water scarcity farmers were already, in some unconscious manner, practicing deficit irrigation? The yields obtained in the rainy season for rice and maize are also low: 5 tons/ha and 1.7 tons/ha respectively. Tomato is not grown in the rainy season but the yields of groundnuts is 0.20 tons/ha. Therefore, it seems that the low yields are not caused by water scarcity.

Crop yields must be improved first and depend on several other factors different from water. Among those factors can be mentioned: soil nutrients, respect of cropping calendar and high variety seeds.

4.2.6 Size and location of the cropping lands

Soil suitability

The land sizes were determined by agro-pedological classes:

- 2R covers 1900 ha and is very good for rice only in the rainy season
- 1P and 2P cover 670 ha and are very good for maize and vegetables in both rainy and the dry season
- 1R with 500 ha is very good for rice in both rainy and the dry seasons. It is also very good for maize and vegetables in the dry seasons.

Therefore in Baguineda while *rice production* in the rainy season can be important, it *should be reduced to less than 500 ha in the dry season. Vegetables must be grown on at least 60% of the soils in the dry season.* What reveals the current practice? In 2007, rice was grown on 207 ha (30% of the cropping area) against 470 ha in maize and vegetables. (section 3.6.1). Hence, it appears that despite of water problems farmers have already come to the conclusion that *in the dry season maize and vegetables rather than rice are suitable on 70% of the soils in Baguineda.* However, this can be challenging for many families as rice is the basis of food and 80% of the rice is consumed by the producers themselves.

The total soil map neat area delineated with GIS is 2,833 ha while the rough area, (comprising roads, canal sites and embankments) is 3,456 ha. BCEOM reported a size of 3,067 ha using a planimeter BCEOM (BCEOM, 1992) but the boundaries of its calculated area are not always materialized on the hard copy map. Therefore, a straight comparison is not reasonable. Nevertheless, it can be noticed that the GIS average value of 3,140 ha is in agreement with BCEOM's value. The *neat area* of 2,833 ha when compared to the current cropping area of 2,846 ha leads to the conclusions that the values are accurate.

Size of the blocks

In addition to canals and drains sizes, tertiary and secondary blocks sizes were determined by GPS/GIS application (section 3.2.3). The total crop land area was

evaluated to 2846 ha. The average tertiary block size is about 7 ha; varying from 1 ha to 90 ha. The average secondary block size amounted 70 ha with a minimum of 5 ha and a maximum of 200 ha.

As suggested in section 4.2.2, the secondary block - that is managed by a CIE - should be the level at which a contract is signed between OPIB and group of farmers. However, some secondary blocks are so small (e.g. 5 ha) that one can wonder whether a contract can be signed between them and OPIB. But the basic principle here is much the fact that the block has a secondary canal *directly fed by the main canal*. The *discharge delivered to them by OPIB must be known and assured*, no matter the size of the block.

4.2.7 Water fee that farmers can afford and advised crops

When comparing for 1kg the production cost and the producer price, rice is the best crop : it costs 0.12 €/kg to produce and the producer can earn 0.30 €/kg. (section 3.7) But when the production mass is considered, onion, tomato, okra and generally vegetables are much more valuable. The yield of tomato in Baguineda is 30 tons/ha versus 5 tons/ha for rice. Therefore, *growing vegetables will render a higher turnover and more profit to farmers*. However, the conservation of vegetables such as tomato may be a constraint. The development of artisanal conservation and transformation units may be a solution. Some ongoing efforts are already present in Baguineda and need to be pursued.

The lowest ratio (water fee)/(profit margin) is obtained with tomato (or vegetable) with less than 0.30% followed by rice (less than 0.70%) for both scenarios in rainy and the dry season (tomato is grown only in the dry season). In the rainy season, maize actually does not need the irrigation water. The maize IWR of 560 mm is covered by rainfall. *Paying water fee for maize is not rational in the rainy season*. In the dry season, due to its low profit margin of 40 €/ha³², the ratio (water fee)/(profit margin) amounted to more than 30%. Thus, maize is not a good choice as crop to grow in the dry season.

To summarize: *rice and vegetables are a good choice to produce in the rainy season. In the dry season although rice will be grown, more effort must be put on vegetables (tomato, onion, okra...) which provide a much more important turnover.*

³² In Burkina Faso, maize is more consumed by human than in Mali. Hence, the interest for growing dry season maize is certainly higher.

5 Conclusions and recommendations

Conclusions

Irrigated crop land productivity can be substantially be improved using GPS/GIS and scenarios analyses. A GPS/GIS application was used in Baguineda (30 km from Bamako in Mali) to carry out the main characteristics of a complex and extended 100 km irrigation network and the key features of a 2,846 ha crop land. These attributes of the system network and the commanded cropland were introduced into spreadsheets and a hydraulic modelling software to perform 4 pairs scenarios analyses.

1. **GPS/GIS application brought forth the main characteristics of a complex irrigation system.** Along the 37 km long main canal of Baguineda, 207 points were measured with GPS at locations including gates, weirs, intakes, canal elbows, cross section changes, bridges with an average accuracy of ± 6 m. A digital camera was used to scan a soil and farm system maps respectively at scale 1:2,000 and 1:10,000. The set of georeferenced points, soil map and farm system map were processed with a GIS to generate the properties of the i) water delivery system network, ii) crop land, iii) drainage system network. Based on these results, a nomenclature of the cropland was produced.
2. **HEC River Analysis System modelling software was applied to the GIS and topographic cross sections data to create the geometry and flow transfer through the first 15 km of the main canal of called Upper Baguineda.** The simulation produced on this upper portion of the system took into account the i) headwork double gate, ii) seepage, iii) eleven first secondary canal intakes and iv) R1 (the first of seven regulators on the main) with its 2 lateral vertical gates. This simulation process provides the way for modelling the complete system made of 37 km of main canal and 54 km of secondary canals with their flow control structures.
3. **The initial overall objective of Baguineda Irrigation System was *productive irrigation* which has been turned into *protective irrigation*.** The system was designed with a specific discharge of $q = 3 \text{ l/s/ha}$ with upstream control as flow control method. A great flexibility is ensured by the presence on the main canal of seven regulators in the centre of two lateral gates. This flexibility in flow transfer is reinforced by the vertical gates at the intake every secondary canal. There was a tomato production factory called SOCAM which was transforming the production and trading tomato pasta. Therefore, the system was designed with high production in mind. But nowadays, under the pressure of water scarcity due to seepage, hydropower consumption and cropland extension, the system objective has been turned into *protective irrigation*. In consequence, the system operation has become *very complex* in the dry season and discharges transferred are not actually known. The *equity aimed in protective irrigation can not be met*

and spontaneous *non-authorized water withdrawals* are emerging along the main canal.

4. **During water scarcity, rotations along the main and secondary canals are applied and flow through secondary canals is intermittent.** Two sets of secondary canals are formed for supply. The first includes CSK1 to CSB14 (regulated by R1, R2, R3 and R4) and the second gathers CSB15 to CSB25 (regulated by R5, R6 and R7). The lateral gates of the regulators on the main canal are manipulated to deliver wished equitable water the canals. The gates openings on a regulator can have at least three configurations: i) both are closed, ii) both are open and iii) one is open the other is closed. The central weir is used as well. In addition to this *operation complexity*, moving the gates is a rather *physical hard work*.
5. **The decisions making process for water allocation to secondary blocks in the dry season is *pre-arranged allocation*.** The CIE (Committee for Irrigation and Maintenance) is the highest farmers' organization in which the OPIB (O&M agency) is not formally involved. The CIE manages a secondary block and is at the junction main canal/secondary canal. There is no rotation in the rainy season. On the contrary, during the dry season water is delivered to the CIE (secondary canal) on a rational basis with three or four day durations. *The organization that takes this decision is the CPEE* (Parity Commission for Exploitation and Maintenance) in which farmers have representatives. The organization between the CPEE and the CIE is the CPIE (Parity Committee for Irrigation and Maintenance). The CPIE brings together a group of CIE and includes both farmer representatives and OPIB agents.
6. **Due to water scarcity in the dry season, the *upstream control* of the system is turned into *simultaneous control option*.** The irrigation needs in the rainy season are 420 mm and the system works in *upstream control mode*. During the dry season, 2680 mm need to be satisfied. Under water scarcity pressure the system water levels and discharges are changed by manipulation of the gates on the 7 regulators. Flow moves under *simultaneous control* method. The 15 km of not lined canal upstream regulator R1 was considered in *flow simulations with HEC-RAS*. In the *current scenario* analysis (8.0 m³/s at the headwork and not lined main canal with 0.22 m³/s/km), when the lateral gates of regulator R1 are opened, water level drops 20 cm reducing the discharge taken in the 11 first secondary intakes. In the *modern scenario* (with 9.5 m³/s at the headwork and lined main canal with seepage of 0.10 m³/s/km) water levels are 14 cm higher upstream R1 than in current scenario. This ensures a proper water delivery to the secondary canals.
7. **Under current conditions, the required specific discharge is $q = 3$ l/s/ha against 2 l/s/ha in modern lined canals for any secondary block.** In the current figure, the 42 secondary canals are not lined and their efficiency is estimated equal to 60%. In the modern scenario, the secondary canals are lined and the efficiency is evaluated to 80%.

8. **In the current scenario of non lined main canal , not more than 615 ha are cultivable in the dry season while at maximum 2000 ha can be grown under modern lined main canal.** Taking into account that the 416 ha of cropland upstream regulator R1 are conveniently supplied with water, the *current scenario* hydraulic simulations (with HEC-RAS) – with 8.0 m³/s at the headwork and 0.22 m³/s/km of seepage – yield a specific discharge of $q = 1.50$ l/s/ha for the 2430 ha located downstream R1 while crop water requirements leads to 3l/s/ha. Hence only 615 ha are irrigable, number in agreement with the 2007 dry season cropping area. The *modern scenario* HEC-RAS simulations (9.5 m³/s at the headwork and lined canal) led to a specific discharge $q = 3$ l/s/ha if only not more than 2,000 ha are cultivated
9. **Practicing deficit irrigation with 25% of the required irrigation water will increase the current cropping area in the dry season by 160 ha. In a modern figure using 50% of the required irrigation water, 315 ha more will be gained.** The actual yields in the cropland of Baguineda obtained in 2007 are low in both and the rainy season. This implies that water scarcity is not the cause of the problem: farmers are not already unconsciously practicing deficit irrigation. Deficit irrigation is only applicable once other yield limiting factors are eliminated. Nevertheless, 2 scenarios were studied with a targeted crop yield of 80% of the maximum. The 3 crops considered in the dry season were rice (0.80x6 tons/ha), tomato maize (0.8x6 tons/ha) and tomato (0.80x45 tons/ha). In the first scenario, 160 ha can be gained in addition to 700 ha. In the second figure, 315 ha would be added to 1,420 ha.
10. **Land suitability map of Baguineda helps to distinguish that in the dry season 60% of the soils are quite good for vegetable production while in the rainy season 80% of the soils are very good for rice.** The soil agro suitability map was scanned and georeferenced. Processing this map in GIS resulted into the delineation of the areas of 4 soil classes. The classes are 2R, 1P, 2P and 1R. The class 2R represents 1900 ha and is very good for rice but only in the rainy season. The classes 1P and 2P are very good for maize and vegetables in both rainy and the dry season. Together, they cover 670 ha. Spread over 500 ha, class 1R is very good for vegetables in dry-season and very good for rice in both seasons. The soil map produced was made available to OPIB.
11. **The total cropping area amounted to 2846 ha with an average secondary block size of 70 ha.** In addition to canals and drains, tertiary and secondary blocks sizes were determined by GPS/GIS application. A nomenclature these elements of the farm system was developed and made available to the O&M agency (OPIB). On the map produced the centre of each tertiary block is a point which geographic coordinates are known. Hence, any agent with a GPS can navigate to the point.
12. **Growing rice and vegetables, farmers can afford the water fee. Maize is not a rational choice in the rainy season.** Maize irrigation water

requirement (560 mm) are satisfied by rainfall in the rainy season. In the dry season, the ratio water fee/profit margin for maize amount to 30%. Hence, when considering the fees, maize is not a rational choice in the dry season. The water fee is currently 48.8 €/ha and was assumed to be 10% higher in the modern scenario with lined main and secondary canals. The lowest ratio (water fee)/(profit margin) corresponds to tomato (or vegetable) with less than 0.30% followed by rice with less than 0.70% for *both scenarios* (tomato is only grown in the dry season). However, 80% of the rice productions are consumed by farmer themselves.

Recommendations

As expressed during the discussions of the results of this study, the following recommendations can be formulated:

1. **OPIB should use the GIS developed in the daily management of the irrigation network and the cropland.**

In time the maps must be made more accurate and updated. Therefore, *we recommend also OPIB to acquire for the sub-sector responsables GPS and include in their activities to make GPS measurements.* Firstly the GPS delineation of the secondary blocks will be done. Afterwards, tertiary blocks and finally the farm borders must be measured with GPS.

The progressive importation of these data into the Geographic Information System (GIS) created will allow a very accurate and flexible follow up of the land being cultivated every season. Hence, the measurement of crop yields will be precise and regularly updated in the GIS. Furthermore the water fee based on the size of the farms will be really adapted.

A GIS Centre composed of agents from both the *Division Rural Advice and Vulgarization* and the *Division of Works* to collect, treat and interpret the GIS data would be created.

2. **The irrigation system should reorient its overall objective toward productive irrigation (high crop yields and priority areas in the crop land) during the dry season with emphasis on vegetable production.**

The aim is to simplify the operation and increase farmers' turnover. Vegetable production requires of course concomitant measures for crop product conservation and transformation. Nevertheless, the authority of OPIB must be strengthened. This will be possible if OPIB can deliver *a reliable water service in quantity and in accuracy.* Therefore, two things are recommended: i) in addition to lining the 10 km currently planned in the on going OPIB's project, *we recommend to line the entire main canal and all the secondary canals,* ii) given that the system is designed with the method of upstream control, *a Water Operation Centre (WOC) can be created within the existing Division of Works; this centre must be well trained to collect, treat and interpret data on the irrigation and drainage network* (Ankum, 2004).

It is necessary to know exactly the discharges transferred to the secondary canals at any moment during the season. This would be done by installing long

throat concrete flumes after every secondary intake in the main canal. The flumes can be easily designed using the software WinFlum (USBR et al., 2001). Their big advantage resides in their high accuracy, their robustness and their almost permanent submersion by water. Therefore they will be hardly reached and broken by anybody.

3. **Modelling the entire irrigation network by completing the canal geometry created during the current research should be continued.** This will allow a more complete appreciation of the flow through the system and open the way for a future automation of canal operations.

The current difficult hand operation of the regulator gates by the chief sectors can be electrified and later automated. This should be a process but it is essential to make the manipulation of the gates easier in order to allow discharge and water level adjustments especially in dry season to adapt to priority cropping areas.

The automation will require the installation of sensors to measure water levels and compute discharges based on the long throat flumes data. The *Water Operation Centre* would be in charge of these activities.

4. **The crop land productivity will increase in Baguineda if OPIB could take care of the main canal and make contract with CIE managing secondary canals and the related command areas.**

However, as mentioned above, this assumes that OPIB is able to provide farmers with a *reliable water service*. On the other hand, the secondary canals must be lined before this transfer of their operation to the CIE composed only by farmers (no OPIB's representatives). In addition, it is necessary that farmers are accompanied, trained to constitute *Water User Associations* capable of managing up to 200 ha as it appears in the map of Baguineda. Therefore, what is proposed here is a process for the mean term future.

The CIE will take care of all organisational and technical aspects – with paid assistance if needed – among farmers and make a contract in which the discharge to be delivered by OPIB at the intake of the secondary block for the season is clearly indicated. The CIE will manage the secondary block and the related infrastructure, setting OPIB free of these aspects. The secondary block becomes an autonomous Farmers Unit (FU), receiving independently from other blocks, the contractual water amount.

In this framework, OPIB will take care of the operation and maintenance the main canal and the main drains. The water furnished to the CIE will consequently be charged by OPIB.

5. **As regards with the illegal intakes from the main canal, two solutions are possible. The *first solution* – which we recommend also – is to integrate the additional illegal farming areas to the system by charging them with the water fee as normal farms.**

The sub-sector responsables can now locate exactly with a GPS all illegal intakes and measure the cropping area being supplied by each of them. This justifies

again that they must be given GPSs and trained enough to collect data with these equipments.

The *second solution* would to forbid these illegal intakes from the main canal. The major constraints to this solution are that OPIB must: i) regularly inspect and sanction those contravening against the regulation and ii) ensure a reliable water supply especially during the dry season.

6. **Since the yields are low also in rainy season in which water is sufficient, we recommend investigations about non hydraulic yield limiting factors.**

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Appendices

I. Schedule of Activities

Table 28 : Time schedule

		November 2007				December 2007				January 2008				February				March				April				Field	Not Field
Ref	Sub-Activities	Week1	Week2	Week3	Week4	Week5	Week6	Week7	Week8	Week9	Week10	Week11	Week12	Week13	Week14	Week15	Week16	Week17	Week18	Week19	Week20	Week21	Week22	Week23	Week24		
Google Earth																											
GE1	First identification of the cross section to measure																										X
GE2	First identification of the main system canals																										X
GE3	First identification of the canal segments for slope measurements																										X
Canal Operations																											
CO1	Operation rules in normal time																									X	X
CO2	Operation rules in scarcity (Feb-May)																									X	X
CO3	Rehabilitation operation rules																									X	X
CO4	Modernization operation rules																									X	X
Maintenance																											
MT1	Current maintenance rules and costs																									X	
MT2	Future rehabilitated maint rules and costs																									X	
MT3	Modernized maintenance rules & costs																									X	
GPS (X,Y,Z)																											
GPS1	Literature review on the use																										X
GPS2	Farmer villages locations																									X	
GPS3	Main roads locations																									X	
GPS4	Main cross sections locations																									X	
GPS5	Main flow control structures locations																									X	X
GPS6	Contours of the TU (tertiary unit) blocks																									X	X
GPS7	Crop types areas per TU																									X	X
GPS8	Crops yields obtained per areas within a TU																									X	X
Canal sections/control structures - Hydrometry																											
CS1	Literature review of approaches																										X
CS2	Elevations of the headwork section (topo level)																									X	
CS3	Canal reach 3 sections profiles (topo)																									X	X
CS4	Control structures dimensions (with a decameter)																									X	X
CS5	Sediments measurements at canal reach 3 sections profiles																									X	X
CS6	3 Slopes at canal reach 3 sections (topo level)																									X	X
CS7	Discharges & Water level in main canal reaches for DUFLOW values check																									X	X
CS8	Discharges & Water level at main control structures for DUFLOW values check																									X	X
CS9	Structures lifespan																									X	X
CS10	Structures planned for rehabilitation																									X	X
CS11	Structure proposed for modernization																									X	X
CS12	Location on the Network of ARC View																									X	X
Economy																											
ECO1	Water service charges (Rehab & Modern)																									X	X
ECO2	Operation costs																									X	X
ECO3	Maintenance costs																									X	X
ECO4	Interest rates																									X	X
ECO5	Loan duration																									X	X
ECO6	Economic Cost/Benefit Analysis																									X	X

[illegible]

II. Canal and drains lengths, names and nominal discharges

II.1. Secondary canal names and lengths

LENGTH (m)	FULL_NAME	QNOM_L_S_(l/s)	CAN_ORDER
281	CSK1	60	1.00
279	CSK2	76	2.00
837	CSK3	56	3.00
334	CSK4	83	4.00
723	CSK5	103	5.00
931	CSK6	180	6.00
635	CSK7	178	7.00
1374	CSK8	255	8.00
314	CSK9	63	9.00
2499	CSK10	135	10.00
425	CSK11	36	11.00
271	CSK12	43	12.00
2311	CSK13	188	13.00
411	CSK15	62	15.00
1131	CSK16	157	16.00
161	CSK17	36	17.00
871	CSB1	36	101.00
282	CSB2	23	102.00
615	CSB3	48	103.00
2398	CSB4	282	104.00
1275	CSB5	238	105.00
1401	CSB6	210	106.00
1721	CSB7	265	107.00
1050	CSB8	191	108.00
2361	CSB9	287	109.00
305	CSB10	24	110.00
2077	CSB11	157	111.00
1731	CSB12	260	112.00
2062	CSB13	236	113.00
2581	CSB14	452	114.00
2175	CSB15	307	115.00
2591	CSB16	515	116.00
1661	CSB17	299	117.00
904	CSB18	184	118.00
1517	CSB19	81	119.00
1739	CSB20	225	120.00
1760	CSB21	126	121.00
1675	CSB22a	156	122.01
1804	CSB22b	199	122.02
1486	CSB23	207	123.00
2265	CSB24	414	124.00
1058	CSB25	114	125.00

II.2. Tertiary canal names and lengths

TERTRY_NAM	AGENCY	DATE	HOUR	MODEL	LENGTH (m)
CSK1/CTG1	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	213
CSK1/CTG2	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	233
CSK1/CTG3	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	369
CSK1/CTG4	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	416
CSK1/CTG5	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	218
CSK2/CTD2	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	194
CSK2/CTD1	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	503
CSK3/CTG1	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	198
CSK3/CTD1	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	108
CSK3/CTD2	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	113
CSK3/CTD3	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	433
CSK4/CTG1	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	308
CSK4/CTG2	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	274
CSK4/CTD1	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	259
CSK4/CTD2	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	255
CSK4/CTD3	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	359
CSK5/CTG1	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	200
CSK5/CTG2	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	181
CSK5/CTG3	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	172
CSK5/CTG4	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	191
CSK5/CTG5	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	465
CSK5/CTD1	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	147
CSK5/CTD3	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	215
CSK5/CTD3	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	212
CSK5/CTD4	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	186
CSK6/CTG1	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	326
CSK6/CTG2	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	289
CSK6/CTG3	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	232
CSK6/CTG4	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	351
CSK6/CTG5	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	339
CSK6/CTD1	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	293
CSK6/CTD2	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	337
CSK6/CTD3	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	369
CSK7/CTG1	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	254
CSK7/CTG2	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	179
CSK7/CTG3	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	123
CSK7/CTG4	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	181
CSK7/CTG5	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	92
CSK7/CTD4	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	123
CSK7/CTD1	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	341
CSK7/CTD2	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	96
CSK7/CTD3	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	95
CSK8/CTG1	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	243
CSK8/CTG2	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	473

CSK8/CTG3	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	424
CSK8/CTG5	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	419
CSK8/CTD6	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	421
CSK8/CTD7	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	388
CSK8/CTD8	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	369
CSK8/CTD5	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	440
CSK8/CTD4	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	317
CSK8/CTD3	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	429
CSK8/CTD2	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	556
CSK8/CTD1	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	433
CSK10/CTG1	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	193
CSK10/CTG2	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	331
CSK9/CTG1	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	270
CSK9/CTD1	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	211
CSK10/CTG3	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	382
CSK10/CTG4	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	582
CSK10/CTG6	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	315
CSK10/CTG7	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	439
CSK10/CTG8	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	539
CSK10/CTG9	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	192
CSK10/CTG5	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	231
CSK13/CTD10	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	411
CSK13/CTD9	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	332
CSK13/CTD8	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	374
CSK13/CTD7	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	436
CSK13/CTD6	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	474
CSK13/CTD5	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	376
CSK13/CTD4	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	445
CSK13/CTD3	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	312
CSK13/CTD2	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	268
CSK13/CTD1	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	429
CSK15/CTG1	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	219
CSK15/CTG2	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	111
CSK15/CTG3	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	309
CSK15/CTD3	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	509
CSK15/CTG4	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	212
CSK16/CTG7	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	265
CSK16/CTG5	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	283
CSK16/CTG6	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	278
CSK16/CTG3	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	233
CSK16/CTG4	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	242
CSK16/CTG1	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	153
CSK16/CTG2	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	201
CSK16/CTD1	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	137
CSK16/CTD2	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	111
CSK16/CTD3	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	313
CSK16/CTD4	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	383
CSK16/CTD6	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	798

CSK17/CTG1	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	285
CSK17/CTG2	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	162
CSK17/CTG3	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	721
CSB1/CTG1	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	267
CSB1/CTG2	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	394
CSB2/CTD	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	190
CSB2/CTG	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	170
CSB2/CTG	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	238
CSB3/CTD1	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	76
CSB3/CTD2	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	71
CSB3/CTG1	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	280
CSB4/CTG1	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	291
CSB4/CTG2	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	308
CSB4/CTG3	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	368
CSB4/CTG4	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	316
CSB4/CTD1	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	144
CSB4/CTD2	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	148
CSB4/CTD3	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	161
CSB4/CTD4	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	165
CSB4/CTD5	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	247
CSB4/CTD6	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	381
CSB4/CTD7	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	319
CSB4/CTD8	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	483
CSB4/CTD9	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	529
CSB4/CTD10	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	577
CSB4/CTD11	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	560
CSB4/CTD12	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	450
CSB6/CTG1	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	305
CSB6/CTG2	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	269
CSB6/CTG3	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	245
CSB6/CTG4	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	196
CSB6/CTG5	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	168
CSB6/CTG6	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	175
CSB7/CTG8	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	277
CSB7/CTD9	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	46
CSB7/CTD8	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	140
CSB7/CTD7	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	220
CSB7/CTD6	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	258
CSB7/CTD5	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	257
CSB7/CTD4	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	281
CSB7/CTD3	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	295
CSB7/CTD2	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	375
CSB7/CTD1	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	341
CSB7/CTG1	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	454
CSB7/CTG2	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	354
CSB7/CTG3	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	409
CSB7/CTG4	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	335
CSB7/CTG5	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	318

CSB7/CTG6	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	313
CSB7/CTG7	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	321
CSB9/CTD13	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	215
CSB9/CTG11	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	572
CSB9/CTG10	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	516
CSB9/CTG9	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	513
CSB9/CTG8	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	420
CSB9/CTG7	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	519
CSB9/CTG5	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	174
CSB9/CTG4	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	170
CSB9/CTG3	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	219
CSB9/CTG2	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	203
CSB8/CTD1	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	489
CSB8/CTD2	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	430
CSB8/CTD3	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	419
CSB8/CTD4	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	357
CSB8/CTD5	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	279
CSB8/CTG1	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	262
CSB8/CTG2	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	241
CSB8/CTG3	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	249
CSB8/CTG4	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	231
CSB9/CTD1	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	229
CSB10/CTD1	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	367
CSB10/CTG1	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	285
CSB11/CTD2	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	291
CSB11/CTD3	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	337
CSB11/CTD4	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	284
CSB11/CTD5	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	391
CSB11/CTD6	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	380
CSB11/CTD7	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	403
CSB11/CTD8	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	275
CSB11/CTD9	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	122
CSB11/CTD10	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	90
CSB12/CTG7	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	408
CSB12/CTG6	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	438
CSB12/CTG5	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	365
CSB12/CTG4	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	356
CSB12/CTG3	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	362
CSB12/CTG2	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	268
CSB12/CTG1	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	290
CSB12/CTD1	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	262
CSB12/CTD2	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	370
CSB12/CTD3	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	396
CSB12/CTD4	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	547
CSB12/CTD5	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	581
CSB12/CTD6	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	474
CSB12/CTD7	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	387
CSB12/CTD8	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	175

CSB13/CTG9	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	343
CSB13/CTG10	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	399
CSB13/CTG8	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	291
CSB13/CTG7	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	324
CSB13/CTG6	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	148
CSB13/CTG5	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	310
CSB13/CTG4	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	343
CSB13/CTG3	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	330
CSB14/CTG1	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	420
CSB14/CTG2	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	397
CSB14/CTG3	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	420
CSB14/CTG4	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	445
CSB14/CTG5	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	483
CSB14/CTG6	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	505
CSB14/CTG7	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	531
CSB14/CTG8	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	762
CSB14/CTD1	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	634
CSB14/CTD2	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	590
CSB14/CTD3	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	569
CSB14/CTD4	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	609
CSB14/CTD5	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	576
CSB14/CTD6	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	551
CSB14/CTD7	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	574
CSB14/CTD8	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	295
CSB14/CTD9	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	421
CSB14/CTD10	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	434
CSB14/CTD11	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	356
CSB15/CTD11	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	85
CSB15/CTG14	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	264
CSB15/CTG13	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	59
CSB15/CTD9	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	122
CSB15/CTD10	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	75
CSB15/CTD7	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	132
CSB15/CTD8	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	81
CSB15/CTD6	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	189
CSB15/CTD5	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	266
CSB15/CTD4	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	346
CSB15/CTD3	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	409
CSB15/CTD2	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	402
CSB15/CTD1	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	388
CSB15/CTG1	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	359
CSB15/CTG2	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	343
CSB15/CTG3	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	345
CSB15/CTG4	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	332
CSB15/CTG5	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	280
CSB15/CTG6	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	420
CSB15/CTG7	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	282
CSB15/CTG8	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	152

CSB15/CTG9	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	110
CSB15/CTG10	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	78
CSB15/CTG11	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	95
CSB15/CTG12	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	95
CSB16/CTD14	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	338
CSB16/CTD13	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	134
CSB16/CTD12	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	137
CSB16/CTD11	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	184
CSB16/CTD10	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	257
CSB16/CTD9	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	293
CSB16/CTD8	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	345
CSB16/CTD7	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	368
CSB16/CTD6	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	411
CSB16/CTD5	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	403
CSB16/CTD4	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	423
CSB16/CTD3	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	400
CSB16/CTD2	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	398
CSB16/CTD1	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	407
CSB16/CTG1	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	386
CSB16/CTG2	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	398
CSB16/CTG3	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	414
CSB16/CTG4	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	439
CSB16/CTG5	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	433
CSB16/CTG6	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	429
CSB16/CTG7	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	408
CSB16/CTG8	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	349
CSB16/CTG9	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	364
CSB16/CTG10	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	377
CSB16/CTG11	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	426
CSB16/CTG12	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	406
CSB16/CTG13	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	342
CSB16/CTG14	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	227
CSB17/CTG2	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	336
CSB17/CTG3	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	342
CSB17/CTG4	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	294
CSB17/CTG5	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	196
CSB17/CTG6	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	117
CSB17/CTG7	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	79
CSB17/CTG8	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	72
CSB17/CTG9	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	390
CSB17/CTD8	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	163
CSB17/CTD7	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	153
CSB17/CTD5	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	226
CSB17/CTD6	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	147
CSB17/CTD4	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	301
CSB17/CTD3	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	330
CSB17/CTD2	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	360
CSB17/CTD1	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	432

CSB18/CTG1	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	539
CSB18/CTG2	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	401
CSB18/CTG3	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	313
CSB18/CTG4	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	217
CSB18/CTD1	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	472
CSB18/CTD2	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	428
CSB18/CTD3	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	310
CSB18/CTD4	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	186
CSB18/CTD5	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	56
CSB19/CTG1	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	480
CSB19/CTG2	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	189
CSB19/CTG4	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	230
CSB19/CTG5	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	234
CSB19/CTG6	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	207
CSB20/CTG1	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	386
CSB20/CTG2	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	448
CSB20/CTG3	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	484
CSB20/CTG4	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	529
CSB20/CTG5	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	513
CSB20/CTG6	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	483
CSB20/CTG7	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	433
CSB20/CTG8	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	332
CSB20/CTG10	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	321
CSB20/CTG9	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	325
CSB20/CTG11	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	282
CSB21/CTG1	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	207
CSB21/CTG3	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	274
CSB21/CTG2	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	275
CSB21/CTG4	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	264
CSB21/CTG5	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	667
CSB21/CTG6	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	533
CSB21/CTG7	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	426
CSB21/CTG8	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	409
CSB21/CTG9	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	340
CSB21/CTG10	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	319
CSB21/CTG11	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	396
CSB22a/CTG1	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	553
CSB22a/CTG2	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	481
CSB22a/CTG3	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	542
CSB22a/CTG4	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	398
CSB22a/CTG5	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	470
CSB22a/CTG6	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	444
CSB22a/CTG7	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	343
CSB22a/CTG8	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	339
CSB22a/CTG9	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	318
CSB22a/CTG10	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	319
CSB22b/CTD9	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	366
CSB22b/CTD8	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	455

CSB22b/CTD7	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	459
CSB22b/CTD6	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	466
CSB22b/CTD5	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	460
CSB22b/CTD4	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	472
CSB22b/CTD3	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	483
CSB22b/CTD2	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	483
CSB22b/CTD1	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	489
CSB23/CTG2	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	508
CSB23/CTG3	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	473
CSB23/CTG4	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	515
CSB23/CTG5	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	508
CSB23/CTG6	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	524
CSB23/CTG7	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	523
CSB23/CTG8	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	512
CSB23/CTG9	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	493
CSB23/CTG10	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	486
CSB23/CTG11	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	418
CSB24/CTG1	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	469
CSB24/CTG2	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	389
CSB24/CTG3	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	363
CSB24/CTG4	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	319
CSB24/CTG5	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	295
CSB24/CTG6	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	268
CSB24/CTG7	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	228
CSB24/CTG8	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	177
CSB24/CTG9	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	608
CSB24/CTG10	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	603
CSB24/CTG11	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	513
CSB24/CTG12	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	260
CSB24/CTD14	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	697
CSB24/CTD13	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	190
CSB24/CTD12	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	567
CSB24/CTD11	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	589
CSB24/CTD10	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	597
CSB24/CTD9	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	621
CSB24/CTD8	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	622
CSB24/CTD7	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	368
CSB24/CTD6	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	409
CSB24/CTD5	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	449
CSB24/CTD4	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	482
CSB24/CTD3	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	469
CSB24/CTD2	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	486
CSB24/CTD1	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	552
CSB25/CTD1	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	495
CSB25/CTD2	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	483
CSB25/CTD3	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	436
CSB25/CTD4	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	384
CSB25/CTD5	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	386

CSB25/CTD6	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	321
CSB20/CTD1	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	144
CSK15/CTD1	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	203
CSK15/CTD2	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	185
CSK11/CTG1	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	263
CSK11/CTG2	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	122
CSK12/CTD2	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	312
CSK13/CTG1	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	116
CSK16/CTD5	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	392
CSB6/CTD7	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	64
CSB6/CTD6	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	109
CSB6/CTD5	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	143
CSB6/CTD4	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	159
CSB6/CTD3	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	183
CSB6/CTD2	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	232
CSB6/CTD1	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	301
CSB18/CTG5	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	188
CSB19/CTG3	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	194
CSB19/CTG2	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	174
CSB1/CTG3	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	204
CSB17/CTG1	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	628
CSB23/CTG1	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	834
CSK9/CTG2	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	452
CSK3/CTD4	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	405
CSK12/CTD1	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	257
CSB6/CTG7	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	298
CSK8/CTG4	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	215
CSB9/CTG6	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	438
CSB9/CTG1	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	559
CSB9/CTG12	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	703
CSB8/CTG5	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	411
CSB22b/CTD10	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	446
CSB22b/CTD11	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	534
CSB20/CTD2	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	758
CSB19/CTG7	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	481
CSB18/CTG6	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	427
CSB14/CTD12	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	612
CSB13/CTG2	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	296
CSB13/CTG1	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	248
CSB11/CTD1	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	657
CSB5/CTGD1	UNESCO-IHE/OPIB	27/01/2008	17	GPSMap 60CSx	2287

II.3. Secondary drain names and lengths

ID	FULL_NAME	LENGTH (m)
1	N°1	982
14	N°2a	1000
2	N°2	1790
15	N°2b	1391
16	N°3a	825
17	N°3b	1049
3	N°3	1337
4	N°4	2679
18	N°4a	971
5	N°5	2327
19	N°5a	965
6	N°6	1485
20	N°6a	240
21	N°6b	329
7	N°7	298
8	N°8	592
9	N°9	668
10	N°10	2209
23	N°10b	1516
22	N°10a	1309
24	N°10c	1768
26	N°10e	1333
25	N°10d	2521
11	N°11	2329
27	N°12a	456
12	N°12	2475
28	N°12b	1487
30	N°12d	519
29	N°12c	1332
31	N°13b	2422
32	N°13c	2996
33	N°13d	1586
34	N°13e	1848
35	N°13f	1841
36	N°13g	2433
37	N°13h	2538
39	N°13j	1942
41	N°13l	1656
40	N°13k	2164
38	N°13i	2275
30	N°13a	4202
13	N°13	3274
42	N°1a	405

III.Secondary and tertiary blocks of Baguineda

III.1. Secondary block names, perimeters and areas in Baguineda

Full_Name	Order_Can	Hectares (ha)	Perimeter
CSK1	1	22.73	4458
CSK2	2	10.72	1914
CSK3	3	21.40	5150
CSK4	4	27.77	4927
CSK5	5	41.72	9046
CSK6	6	57.25	9289
CSK7	7	35.12	7323
CSK8	8	103.63	16748
CSK9	9	23.37	3913
CSK10	10	65.98	11560
CSK11	11	5.29	1243
CSK12	12	9.74	2187
CSK13	13	80.74	13490
CSK15	15	27.51	5865
CSK16	16	70.19	14211
CSK17	17	16.75	2899
CSB1	18	20.15	3756
CSB2	19	6.60	2377
CSB3	20	7.94	1998
CSB4	21	111.75	19450
CSB5	22	91.67	4212
CSB6	23	65.34	12426
CSB7	24	108.19	18651
CSB8	25	71.36	11814
CSB9	26	94.94	18590
CSB10	27	8.70	1817
CSB11	28	62.19	11547
CSB12	29	112.74	19254
CSB13	30	79.66	12574
CSB14	31	200.48	31421
CSB15	32	124.61	22980
CSB16	33	200.29	33303
CSB17	34	97.85	17322
CSB18	35	72.50	12618
CSB19	36	39.00	7882
CSB20	37	102.67	18710
CSB21	38	58.63	11831
CSB22a	39	72.87	12781
CSB22b	40	89.04	15816
CSB23	41	90.89	16510
CSB24	42	186.64	33575
CSB25	43	49.78	7766

III.2. Tertiary block names, perimeters and areas in Baguineda

BCLOCK NAME	PERIMETER (m)	AREA (ha)	AGENCY	DATE
CSB1/BTG1	1123	7.68	UNESCO-IHE/OPIB	27/01/2008
CSB1/BTG2	1340	6.85	UNESCO-IHE/OPIB	27/01/2008
CSB1/BTG3	1293	5.62	UNESCO-IHE/OPIB	27/01/2008
CSB10/BTD1	814	3.46	UNESCO-IHE/OPIB	27/01/2008
CSB10/BTG1	1003	5.24	UNESCO-IHE/OPIB	27/01/2008
CSB11/BTD1	2166	11.14	UNESCO-IHE/OPIB	27/01/2008
CSB11/BTD10	718	2.74	UNESCO-IHE/OPIB	27/01/2008
CSB11/BTD11	694	2.95	UNESCO-IHE/OPIB	27/01/2008
CSB11/BTD3	1067	5.65	UNESCO-IHE/OPIB	27/01/2008
CSB11/BTD4	1128	7.27	UNESCO-IHE/OPIB	27/01/2008
CSB11/BTD5	1036	5.40	UNESCO-IHE/OPIB	27/01/2008
CSB11/BTD6	1016	4.62	UNESCO-IHE/OPIB	27/01/2008
CSB11/BTD7	1222	7.80	UNESCO-IHE/OPIB	27/01/2008
CSB11/BTD8	1265	7.69	UNESCO-IHE/OPIB	27/01/2008
CSB11/BTD9	1237	7.05	UNESCO-IHE/OPIB	27/01/2008
CSB12/BTD1	1100	6.97	UNESCO-IHE/OPIB	27/01/2008
CSB12/BTD2	1190	7.23	UNESCO-IHE/OPIB	27/01/2008
CSB12/BTD3	1428	9.81	UNESCO-IHE/OPIB	27/01/2008
CSB12/BTD4	1518	10.41	UNESCO-IHE/OPIB	27/01/2008
CSB12/BTD5	1461	9.46	UNESCO-IHE/OPIB	27/01/2008
CSB12/BTD6	1319	7.61	UNESCO-IHE/OPIB	27/01/2008
CSB12/BTD7	1365	7.25	UNESCO-IHE/OPIB	27/01/2008
CSB12/BTD8	809	3.30	UNESCO-IHE/OPIB	27/01/2008
CSB12/BTG1	667	2.74	UNESCO-IHE/OPIB	27/01/2008
CSB12/BTG2	771	3.43	UNESCO-IHE/OPIB	27/01/2008
CSB12/BTG3	1039	6.30	UNESCO-IHE/OPIB	27/01/2008
CSB12/BTG4	1146	6.95	UNESCO-IHE/OPIB	27/01/2008
CSB12/BTG5	1253	7.46	UNESCO-IHE/OPIB	27/01/2008
CSB12/BTG6	1382	8.53	UNESCO-IHE/OPIB	27/01/2008
CSB12/BTG7	1442	9.01	UNESCO-IHE/OPIB	27/01/2008
CSB12/BTG8	1362	6.31	UNESCO-IHE/OPIB	27/01/2008
CSB13/BTG1	1737	7.96	UNESCO-IHE/OPIB	27/01/2008
CSB13/BTG10	1179	7.95	UNESCO-IHE/OPIB	27/01/2008
CSB13/BTG11	1724	11.68	UNESCO-IHE/OPIB	27/01/2008
CSB13/BTG3	1178	6.97	UNESCO-IHE/OPIB	27/01/2008
CSB13/BTG4	1179	8.23	UNESCO-IHE/OPIB	27/01/2008
CSB13/BTG5	1243	9.02	UNESCO-IHE/OPIB	27/01/2008
CSB13/BTG6	1175	8.10	UNESCO-IHE/OPIB	27/01/2008
CSB13/BTG7	787	3.55	UNESCO-IHE/OPIB	27/01/2008
CSB13/BTG8	1109	7.47	UNESCO-IHE/OPIB	27/01/2008
CSB13/BTG9	1264	8.73	UNESCO-IHE/OPIB	27/01/2008
CSB14/BTD1	1756	12.79	UNESCO-IHE/OPIB	27/01/2008
CSB14/BTD10	1380	10.19	UNESCO-IHE/OPIB	27/01/2008
CSB14/BTD11	1359	10.54	UNESCO-IHE/OPIB	27/01/2008
CSB14/BTD12	1309	10.43	UNESCO-IHE/OPIB	27/01/2008
CSB14/BTD12	1982	11.35	UNESCO-IHE/OPIB	27/01/2008

CSB14/BTD2	1604	8.31	UNESCO-IHE/OPIB	27/01/2008
CSB14/BTD3	1501	6.30	UNESCO-IHE/OPIB	27/01/2008
CSB14/BTD4	1711	13.57	UNESCO-IHE/OPIB	27/01/2008
CSB14/BTD5	1489	8.14	UNESCO-IHE/OPIB	27/01/2008
CSB14/BTD6	1535	9.78	UNESCO-IHE/OPIB	27/01/2008
CSB14/BTD7	1459	9.70	UNESCO-IHE/OPIB	27/01/2008
CSB14/BTD8	2022	10.73	UNESCO-IHE/OPIB	27/01/2008
CSB14/BTG1	1318	7.24	UNESCO-IHE/OPIB	27/01/2008
CSB14/BTG2	1314	7.82	UNESCO-IHE/OPIB	27/01/2008
CSB14/BTG3	1392	9.01	UNESCO-IHE/OPIB	27/01/2008
CSB14/BTG4	1453	9.41	UNESCO-IHE/OPIB	27/01/2008
CSB14/BTG5	1499	9.41	UNESCO-IHE/OPIB	27/01/2008
CSB14/BTG6	1557	9.73	UNESCO-IHE/OPIB	27/01/2008
CSB14/BTG7	1711	14.79	UNESCO-IHE/OPIB	27/01/2008
CSB14/BTG8	2069	11.48	UNESCO-IHE/OPIB	27/01/2008
CSB15/BTD1	1275	8.90	UNESCO-IHE/OPIB	27/01/2008
CSB15/BTD10	641	2.52	UNESCO-IHE/OPIB	27/01/2008
CSB15/BTD11	691	2.73	UNESCO-IHE/OPIB	27/01/2008
CSB15/BTD2	1232	8.11	UNESCO-IHE/OPIB	27/01/2008
CSB15/BTD3	1316	9.91	UNESCO-IHE/OPIB	27/01/2008
CSB15/BTD4	1132	6.77	UNESCO-IHE/OPIB	27/01/2008
CSB15/BTD5	1069	6.87	UNESCO-IHE/OPIB	27/01/2008
CSB15/BTD6	1026	6.38	UNESCO-IHE/OPIB	27/01/2008
CSB15/BTD7	663	2.69	UNESCO-IHE/OPIB	27/01/2008
CSB15/BTD8	653	2.64	UNESCO-IHE/OPIB	27/01/2008
CSB15/BTD9	651	2.63	UNESCO-IHE/OPIB	27/01/2008
CSB15/BTG1	1112	6.69	UNESCO-IHE/OPIB	27/01/2008
CSB15/BTG10	711	2.44	UNESCO-IHE/OPIB	27/01/2008
CSB15/BTG11	718	2.92	UNESCO-IHE/OPIB	27/01/2008
CSB15/BTG12	679	2.71	UNESCO-IHE/OPIB	27/01/2008
CSB15/BTG13	585	1.48	UNESCO-IHE/OPIB	27/01/2008
CSB15/BTG14	746	2.38	UNESCO-IHE/OPIB	27/01/2008
CSB15/BTG2	1160	7.50	UNESCO-IHE/OPIB	27/01/2008
CSB15/BTG3	1174	7.81	UNESCO-IHE/OPIB	27/01/2008
CSB15/BTG4	1037	5.35	UNESCO-IHE/OPIB	27/01/2008
CSB15/BTG5	1106	5.88	UNESCO-IHE/OPIB	27/01/2008
CSB15/BTG6	1099	6.11	UNESCO-IHE/OPIB	27/01/2008
CSB15/BTG7	1067	6.89	UNESCO-IHE/OPIB	27/01/2008
CSB15/BTG8	772	3.59	UNESCO-IHE/OPIB	27/01/2008
CSB15/BTG9	666	2.70	UNESCO-IHE/OPIB	27/01/2008
CSB16/BTD1	1312	8.42	UNESCO-IHE/OPIB	27/01/2008
CSB16/BTD10	981	5.27	UNESCO-IHE/OPIB	27/01/2008
CSB16/BTD11	819	3.95	UNESCO-IHE/OPIB	27/01/2008
CSB16/BTD12	815	3.55	UNESCO-IHE/OPIB	27/01/2008
CSB16/BTD13	527	1.46	UNESCO-IHE/OPIB	27/01/2008
CSB16/BTD14	1294	5.34	UNESCO-IHE/OPIB	27/01/2008
CSB16/BTD2	1257	7.17	UNESCO-IHE/OPIB	27/01/2008
CSB16/BTD3	1279	7.90	UNESCO-IHE/OPIB	27/01/2008

CSB16/BTD4	1340	9.55	UNESCO-IHE/OPIB	27/01/2008
CSB16/BTD5	1280	8.08	UNESCO-IHE/OPIB	27/01/2008
CSB16/BTD6	1273	7.57	UNESCO-IHE/OPIB	27/01/2008
CSB16/BTD7	1181	6.11	UNESCO-IHE/OPIB	27/01/2008
CSB16/BTD8	1125	5.81	UNESCO-IHE/OPIB	27/01/2008
CSB16/BTD9	1026	5.12	UNESCO-IHE/OPIB	27/01/2008
CSB16/BTG1	1356	9.88	UNESCO-IHE/OPIB	27/01/2008
CSB16/BTG10	1376	11.02	UNESCO-IHE/OPIB	27/01/2008
CSB16/BTG11	1259	8.24	UNESCO-IHE/OPIB	27/01/2008
CSB16/BTG12	1238	7.64	UNESCO-IHE/OPIB	27/01/2008
CSB16/BTG13	1154	6.11	UNESCO-IHE/OPIB	27/01/2008
CSB16/BTG14	844	2.41	UNESCO-IHE/OPIB	27/01/2008
CSB16/BTG2	1277	7.33	UNESCO-IHE/OPIB	27/01/2008
CSB16/BTG3	1321	7.62	UNESCO-IHE/OPIB	27/01/2008
CSB16/BTG4	1406	9.73	UNESCO-IHE/OPIB	27/01/2008
CSB16/BTG5	1291	7.25	UNESCO-IHE/OPIB	27/01/2008
CSB16/BTG6	1385	10.08	UNESCO-IHE/OPIB	27/01/2008
CSB16/BTG7	1365	10.24	UNESCO-IHE/OPIB	27/01/2008
CSB16/BTG8	1233	8.02	UNESCO-IHE/OPIB	27/01/2008
CSB16/BTG9	1291	9.46	UNESCO-IHE/OPIB	27/01/2008
CSB17/BTD1	1318	9.60	UNESCO-IHE/OPIB	27/01/2008
CSB17/BTD2	1199	7.61	UNESCO-IHE/OPIB	27/01/2008
CSB17/BTD3	1182	7.94	UNESCO-IHE/OPIB	27/01/2008
CSB17/BTD4	1143	7.92	UNESCO-IHE/OPIB	27/01/2008
CSB17/BTD5	846	4.20	UNESCO-IHE/OPIB	27/01/2008
CSB17/BTD6	763	3.56	UNESCO-IHE/OPIB	27/01/2008
CSB17/BTD7	823	3.84	UNESCO-IHE/OPIB	27/01/2008
CSB17/BTD8	983	6.09	UNESCO-IHE/OPIB	27/01/2008
CSB17/BTG1	1943	9.99	UNESCO-IHE/OPIB	27/01/2008
CSB17/BTG2	1138	6.77	UNESCO-IHE/OPIB	27/01/2008
CSB17/BTG3	1186	8.19	UNESCO-IHE/OPIB	27/01/2008
CSB17/BTG4	1089	7.13	UNESCO-IHE/OPIB	27/01/2008
CSB17/BTG5	820	3.97	UNESCO-IHE/OPIB	27/01/2008
CSB17/BTG6	683	2.81	UNESCO-IHE/OPIB	27/01/2008
CSB17/BTG7	739	3.06	UNESCO-IHE/OPIB	27/01/2008
CSB17/BTG8	613	2.14	UNESCO-IHE/OPIB	27/01/2008
CSB17/BTG9	854	3.05	UNESCO-IHE/OPIB	27/01/2008
CSB18/BTD1	1380	7.93	UNESCO-IHE/OPIB	27/01/2008
CSB18/BTD2	1285	8.32	UNESCO-IHE/OPIB	27/01/2008
CSB18/BTD3	1243	8.76	UNESCO-IHE/OPIB	27/01/2008
CSB18/BTD4	821	3.83	UNESCO-IHE/OPIB	27/01/2008
CSB18/BTD5	684	2.74	UNESCO-IHE/OPIB	27/01/2008
CSB18/BTG1	1426	9.37	UNESCO-IHE/OPIB	27/01/2008
CSB18/BTG2	1293	7.55	UNESCO-IHE/OPIB	27/01/2008
CSB18/BTG3	1223	8.37	UNESCO-IHE/OPIB	27/01/2008
CSB18/BTG4	904	4.56	UNESCO-IHE/OPIB	27/01/2008
CSB18/BTG5	804	3.81	UNESCO-IHE/OPIB	27/01/2008
CSB18/BTG6	1558	7.29	UNESCO-IHE/OPIB	27/01/2008

CSB19/BTG1	1775	7.52	UNESCO-IHE/OPIB	27/01/2008
CSB19/BTG2	753	3.05	UNESCO-IHE/OPIB	27/01/2008
CSB19/BTG3	906	4.86	UNESCO-IHE/OPIB	27/01/2008
CSB19/BTG4	985	5.88	UNESCO-IHE/OPIB	27/01/2008
CSB19/BTG5	976	5.83	UNESCO-IHE/OPIB	27/01/2008
CSB19/BTG6	882	4.60	UNESCO-IHE/OPIB	27/01/2008
CSB19/BTG7	1603	7.30	UNESCO-IHE/OPIB	27/01/2008
CSB2/BTD1	765	1.62	UNESCO-IHE/OPIB	27/01/2008
CSB2/BTD2	1172	3.92	UNESCO-IHE/OPIB	27/01/2008
CSB2/BTG1	440	1.07	UNESCO-IHE/OPIB	27/01/2008
CSB20/BTD1	864	3.98	UNESCO-IHE/OPIB	27/01/2008
CSB20/BTD2	2082	9.67	UNESCO-IHE/OPIB	27/01/2008
CSB20/BTG1	1181	6.05	UNESCO-IHE/OPIB	27/01/2008
CSB20/BTG10	1378	9.62	UNESCO-IHE/OPIB	27/01/2008
CSB20/BTG11	1243	5.68	UNESCO-IHE/OPIB	27/01/2008
CSB20/BTG2	1484	7.73	UNESCO-IHE/OPIB	27/01/2008
CSB20/BTG3	1553	8.21	UNESCO-IHE/OPIB	27/01/2008
CSB20/BTG4	1558	8.22	UNESCO-IHE/OPIB	27/01/2008
CSB20/BTG5	1639	8.06	UNESCO-IHE/OPIB	27/01/2008
CSB20/BTG6	1485	7.99	UNESCO-IHE/OPIB	27/01/2008
CSB20/BTG7	1483	9.51	UNESCO-IHE/OPIB	27/01/2008
CSB20/BTG8	1397	9.08	UNESCO-IHE/OPIB	27/01/2008
CSB20/BTG9	1364	8.90	UNESCO-IHE/OPIB	27/01/2008
CSB21/BTG1	789	3.41	UNESCO-IHE/OPIB	27/01/2008
CSB21/BTG10	1045	3.95	UNESCO-IHE/OPIB	27/01/2008
CSB21/BTG11	1069	5.12	UNESCO-IHE/OPIB	27/01/2008
CSB21/BTG2	891	4.71	UNESCO-IHE/OPIB	27/01/2008
CSB21/BTG3	992	5.47	UNESCO-IHE/OPIB	27/01/2008
CSB21/BTG4	898	4.26	UNESCO-IHE/OPIB	27/01/2008
CSB21/BTG5	1553	7.12	UNESCO-IHE/OPIB	27/01/2008
CSB21/BTG6	1366	7.85	UNESCO-IHE/OPIB	27/01/2008
CSB21/BTG7	1134	5.11	UNESCO-IHE/OPIB	27/01/2008
CSB21/BTG8	962	4.53	UNESCO-IHE/OPIB	27/01/2008
CSB21/BTG9	1133	7.11	UNESCO-IHE/OPIB	27/01/2008
CSB22a/BTG1	1582	11.83	UNESCO-IHE/OPIB	27/01/2008
CSB22a/BTG10	832	3.13	UNESCO-IHE/OPIB	27/01/2008
CSB22a/BTG2	1410	7.83	UNESCO-IHE/OPIB	27/01/2008
CSB22a/BTG3	1370	8.08	UNESCO-IHE/OPIB	27/01/2008
CSB22a/BTG4	1171	4.95	UNESCO-IHE/OPIB	27/01/2008
CSB22a/BTG5	1321	8.59	UNESCO-IHE/OPIB	27/01/2008
CSB22a/BTG6	1274	8.14	UNESCO-IHE/OPIB	27/01/2008
CSB22a/BTG7	1196	7.80	UNESCO-IHE/OPIB	27/01/2008
CSB22a/BTG8	1151	6.92	UNESCO-IHE/OPIB	27/01/2008
CSB22a/BTG9	1474	5.61	UNESCO-IHE/OPIB	27/01/2008
CSB22b/BTD1	1431	7.21	UNESCO-IHE/OPIB	27/01/2008
CSB22b/BTD10	1551	7.27	UNESCO-IHE/OPIB	27/01/2008
CSB22b/BTD11	1604	8.07	UNESCO-IHE/OPIB	27/01/2008
CSB22b/BTD2	1520	8.95	UNESCO-IHE/OPIB	27/01/2008

CSB22b/BTD3	1487	7.95	UNESCO-IHE/OPIB	27/01/2008
CSB22b/BTD4	1505	8.63	UNESCO-IHE/OPIB	27/01/2008
CSB22b/BTD5	1496	8.10	UNESCO-IHE/OPIB	27/01/2008
CSB22b/BTD6	1469	7.93	UNESCO-IHE/OPIB	27/01/2008
CSB22b/BTD7	1487	8.41	UNESCO-IHE/OPIB	27/01/2008
CSB22b/BTD8	1398	8.41	UNESCO-IHE/OPIB	27/01/2008
CSB22b/BTD9	1286	8.12	UNESCO-IHE/OPIB	27/01/2008
CSB23/BTG1	2336	11.53	UNESCO-IHE/OPIB	27/01/2008
CSB23/BTG10	1418	9.37	UNESCO-IHE/OPIB	27/01/2008
CSB23/BTG11	1350	8.05	UNESCO-IHE/OPIB	27/01/2008
CSB23/BTG2	1477	8.17	UNESCO-IHE/OPIB	27/01/2008
CSB23/BTG3	1399	5.76	UNESCO-IHE/OPIB	27/01/2008
CSB23/BTG4	1440	7.44	UNESCO-IHE/OPIB	27/01/2008
CSB23/BTG5	1452	8.32	UNESCO-IHE/OPIB	27/01/2008
CSB23/BTG6	1433	8.15	UNESCO-IHE/OPIB	27/01/2008
CSB23/BTG7	1438	8.59	UNESCO-IHE/OPIB	27/01/2008
CSB23/BTG8	1428	8.66	UNESCO-IHE/OPIB	27/01/2008
CSB23/BTG9	1339	6.86	UNESCO-IHE/OPIB	27/01/2008
CSB24/BTD1	1386	7.86	UNESCO-IHE/OPIB	27/01/2008
CSB24/BTD10	1573	7.34	UNESCO-IHE/OPIB	27/01/2008
CSB24/BTD11	1576	8.30	UNESCO-IHE/OPIB	27/01/2008
CSB24/BTD12	1512	7.74	UNESCO-IHE/OPIB	27/01/2008
CSB24/BTD13	1156	7.86	UNESCO-IHE/OPIB	27/01/2008
CSB24/BTD14	967	5.37	UNESCO-IHE/OPIB	27/01/2008
CSB24/BTD2	1378	8.26	UNESCO-IHE/OPIB	27/01/2008
CSB24/BTD3	1281	7.02	UNESCO-IHE/OPIB	27/01/2008
CSB24/BTD4	1261	7.22	UNESCO-IHE/OPIB	27/01/2008
CSB24/BTD5	1239	7.54	UNESCO-IHE/OPIB	27/01/2008
CSB24/BTD6	1281	8.34	UNESCO-IHE/OPIB	27/01/2008
CSB24/BTD7	1132	6.51	UNESCO-IHE/OPIB	27/01/2008
CSB24/BTD8	1644	7.56	UNESCO-IHE/OPIB	27/01/2008
CSB24/BTD9	1643	8.39	UNESCO-IHE/OPIB	27/01/2008
CSB24/BTG1	1335	8.17	UNESCO-IHE/OPIB	27/01/2008
CSB24/BTG10	1556	8.08	UNESCO-IHE/OPIB	27/01/2008
CSB24/BTG11	1492	7.39	UNESCO-IHE/OPIB	27/01/2008
CSB24/BTG12	1205	6.05	UNESCO-IHE/OPIB	27/01/2008
CSB24/BTG2	1259	7.35	UNESCO-IHE/OPIB	27/01/2008
CSB24/BTG3	1202	7.16	UNESCO-IHE/OPIB	27/01/2008
CSB24/BTG4	1188	7.74	UNESCO-IHE/OPIB	27/01/2008
CSB24/BTG5	1128	7.14	UNESCO-IHE/OPIB	27/01/2008
CSB24/BTG6	1019	6.09	UNESCO-IHE/OPIB	27/01/2008
CSB24/BTG7	880	4.47	UNESCO-IHE/OPIB	27/01/2008
CSB24/BTG8	742	2.82	UNESCO-IHE/OPIB	27/01/2008
CSB24/BTG9	1545	8.90	UNESCO-IHE/OPIB	27/01/2008
CSB25/BTD1	1467	9.31	UNESCO-IHE/OPIB	27/01/2008
CSB25/BTD2	1357	8.26	UNESCO-IHE/OPIB	27/01/2008
CSB25/BTD3	1256	7.65	UNESCO-IHE/OPIB	27/01/2008
CSB25/BTD4	1231	7.77	UNESCO-IHE/OPIB	27/01/2008

CSB25/BTD5	1308	10.00	UNESCO-IHE/OPIB	27/01/2008
CSB25/BTD6	1146	7.16	UNESCO-IHE/OPIB	27/01/2008
CSB3/BTD1	592	2.14	UNESCO-IHE/OPIB	27/01/2008
CSB3/BTD2	652	2.48	UNESCO-IHE/OPIB	27/01/2008
CSB3/BTG1	754	3.32	UNESCO-IHE/OPIB	27/01/2008
CSB4/BTD1	766	3.46	UNESCO-IHE/OPIB	27/01/2008
CSB4/BTD10	1534	7.83	UNESCO-IHE/OPIB	27/01/2008
CSB4/BTD11	1536	9.83	UNESCO-IHE/OPIB	27/01/2008
CSB4/BTD12	1604	10.50	UNESCO-IHE/OPIB	27/01/2008
CSB4/BTD2	697	3.03	UNESCO-IHE/OPIB	27/01/2008
CSB4/BTD3	772	3.72	UNESCO-IHE/OPIB	27/01/2008
CSB4/BTD4	974	5.57	UNESCO-IHE/OPIB	27/01/2008
CSB4/BTD5	1261	9.05	UNESCO-IHE/OPIB	27/01/2008
CSB4/BTD6	1656	6.96	UNESCO-IHE/OPIB	27/01/2008
CSB4/BTD7	1179	6.86	UNESCO-IHE/OPIB	27/01/2008
CSB4/BTD8	1374	7.80	UNESCO-IHE/OPIB	27/01/2008
CSB4/BTD9	1496	7.42	UNESCO-IHE/OPIB	27/01/2008
CSB4/BTG1	1185	8.22	UNESCO-IHE/OPIB	27/01/2008
CSB4/BTG2	1184	7.94	UNESCO-IHE/OPIB	27/01/2008
CSB4/BTG3	1181	7.75	UNESCO-IHE/OPIB	27/01/2008
CSB4/BTG4	1050	5.92	UNESCO-IHE/OPIB	27/01/2008
CSB5/BTGD1	4212	91.67	UNESCO-IHE/OPIB	27/01/2008
CSB6/BTD1	1067	5.93	UNESCO-IHE/OPIB	27/01/2008
CSB6/BTD2	983	5.91	UNESCO-IHE/OPIB	27/01/2008
CSB6/BTD3	778	3.58	UNESCO-IHE/OPIB	27/01/2008
CSB6/BTD4	765	3.54	UNESCO-IHE/OPIB	27/01/2008
CSB6/BTD5	819	4.11	UNESCO-IHE/OPIB	27/01/2008
CSB6/BTD6	701	2.96	UNESCO-IHE/OPIB	27/01/2008
CSB6/BTD7	696	2.66	UNESCO-IHE/OPIB	27/01/2008
CSB6/BTG1	1118	7.14	UNESCO-IHE/OPIB	27/01/2008
CSB6/BTG2	1076	6.58	UNESCO-IHE/OPIB	27/01/2008
CSB6/BTG3	1024	6.13	UNESCO-IHE/OPIB	27/01/2008
CSB6/BTG4	792	3.59	UNESCO-IHE/OPIB	27/01/2008
CSB6/BTG5	767	3.29	UNESCO-IHE/OPIB	27/01/2008
CSB6/BTG6	837	4.06	UNESCO-IHE/OPIB	27/01/2008
CSB6/BTG7	1005	5.96	UNESCO-IHE/OPIB	27/01/2008
CSB7/BTD1	1126	4.29	UNESCO-IHE/OPIB	27/01/2008
CSB7/BTD2	1219	7.43	UNESCO-IHE/OPIB	27/01/2008
CSB7/BTD3	1160	7.25	UNESCO-IHE/OPIB	27/01/2008
CSB7/BTD4	1117	7.16	UNESCO-IHE/OPIB	27/01/2008
CSB7/BTD5	1105	7.18	UNESCO-IHE/OPIB	27/01/2008
CSB7/BTD6	1101	7.21	UNESCO-IHE/OPIB	27/01/2008
CSB7/BTD7	909	4.27	UNESCO-IHE/OPIB	27/01/2008
CSB7/BTD8	850	3.98	UNESCO-IHE/OPIB	27/01/2008
CSB7/BTD9	793	2.90	UNESCO-IHE/OPIB	27/01/2008
CSB7/BTG1	1276	8.51	UNESCO-IHE/OPIB	27/01/2008
CSB7/BTG2	1147	6.28	UNESCO-IHE/OPIB	27/01/2008
CSB7/BTG3	1157	6.75	UNESCO-IHE/OPIB	27/01/2008

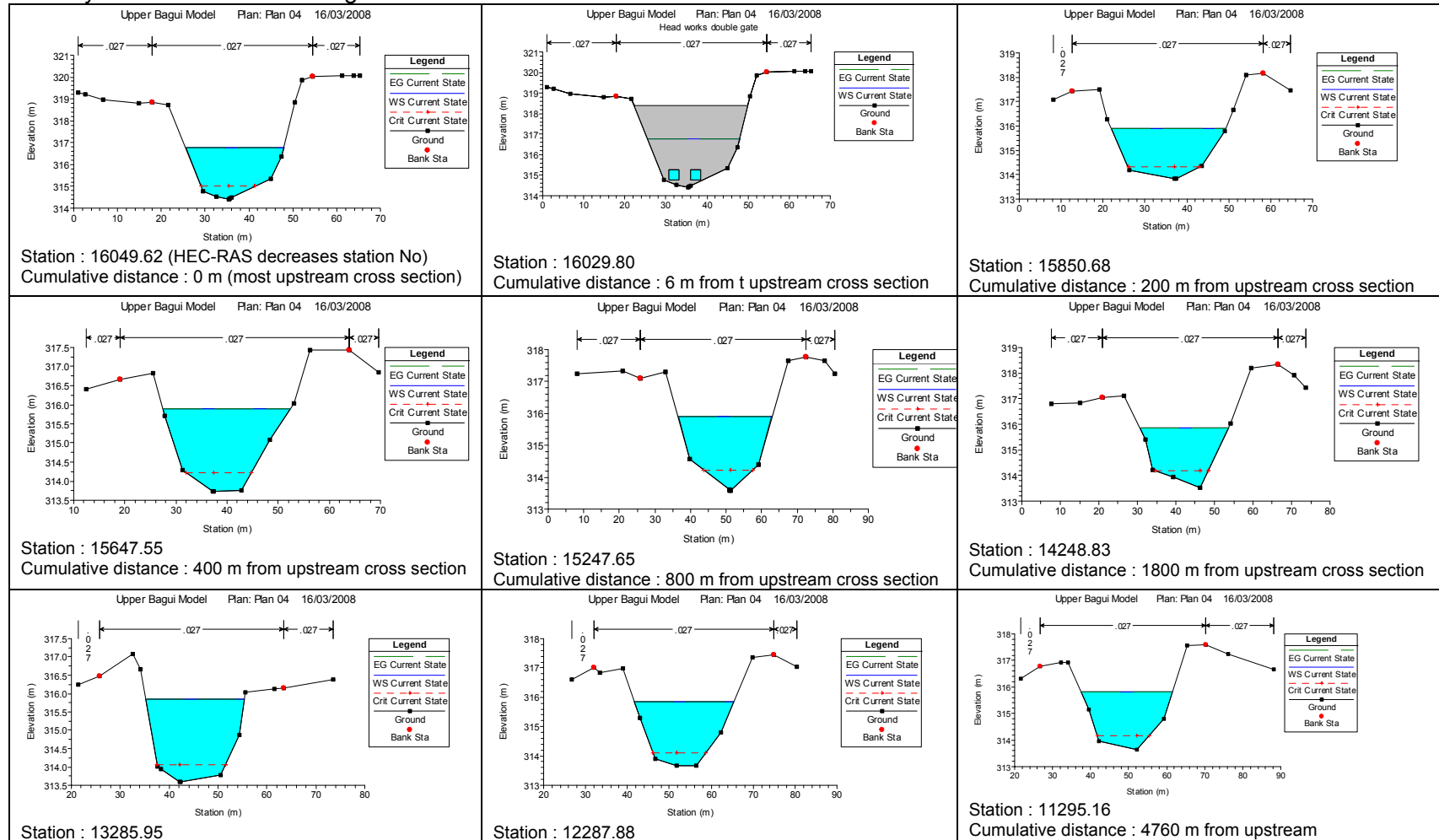
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CSB7/BTG6	1108	6.65	UNESCO-IHE/OPIB	27/01/2008
CSB7/BTG7	1066	6.21	UNESCO-IHE/OPIB	27/01/2008
CSB7/BTG8	1242	8.67	UNESCO-IHE/OPIB	27/01/2008
CSB8/BTD1	1335	9.77	UNESCO-IHE/OPIB	27/01/2008
CSB8/BTD2	1224	7.18	UNESCO-IHE/OPIB	27/01/2008
CSB8/BTD3	1176	6.93	UNESCO-IHE/OPIB	27/01/2008
CSB8/BTD4	1148	7.22	UNESCO-IHE/OPIB	27/01/2008
CSB8/BTD5	994	6.12	UNESCO-IHE/OPIB	27/01/2008
CSB8/BTG1	901	4.28	UNESCO-IHE/OPIB	27/01/2008
CSB8/BTG2	1048	6.74	UNESCO-IHE/OPIB	27/01/2008
CSB8/BTG3	1074	7.17	UNESCO-IHE/OPIB	27/01/2008
CSB8/BTG4	1093	7.40	UNESCO-IHE/OPIB	27/01/2008
CSB8/BTG5	1821	8.71	UNESCO-IHE/OPIB	27/01/2008
CSB9/BTD1	879	4.69	UNESCO-IHE/OPIB	27/01/2008
CSB9/BTD2	951	4.56	UNESCO-IHE/OPIB	27/01/2008
CSB9/BTG1	2006	10.99	UNESCO-IHE/OPIB	27/01/2008
CSB9/BTG10	1455	7.03	UNESCO-IHE/OPIB	27/01/2008
CSB9/BTG12	2035	11.79	UNESCO-IHE/OPIB	27/01/2008
CSB9/BTG13	1437	8.87	UNESCO-IHE/OPIB	27/01/2008
CSB9/BTG2	915	4.02	UNESCO-IHE/OPIB	27/01/2008
CSB9/BTG3	912	4.44	UNESCO-IHE/OPIB	27/01/2008
CSB9/BTG4	943	3.96	UNESCO-IHE/OPIB	27/01/2008
CSB9/BTG5	983	5.62	UNESCO-IHE/OPIB	27/01/2008
CSB9/BTG6	2178	8.25	UNESCO-IHE/OPIB	27/01/2008
CSB9/BTG7	1196	7.23	UNESCO-IHE/OPIB	27/01/2008
CSB9/BTG8	1326	7.47	UNESCO-IHE/OPIB	27/01/2008
CSB9/BTG9	1375	6.03	UNESCO-IHE/OPIB	27/01/2008
CSK1/BTG1	906	5.11	UNESCO-IHE/OPIB	27/01/2008
CSK1/BTG2	629	2.43	UNESCO-IHE/OPIB	27/01/2008
CSK1/BTG3	1182	6.01	UNESCO-IHE/OPIB	27/01/2008
CSK1/BTG4	878	4.71	UNESCO-IHE/OPIB	27/01/2008
CSK1/BTG5	864	4.48	UNESCO-IHE/OPIB	27/01/2008
CSK10/BTG1	1066	4.83	UNESCO-IHE/OPIB	27/01/2008
CSK10/BTG2	1023	3.40	UNESCO-IHE/OPIB	27/01/2008
CSK10/BTG3	1182	5.66	UNESCO-IHE/OPIB	27/01/2008
CSK10/BTG4	1610	11.97	UNESCO-IHE/OPIB	27/01/2008
CSK10/BTG5	946	4.53	UNESCO-IHE/OPIB	27/01/2008
CSK10/BTG6	1334	9.08	UNESCO-IHE/OPIB	27/01/2008
CSK10/BTG7	1517	9.57	UNESCO-IHE/OPIB	27/01/2008
CSK10/BTG8	1694	10.56	UNESCO-IHE/OPIB	27/01/2008
CSK10/BTG9	1187	6.38	UNESCO-IHE/OPIB	27/01/2008
CSK11/BTG1	848	4.34	UNESCO-IHE/OPIB	27/01/2008
CSK11/BTG2	395	0.95	UNESCO-IHE/OPIB	27/01/2008
CSK12/BTD1	968	4.47	UNESCO-IHE/OPIB	27/01/2008
CSK12/BTD2	1219	5.27	UNESCO-IHE/OPIB	27/01/2008
CSK13/BTD1	1257	5.98	UNESCO-IHE/OPIB	27/01/2008

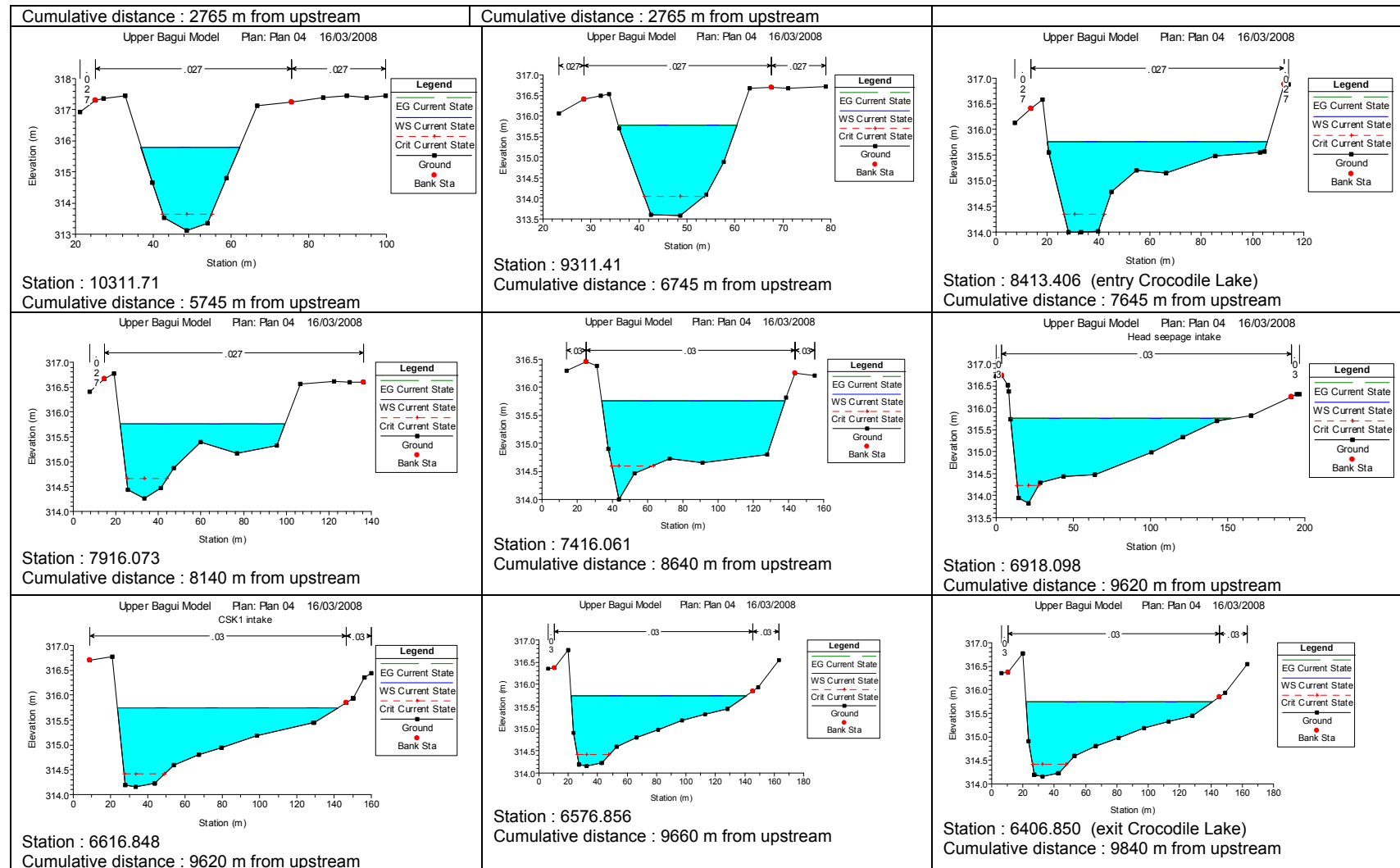
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CSK13/BTD2	1139	6.01	UNESCO-IHE/OPIB	27/01/2008
CSK13/BTD3	1304	8.20	UNESCO-IHE/OPIB	27/01/2008
CSK13/BTD4	1385	8.54	UNESCO-IHE/OPIB	27/01/2008
CSK13/BTD5	1315	8.22	UNESCO-IHE/OPIB	27/01/2008
CSK13/BTD6	1450	9.19	UNESCO-IHE/OPIB	27/01/2008
CSK13/BTD7	1344	7.20	UNESCO-IHE/OPIB	27/01/2008
CSK13/BTD8	1254	8.62	UNESCO-IHE/OPIB	27/01/2008
CSK13/BTD9	1183	8.37	UNESCO-IHE/OPIB	27/01/2008
CSK13/BTG1	589	2.05	UNESCO-IHE/OPIB	27/01/2008
CSK15/BTD1	815	3.84	UNESCO-IHE/OPIB	27/01/2008
CSK15/BTD2	883	4.85	UNESCO-IHE/OPIB	27/01/2008
CSK15/BTD3	1021	5.56	UNESCO-IHE/OPIB	27/01/2008
CSK15/BTD4	1045	4.54	UNESCO-IHE/OPIB	27/01/2008
CSK15/BTG1	657	2.65	UNESCO-IHE/OPIB	27/01/2008
CSK15/BTG2	554	1.77	UNESCO-IHE/OPIB	27/01/2008
CSK15/BTG3	889	4.30	UNESCO-IHE/OPIB	27/01/2008
CSK16/BTD1	729	3.14	UNESCO-IHE/OPIB	27/01/2008
CSK16/BTD2	647	2.47	UNESCO-IHE/OPIB	27/01/2008
CSK16/BTD3	1547	6.45	UNESCO-IHE/OPIB	27/01/2008
CSK16/BTD4	1307	7.79	UNESCO-IHE/OPIB	27/01/2008
CSK16/BTD5	1352	7.79	UNESCO-IHE/OPIB	27/01/2008
CSK16/BTD6	2321	11.45	UNESCO-IHE/OPIB	27/01/2008
CSK16/BTG1	774	3.17	UNESCO-IHE/OPIB	27/01/2008
CSK16/BTG2	897	4.61	UNESCO-IHE/OPIB	27/01/2008
CSK16/BTG3	866	3.86	UNESCO-IHE/OPIB	27/01/2008
CSK16/BTG4	893	4.07	UNESCO-IHE/OPIB	27/01/2008
CSK16/BTG5	918	4.32	UNESCO-IHE/OPIB	27/01/2008
CSK16/BTG6	911	4.15	UNESCO-IHE/OPIB	27/01/2008
CSK16/BTG7	1049	6.96	UNESCO-IHE/OPIB	27/01/2008
CSK17/BTG1	923	5.30	UNESCO-IHE/OPIB	27/01/2008
CSK17/BTG2	875	4.64	UNESCO-IHE/OPIB	27/01/2008
CSK17/BTG3	1101	6.82	UNESCO-IHE/OPIB	27/01/2008
CSK2/BTG1	865	4.64	UNESCO-IHE/OPIB	27/01/2008
CSK2/BTG2	1049	6.09	UNESCO-IHE/OPIB	27/01/2008
CSK3/BTD1	638	2.45	UNESCO-IHE/OPIB	27/01/2008
CSK3/BTD2	653	2.56	UNESCO-IHE/OPIB	27/01/2008
CSK3/BTD3	1088	4.02	UNESCO-IHE/OPIB	27/01/2008
CSK3/BTD4	1791	7.37	UNESCO-IHE/OPIB	27/01/2008
CSK3/BTG1	979	5.01	UNESCO-IHE/OPIB	27/01/2008
CSK4/BTD1	1084	6.82	UNESCO-IHE/OPIB	27/01/2008
CSK4/BTD2	983	5.55	UNESCO-IHE/OPIB	27/01/2008
CSK4/BTD3	912	4.93	UNESCO-IHE/OPIB	27/01/2008
CSK4/BTG1	1020	6.02	UNESCO-IHE/OPIB	27/01/2008
CSK4/BTG2	928	4.45	UNESCO-IHE/OPIB	27/01/2008
CSK5/BTD1	749	3.38	UNESCO-IHE/OPIB	27/01/2008
CSK5/BTD2	860	4.46	UNESCO-IHE/OPIB	27/01/2008
CSK5/BTD3	785	3.44	UNESCO-IHE/OPIB	27/01/2008

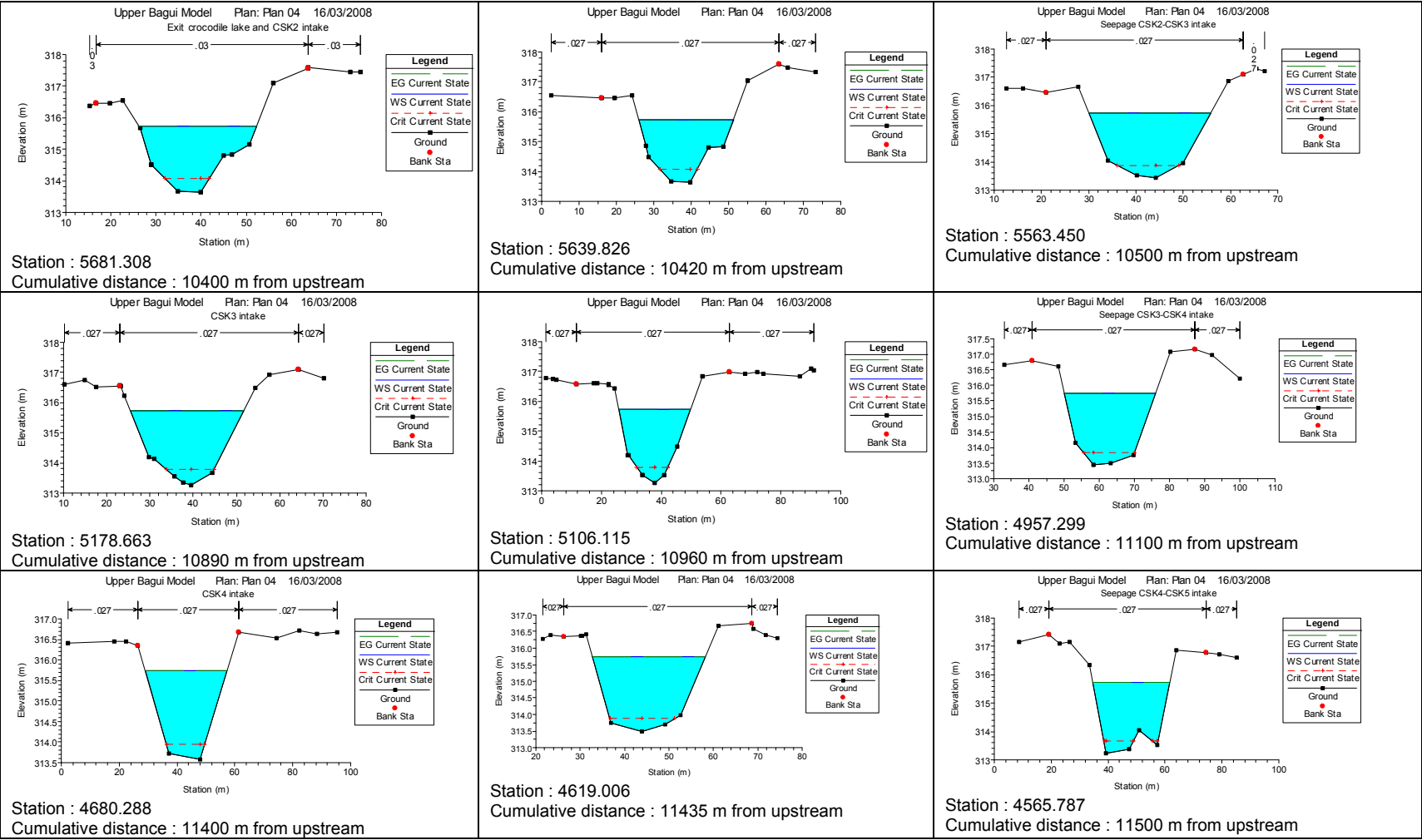
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CSK5/BTG2	843	4.31	UNESCO-IHE/OPIB	27/01/2008
CSK5/BTG3	776	3.57	UNESCO-IHE/OPIB	27/01/2008
CSK5/BTG4	792	3.90	UNESCO-IHE/OPIB	27/01/2008
CSK5/BTG5	2604	10.64	UNESCO-IHE/OPIB	27/01/2008
CSK6/BTD1	1202	7.24	UNESCO-IHE/OPIB	27/01/2008
CSK6/BTD2	1166	6.84	UNESCO-IHE/OPIB	27/01/2008
CSK6/BTD3	1296	8.26	UNESCO-IHE/OPIB	27/01/2008
CSK6/BTG1	1105	7.06	UNESCO-IHE/OPIB	27/01/2008
CSK6/BTG2	1133	7.80	UNESCO-IHE/OPIB	27/01/2008
CSK6/BTG3	1071	5.88	UNESCO-IHE/OPIB	27/01/2008
CSK6/BTG4	1222	7.93	UNESCO-IHE/OPIB	27/01/2008
CSK6/BTG5	1094	6.85	UNESCO-IHE/OPIB	27/01/2008
CSK7/BTD1	1313	9.64	UNESCO-IHE/OPIB	27/01/2008
CSK7/BTD2	666	2.75	UNESCO-IHE/OPIB	27/01/2008
CSK7/BTD3	691	2.96	UNESCO-IHE/OPIB	27/01/2008
CSK7/BTD4	712	2.66	UNESCO-IHE/OPIB	27/01/2008
CSK7/BTG1	945	5.08	UNESCO-IHE/OPIB	27/01/2008
CSK7/BTG2	884	3.97	UNESCO-IHE/OPIB	27/01/2008
CSK7/BTG3	706	2.97	UNESCO-IHE/OPIB	27/01/2008
CSK7/BTG4	713	3.02	UNESCO-IHE/OPIB	27/01/2008
CSK7/BTG5	694	2.24	UNESCO-IHE/OPIB	27/01/2008
CSK8/BTD1	1367	8.77	UNESCO-IHE/OPIB	27/01/2008
CSK8/BTD2	1448	8.44	UNESCO-IHE/OPIB	27/01/2008
CSK8/BTD3	1247	7.93	UNESCO-IHE/OPIB	27/01/2008
CSK8/BTD4	1230	6.42	UNESCO-IHE/OPIB	27/01/2008
CSK8/BTD5	1414	9.19	UNESCO-IHE/OPIB	27/01/2008
CSK8/BTD6	1367	8.42	UNESCO-IHE/OPIB	27/01/2008
CSK8/BTD7	1301	7.72	UNESCO-IHE/OPIB	27/01/2008
CSK8/BTD8	1294	8.31	UNESCO-IHE/OPIB	27/01/2008
CSK8/BTG1	1061	6.99	UNESCO-IHE/OPIB	27/01/2008
CSK8/BTG2	1396	9.31	UNESCO-IHE/OPIB	27/01/2008
CSK8/BTG3	1214	5.98	UNESCO-IHE/OPIB	27/01/2008
CSK8/BTG4	1162	7.50	UNESCO-IHE/OPIB	27/01/2008
CSK8/BTG5	1247	8.66	UNESCO-IHE/OPIB	27/01/2008
CSK9/BTD1	1036	5.69	UNESCO-IHE/OPIB	27/01/2008
CSK9/BTG1	1090	7.34	UNESCO-IHE/OPIB	27/01/2008
CSK9/BTG2	1787	10.34	UNESCO-IHE/OPIB	27/01/2008

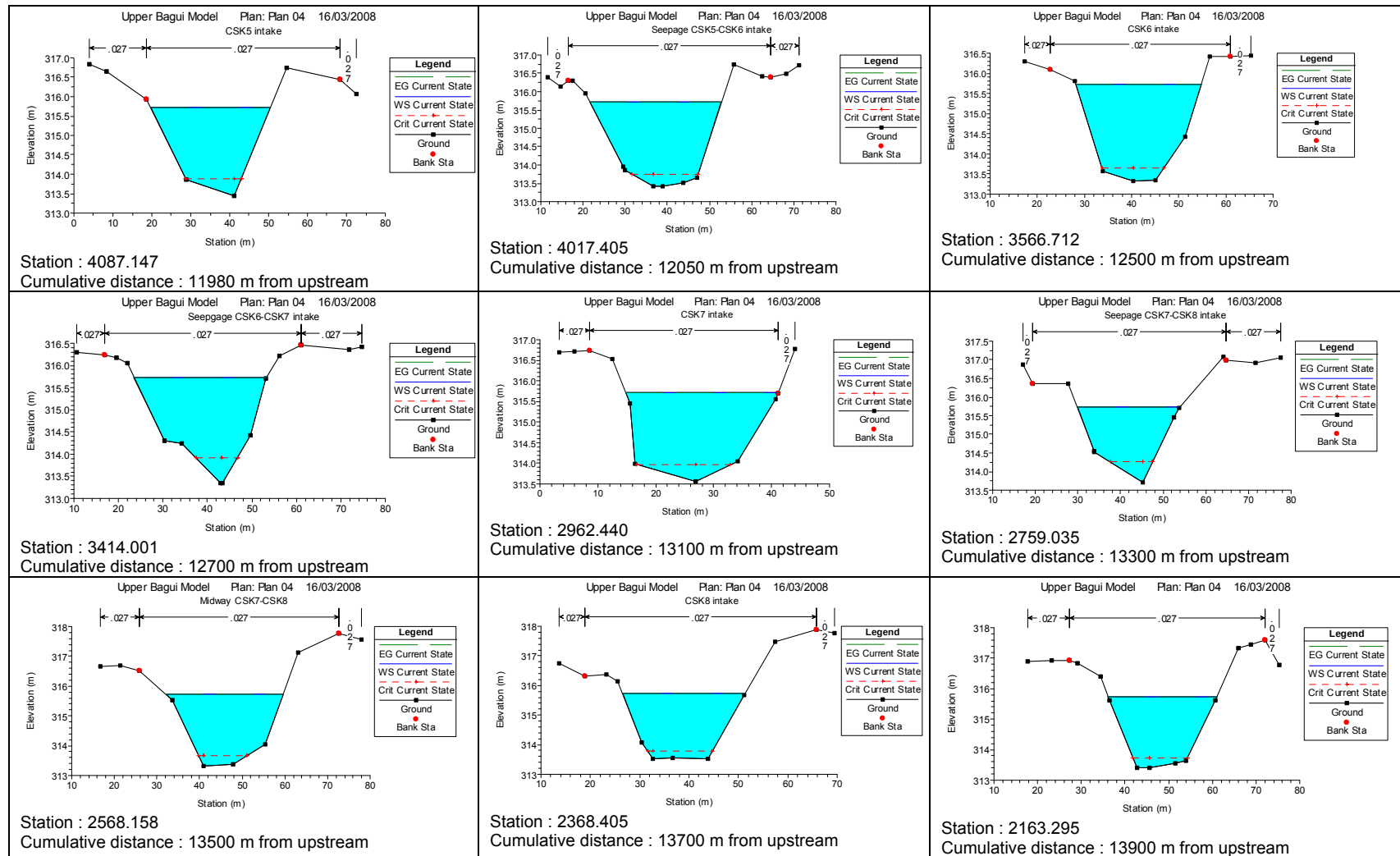
IV. Main canal cross sections

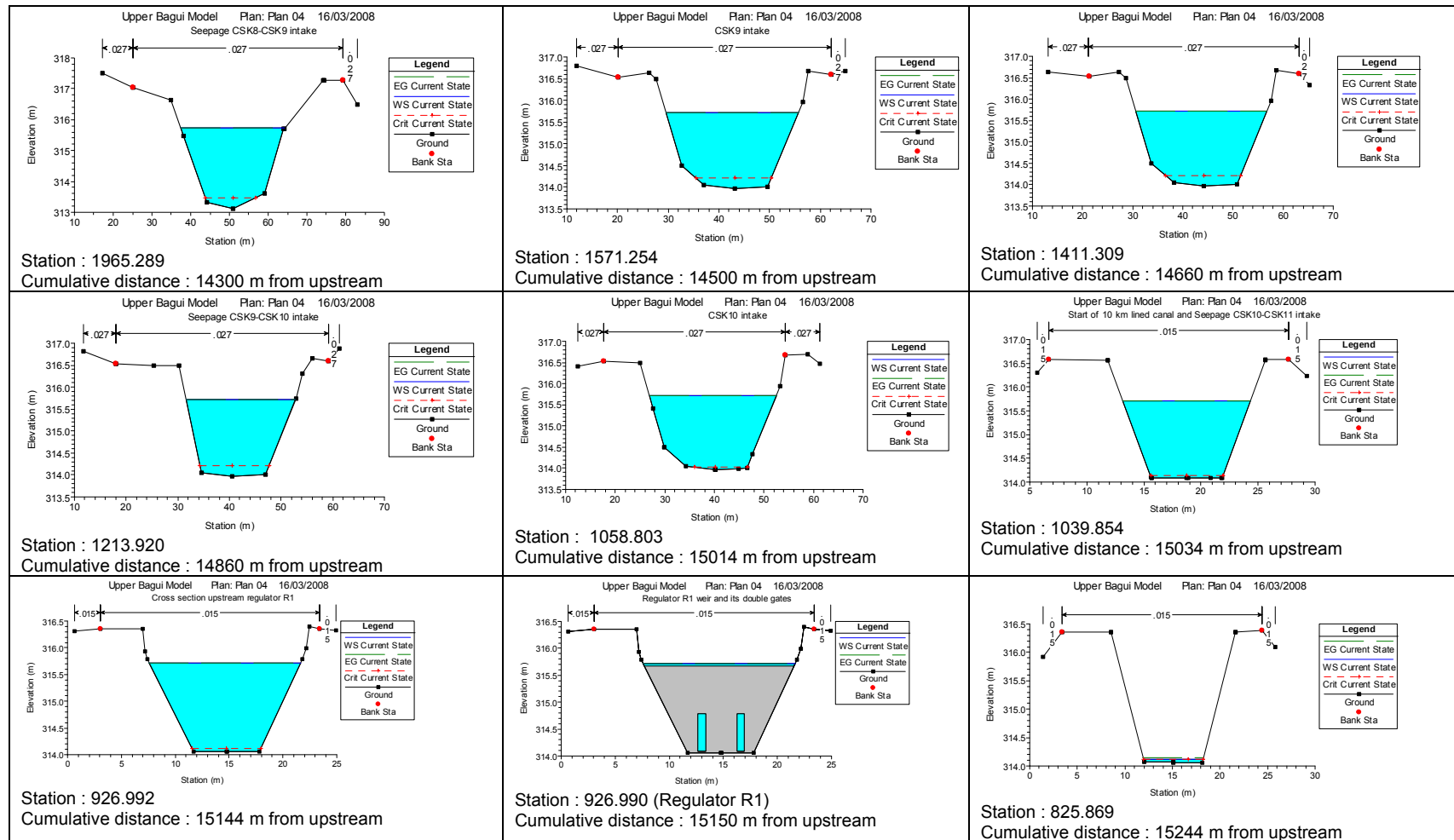
Surveyed cross sections of Baguineda Main Canal. Area modeled from headwork to downstream CSK11

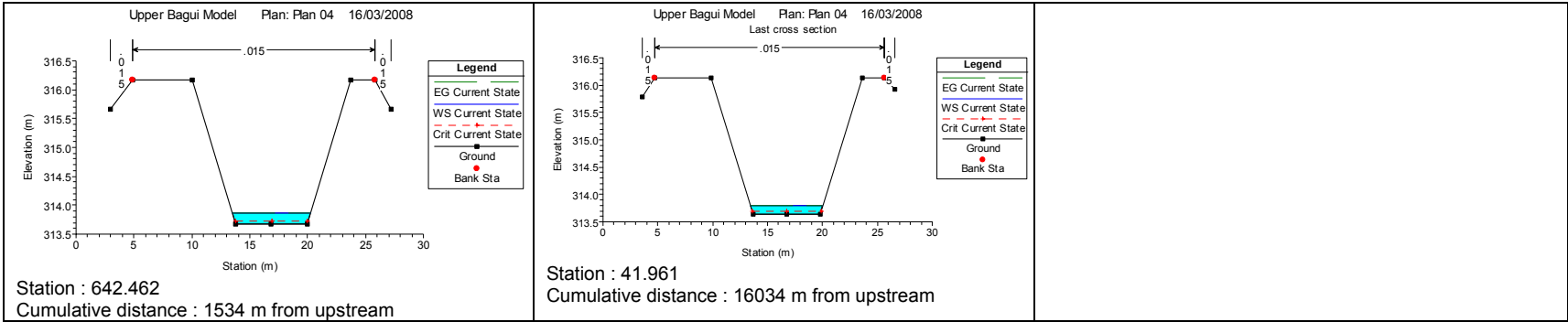












V. Flow characteristics results from HEC-RAS simulation

V.1. Flow change and locations from headwork to CSK11 intake

Table 29: Flow change values and locations from head gate to regulator R1

HEC-RAS Cross Section Station	Cumul distance (m)	Partial distance (m)	Designation	Current scen seepage rate (m ³ /s/km)	Discharge from cross section to downstream (m ³ /s)	Modern scen seepage rate (m ³ /s/km)	Discharge from cross section to downstream (m ³ /s)
16049.6288	0		Headwork Gate at station 16029.80	0.22	8.14	0.10	9.50
8413.4065	7645	900	Entry of crocodile lake at station 8115.00				
6918.0982	9140	500	Head seepage intake (m ³ /s)	2.12	6.02	0.96	8.54
6616.8483	9620	480	CSK1 intake (m ³ /s)	0.06	5.96	0.06	8.48
6406.8504	9840	180	Seepage CSK1-2 intake (m ³ /s)	0.17	5.79	0.08	8.40
5681.3082	10400	560	Exit of crocodile lake/ CSK2 intake	0.08	5.72	0.08	8.32
5563.4504	10500	80	Seepage CSK2-3 intake	0.11	5.61	0.05	8.27
5178.6631	10890	390	CSK3 intake (m ³ /s)	0.06	5.55	0.06	8.22
4957.2991	11100	140	Seepage CSK3-4 intake	0.11	5.44	0.05	8.17
4680.2889	11400	300	CSK4 intake (m ³ /s)	0.08	5.36	0.08	8.09
4565.7869	11500	65	Seepage CSK4-5 intake	0.13	5.23	0.06	8.03
4087.1472	11980	480	CSK5 intake (m ³ /s)	0.10	5.13	0.10	7.92
4017.4053	12050	70	Seepage CSK5-6 intake	0.11	5.01	0.05	7.87
3566.7123	12500	450	CSK6 intake (m ³ /s)	0.18	4.83	0.18	7.69

HEC-RAS Cross Section Station	Cumul distance (m)	Partial distance (m)	Designation	Current scen seepage rate (m ³ /s/km)	Discharge from cross section to downstream (m ³ /s)	Modern scen seepage rate (m ³ /s/km)	Discharge from cross section to downstream (m ³ /s)
3414.0018	12700	200	Seepage CSK6-7 intake	0.13	4.70	0.06	7.63
2962.4402	13100	400	CSK7 intake (m ³ /s)	0.18	4.52	0.18	7.45
2759.0350	13300	200	Seepage CSK7-8 intake	0.13	4.39	0.06	7.39
2568.1586	13500	200					
2368.4056	13700	200	CSK8 intake (m ³ /s)	0.25	4.14	0.25	7.14
2163.2955	13900	200					
1965.2896	14300	400	Seepage CSK8-9 intake	0.18	3.96	0.08	7.06
1571.2549	14500	200	CSK9 intake (m ³ /s)	0.06	3.90	0.06	7.00
1213.9208	14860	200	Seepage CSK9-10 intake	0.11	3.78	0.05	6.95
1058.8038	15014	154	CSK10 intake(m ³ /s)	0.14	3.65	0.14	6.81
1039.8543	15034	20	Seepage CSK10-11 intake	0.03	3.62	0.01	6.80
926.9924	15144	110	CSK11 intake(m ³ /s)	0.04	3.58	0.04	6.76
825.8694	15244	100	Regulator R1 weir and gate at station 926.990				
41.9611	16034	500	End of Modeled part				
	Average	364	Total CSK intakes (m ³ /s)	1.22		1.22	
			Total seepage (m ³ /s)	3.33		1.51	
Total area upstream R1 in ha					415.0		415.0
Specific discharge available for the blocks upstream R1 : q(l/s/ha)					2.9		2.9
Total area (available and possible) downstream R1 in ha					4657.9		2200.0
Specific discharge available for the blocks downstream R1 : q(l/s/ha)					0.8		3.1

V.2. Current scenario discharges and water levels

HEC-RAS Plan 13 River: Upper_Baguineda Reach: HGate-CSK11 Profile: *Water level in current scenario of not lined canal (Manning 0,015; 0.020 and 0.030; see page 0.22 m³/km). Gates of R1 closed.*

River Sta	Profile	Q Total (m ³ /s)	Min Ch El (m)	W.S. Elev (m)	Crit W.S. (m)	E.G. Elev (m)	E.G. Slope (m/m)	Vel Chnl (m/s)	Flow Area (m ²)	Top Width (m)	Froude # Chl
16049.62	Current Scenario	8.00	314.42	316.72	315.00	316.73	0.000020	0.22	36.15	22.24	0.06
16029.8		Inl Struct									
16029.7*	Current Scenario	8.00	314.36	316.08	314.93	316.09	0.000068	0.33	23.89	20.33	0.10
16009.8*	Current Scenario	8.00	314.30	316.08	314.87	316.09	0.000059	0.32	25.25	20.93	0.09
15989.9*	Current Scenario	8.00	314.24	316.08	314.80	316.09	0.000051	0.30	26.77	21.67	0.09
15970.0*	Current Scenario	8.00	314.18	316.08	314.74	316.09	0.000043	0.28	28.52	22.59	0.08
15950.1*	Current Scenario	8.00	314.12	316.08	314.68	316.09	0.000036	0.26	30.56	23.52	0.07
15930.2*	Current Scenario	8.00	314.06	316.08	314.61	316.08	0.000030	0.24	32.88	24.37	0.07
15910.3*	Current Scenario	8.00	314.00	316.08	314.55	316.08	0.000024	0.23	35.49	25.26	0.06
15890.4*	Current Scenario	8.00	313.94	316.08	314.48	316.08	0.000020	0.21	38.47	26.58	0.06
15870.5*	Current Scenario	8.00	313.88	316.08	314.41	316.08	0.000016	0.19	41.80	27.56	0.05
15850.68	Current Scenario	8.00	313.82	316.08	314.31	316.08	0.000012	0.18	45.30	28.23	0.04
15647.55	Current Scenario	8.00	313.73	316.08	314.22	316.08	0.000016	0.20	40.89	26.14	0.05
15247.65	Current Scenario	8.00	313.57	316.07	314.22	316.07	0.000012	0.18	45.63	27.28	0.04
14248.83	Current Scenario	8.00	313.54	316.06	314.19	316.06	0.000016	0.20	39.84	24.26	0.05
13285.95	Current Scenario	8.00	313.59	316.04	314.06	316.05	0.000014	0.20	40.14	21.57	0.05
12287.88	Current Scenario	8.00	313.66	316.03	314.11	316.03	0.000014	0.19	41.32	24.79	0.05
11295.16	Current Scenario	8.00	313.64	316.02	314.15	316.02	0.000014	0.19	41.69	25.09	0.05
10311.71	Current Scenario	8.00	313.11	316.01	313.64	316.01	0.000008	0.16	50.88	26.62	0.04
9311.418	Current Scenario	8.00	313.58	316.00	314.05	316.00	0.000014	0.19	42.79	25.93	0.05
8413.406	Current Scenario	8.00	314.00	315.98	314.35	315.99	0.000012	0.16	50.28	87.56	0.04
8363.67*	Current Scenario	8.00	314.03	315.98	314.40	315.99	0.000013	0.17	48.46	86.29	0.04
8313.93*	Current Scenario	8.00	314.05	315.98	314.44	315.98	0.000013	0.17	48.17	85.16	0.05
8264.20*	Current Scenario	8.00	314.08	315.98	314.48	315.98	0.000014	0.17	47.32	83.91	0.05
8214.47*	Current Scenario	8.00	314.10	315.98	314.51	315.98	0.000015	0.17	46.45	81.96	0.05
8164.74*	Current Scenario	8.00	314.13	315.98	314.55	315.98	0.000015	0.17	47.18	79.73	0.05
8115.00*	Current Scenario	8.00	314.16	315.98	314.58	315.98	0.000016	0.17	46.53	78.56	0.05
8065.27*	Current Scenario	8.00	314.18	315.98	314.61	315.98	0.000016	0.17	45.97	78.19	0.05

8015.54*	Current Scenario	8.00	314.21	315.98	314.63	315.98	0.000016	0.17	46.22	78.35	0.05
7965.80*	Current Scenario	8.00	314.23	315.98	314.65	315.98	0.000017	0.17	46.70	78.94	0.05
7916.073	Current Scenario	8.00	314.26	315.98	314.66	315.98	0.000017	0.17	47.01	79.87	0.05
7416.061	Current Scenario	8.00	314.00	315.97	314.60	315.97	0.000006	0.10	81.39	107.49	0.03
6918.098	Current Scenario	6.02	313.83	315.97	314.23	315.97	0.000002	0.07	92.34	165.70	0.02
6616.848	Current Scenario	5.96	314.15	315.97	314.42	315.97	0.000004	0.09	67.24	127.39	0.02
6576.857	Current Scenario	5.96	314.15	315.97	314.41	315.97	0.000004	0.09	69.75	128.35	0.02
6406.850	Current Scenario	5.79	313.89	315.97	314.26	315.97	0.000003	0.07	80.03	142.77	0.02
5681.308	Current Scenario	5.72	313.64	315.97	314.08	315.97	0.000011	0.14	40.74	27.75	0.04
5639.827	Current Scenario	5.72	313.63	315.97	314.07	315.97	0.000009	0.14	40.51	26.50	0.04
5563.450	Current Scenario	5.61	313.43	315.96	313.88	315.97	0.000005	0.12	47.30	27.07	0.03
5178.663	Current Scenario	5.55	313.27	315.96	313.78	315.96	0.000005	0.12	48.00	27.67	0.03
5106.115	Current Scenario	5.55	313.27	315.96	313.78	315.96	0.000006	0.13	44.41	25.26	0.03
4957.299	Current Scenario	5.44	313.45	315.96	313.82	315.96	0.000004	0.11	49.55	27.08	0.03
4680.289	Current Scenario	5.36	313.59	315.96	313.93	315.96	0.000005	0.11	47.23	30.21	0.03
4619.007	Current Scenario	5.36	313.48	315.96	313.87	315.96	0.000004	0.11	47.36	26.53	0.03
4565.787	Current Scenario	5.23	313.24	315.96	313.65	315.96	0.000003	0.09	55.73	27.91	0.02
4087.147	Current Scenario	5.13	313.44	315.96	313.88	315.96	0.000004	0.10	52.34	32.98	0.02
4017.405	Current Scenario	5.01	313.41	315.96	313.74	315.96	0.000003	0.09	58.43	32.94	0.02
3566.712	Current Scenario	4.83	313.32	315.96	313.65	315.96	0.000003	0.09	52.68	30.20	0.02
3414.002	Current Scenario	4.70	313.34	315.96	313.91	315.96	0.000004	0.09	49.55	32.25	0.02
2962.440	Current Scenario	4.52	313.56	315.96	313.96	315.96	0.000003	0.09	47.73	27.62	0.02
2759.035	Current Scenario	4.39	313.71	315.95	314.25	315.95	0.000008	0.13	35.01	26.48	0.03
2568.159	Current Scenario	4.39	313.31	315.95	313.65	315.95	0.000003	0.09	51.57	29.91	0.02
2368.406	Current Scenario	4.14	313.52	315.95	313.77	315.95	0.000003	0.09	46.06	26.12	0.02
2163.296	Current Scenario	4.14	313.41	315.95	313.72	315.95	0.000003	0.09	46.15	26.13	0.02
1965.290	Current Scenario	3.96	313.11	315.95	313.46	315.95	0.000002	0.07	56.31	28.91	0.02
1571.255	Current Scenario	3.90	313.96	315.95	314.20	315.95	0.000004	0.09	41.56	27.59	0.02
1411.310	Current Scenario	3.90	313.96	315.95	314.20	315.95	0.000004	0.09	41.46	27.53	0.02
1213.921	Current Scenario	3.78	313.96	315.95	314.20	315.95	0.000005	0.11	33.84	22.11	0.03
1058.804	Current Scenario	3.65	313.96	315.95	314.20	315.95	0.000004	0.09	40.55	26.96	0.02
1039.854	Current Scenario	3.62	314.08	315.95	314.40	315.95	0.000007	0.21	16.84	11.87	0.06
926.992	Current Scenario	3.58	314.06	315.95	314.37	315.95	0.000005	0.18	20.03	14.91	0.05
926.990		Ini Struct									

917.799*	Current Scenario	3.58	314.06	314.60	314.38	314.65	0.000575	0.96	3.75	7.77	0.44
908.606*	Current Scenario	3.58	314.06	314.59	314.38	314.64	0.000603	0.97	3.69	7.75	0.45
899.413*	Current Scenario	3.58	314.06	314.59	314.38	314.64	0.000634	0.99	3.63	7.72	0.46
890.22*	Current Scenario	3.58	314.06	314.58	314.38	314.63	0.000671	1.01	3.56	7.70	0.47
881.027*	Current Scenario	3.58	314.06	314.57	314.38	314.62	0.000712	1.03	3.49	7.67	0.49
871.834*	Current Scenario	3.58	314.06	314.56	314.38	314.62	0.000755	1.05	3.43	7.64	0.50
862.641*	Current Scenario	3.58	314.06	314.55	314.38	314.61	0.000811	1.07	3.35	7.61	0.52
853.448*	Current Scenario	3.58	314.06	314.54	314.38	314.60	0.000877	1.10	3.26	7.58	0.53
844.255*	Current Scenario	3.58	314.06	314.53	314.38	314.59	0.000962	1.13	3.17	7.54	0.56
835.062*	Current Scenario	3.58	314.06	314.52	314.38	314.59	0.001074	1.17	3.06	7.50	0.59
825.869	Current Scenario	3.58	314.06	314.50	314.38	314.57	0.001207	1.22	2.94	7.44	0.62
642.462	Current Scenario	3.58	313.67	314.48	313.99	314.50	0.000142	0.60	5.96	8.59	0.23
41.961	Current Scenario	3.58	313.64	314.37	313.96	314.40	0.000200	0.67	5.32	8.36	0.27

HEC-RAS Plan 14 River: Upper_Baguineda Reach: HGate-CSK11 Profile: *Water level in current scenario of not lined canal (Manning 0,015; 0.020 and 0.030; seepage 0.22 m³/km). Gates of R1 closed.*

River Sta	Profile	Q Total (m ³ /s)	Min Ch El (m)	W.S. Elev (m)	Crit W.S. (m)	E.G. Elev (m)	E.G. Slope (m/m)	Vel Chnl (m/s)	Flow Area (m ²)	Top Width (m)	Froude # Chl
16049.62	Current Scenario	8.00	314.42	316.71	315.00	316.71	0.000020	0.22	35.83	22.20	0.06
16029.8		Inl Struct									
16029.7*	Current Scenario	8.00	314.36	315.95	314.93	315.95	0.000098	0.38	21.12	19.68	0.12
16009.8*	Current Scenario	8.00	314.30	315.94	314.87	315.95	0.000084	0.36	22.40	20.25	0.11
15989.9*	Current Scenario	8.00	314.24	315.94	314.80	315.95	0.000071	0.34	23.81	20.94	0.10
15970.0*	Current Scenario	8.00	314.18	315.94	314.74	315.95	0.000060	0.31	25.43	21.81	0.09
15950.1*	Current Scenario	8.00	314.12	315.94	314.68	315.95	0.000050	0.29	27.33	22.87	0.09
15930.2*	Current Scenario	8.00	314.06	315.94	314.61	315.95	0.000041	0.27	29.53	23.71	0.08
15910.3*	Current Scenario	8.00	314.00	315.94	314.55	315.94	0.000033	0.25	32.01	24.59	0.07
15890.4*	Current Scenario	8.00	313.94	315.94	314.48	315.94	0.000026	0.23	34.82	25.71	0.06
15870.5*	Current Scenario	8.00	313.88	315.94	314.41	315.94	0.000021	0.21	38.00	26.80	0.06
15850.68	Current Scenario	8.00	313.82	315.94	314.31	315.94	0.000016	0.19	41.41	27.54	0.05
15647.55	Current Scenario	8.00	313.73	315.94	314.22	315.94	0.000021	0.21	37.27	25.28	0.06
15247.65	Current Scenario	8.00	313.57	315.93	314.22	315.93	0.000015	0.19	41.80	26.57	0.05
14248.83	Current Scenario	8.00	313.54	315.91	314.19	315.91	0.000020	0.22	36.36	23.35	0.06
13285.95	Current Scenario	8.00	313.59	315.89	314.06	315.90	0.000017	0.22	37.06	20.40	0.05
12287.88	Current Scenario	8.00	313.66	315.88	314.11	315.88	0.000019	0.21	37.58	23.97	0.05
11295.16	Current Scenario	8.00	313.64	315.86	314.15	315.86	0.000019	0.21	37.80	24.27	0.05
10311.71	Current Scenario	8.00	313.11	315.85	313.64	315.85	0.000010	0.17	46.69	25.68	0.04
9311.418	Current Scenario	8.00	313.58	315.83	314.05	315.83	0.000018	0.21	38.62	25.00	0.05
8413.406	Current Scenario	8.00	314.00	315.82	314.35	315.82	0.000017	0.18	44.35	86.18	0.05
8363.67*	Current Scenario	8.00	314.03	315.82	314.40	315.82	0.000019	0.19	42.69	84.49	0.05
8313.93*	Current Scenario	8.00	314.05	315.81	314.44	315.82	0.000020	0.19	42.26	82.76	0.05
8264.20*	Current Scenario	8.00	314.08	315.81	314.48	315.82	0.000022	0.19	41.40	79.52	0.06
8214.47*	Current Scenario	8.00	314.10	315.81	314.51	315.81	0.000023	0.20	40.57	76.86	0.06
8164.74*	Current Scenario	8.00	314.13	315.81	314.55	315.81	0.000024	0.20	40.97	75.59	0.06
8115.00*	Current Scenario	8.00	314.16	315.81	314.58	315.81	0.000025	0.20	40.34	75.13	0.06
8065.27*	Current Scenario	8.00	314.18	315.81	314.61	315.81	0.000026	0.20	39.81	75.26	0.06
8015.54*	Current Scenario	8.00	314.21	315.81	314.63	315.81	0.000026	0.20	39.89	75.81	0.06

7965.80*	Current Scenario	8.00	314.23	315.81	314.65	315.81	0.000027	0.20	40.16	76.69	0.06
7916.073	Current Scenario	8.00	314.26	315.80	314.66	315.81	0.000027	0.20	40.31	77.87	0.06
7416.061	Current Scenario	8.00	314.00	315.80	314.60	315.80	0.000009	0.11	70.93	104.90	0.03
6918.098	Current Scenario	6.02	313.83	315.80	314.23	315.80	0.000003	0.07	82.26	151.57	0.02
6616.848	Current Scenario	5.96	314.15	315.79	314.42	315.79	0.000006	0.10	59.19	120.46	0.03
6576.857	Current Scenario	5.96	314.15	315.79	314.41	315.79	0.000006	0.10	61.42	121.06	0.03
6406.850	Current Scenario	5.79	313.89	315.79	314.26	315.79	0.000004	0.08	70.48	124.02	0.02
5681.308	Current Scenario	5.72	313.64	315.79	314.08	315.79	0.000016	0.16	35.89	26.46	0.04
5639.827	Current Scenario	5.72	313.63	315.79	314.07	315.79	0.000012	0.16	35.85	25.59	0.04
5563.450	Current Scenario	5.61	313.43	315.79	313.88	315.79	0.000007	0.13	42.54	26.04	0.03
5178.663	Current Scenario	5.55	313.27	315.78	313.78	315.78	0.000007	0.13	43.12	26.55	0.03
5106.115	Current Scenario	5.55	313.27	315.78	313.78	315.78	0.000008	0.14	39.95	24.27	0.03
4957.299	Current Scenario	5.44	313.45	315.78	313.82	315.78	0.000005	0.12	44.75	26.17	0.03
4680.289	Current Scenario	5.36	313.59	315.78	313.93	315.78	0.000007	0.13	41.91	28.68	0.03
4619.007	Current Scenario	5.36	313.48	315.78	313.87	315.78	0.000006	0.13	42.66	25.58	0.03
4565.787	Current Scenario	5.23	313.24	315.78	313.65	315.78	0.000004	0.10	50.75	27.20	0.02
4087.147	Current Scenario	5.13	313.44	315.78	313.88	315.78	0.000005	0.11	46.54	31.18	0.03
4017.405	Current Scenario	5.01	313.41	315.78	313.74	315.78	0.000003	0.10	52.58	31.62	0.02
3566.712	Current Scenario	4.83	313.32	315.78	313.65	315.78	0.000004	0.10	47.52	26.98	0.02
3414.002	Current Scenario	4.70	313.34	315.77	313.91	315.78	0.000005	0.11	43.87	30.27	0.03
2962.440	Current Scenario	4.52	313.56	315.77	313.96	315.77	0.000005	0.11	42.78	26.61	0.03
2759.035	Current Scenario	4.39	313.71	315.77	314.25	315.77	0.000012	0.14	30.35	24.48	0.04
2568.159	Current Scenario	4.39	313.31	315.77	313.65	315.77	0.000003	0.09	46.26	28.00	0.02
2368.406	Current Scenario	4.14	313.52	315.77	313.77	315.77	0.000004	0.10	41.37	25.06	0.02
2163.296	Current Scenario	4.14	313.41	315.77	313.72	315.77	0.000004	0.10	41.44	25.12	0.02
1965.290	Current Scenario	3.96	313.11	315.77	313.46	315.77	0.000002	0.08	51.15	27.24	0.02
1571.255	Current Scenario	3.90	313.96	315.77	314.20	315.77	0.000006	0.11	36.59	26.48	0.03
1411.310	Current Scenario	3.90	313.96	315.77	314.20	315.77	0.000006	0.11	36.49	26.42	0.03
1213.921	Current Scenario	3.78	313.96	315.76	314.20	315.76	0.000008	0.13	29.82	21.35	0.03
1058.804	Current Scenario	3.65	313.96	315.76	314.20	315.76	0.000005	0.10	35.66	25.87	0.03
1039.854	Current Scenario	3.62	314.08	315.76	314.40	315.76	0.000011	0.25	14.69	11.30	0.07
926.992	Current Scenario	3.58	314.06	315.76	314.37	315.76	0.000008	0.21	17.32	14.25	0.06
926.990		Inl Struct									
917.799*	Current Scenario	3.58	314.06	314.60	314.38	314.65	0.000575	0.96	3.75	7.77	0.44

908.606*	Current Scenario	3.58	314.06	314.59	314.38	314.64	0.000603	0.97	3.69	7.75	0.45
899.413*	Current Scenario	3.58	314.06	314.59	314.38	314.64	0.000634	0.99	3.63	7.72	0.46
890.22*	Current Scenario	3.58	314.06	314.58	314.38	314.63	0.000671	1.01	3.56	7.70	0.47
881.027*	Current Scenario	3.58	314.06	314.57	314.38	314.62	0.000712	1.03	3.49	7.67	0.49
871.834*	Current Scenario	3.58	314.06	314.56	314.38	314.62	0.000755	1.05	3.43	7.64	0.50
862.641*	Current Scenario	3.58	314.06	314.55	314.38	314.61	0.000811	1.07	3.35	7.61	0.52
853.448*	Current Scenario	3.58	314.06	314.54	314.38	314.60	0.000877	1.10	3.26	7.58	0.53
844.255*	Current Scenario	3.58	314.06	314.53	314.38	314.59	0.000962	1.13	3.17	7.54	0.56
835.062*	Current Scenario	3.58	314.06	314.52	314.38	314.59	0.001074	1.17	3.06	7.50	0.59
825.869	Current Scenario	3.58	314.06	314.50	314.38	314.57	0.001207	1.22	2.94	7.44	0.62
642.462	Current Scenario	3.58	313.67	314.48	313.99	314.50	0.000142	0.60	5.96	8.59	0.23
41.961	Current Scenario	3.58	313.64	314.37	313.96	314.40	0.000200	0.67	5.32	8.36	0.27

V.3. Modern scenario discharges and water levels

Water level in modern scenario of lined canal (n Manning = 0.015, seepage $0.10\text{m}^3/\text{km}$)
 HEC-RAS Plan 15 River: Upper_Baguineda Reach: HGate-CSK11 Profile: Modern Scenario

River Sta	Profile	Q Total (m^3/s)	Min Ch El (m)	W.S. Elev (m)	Crit W.S. (m)	E.G. Elev (m)	E.G. Slope (m/m)	Vel Chnl (m/s)	Flow Area (m^2)	Top Width (m)	Froude # Chl
16049.62	Modern Scenario	9.50	314.42	318.74	315.04	318.74	0.000001	0.11	87.54	28.72	0.02
16029.8		Inl Struct									
16029.7*	Modern Scenario	9.50	314.36	316.15	314.98	316.15	0.000025	0.38	25.18	20.63	0.11
16009.8*	Modern Scenario	9.50	314.30	316.15	314.91	316.15	0.000022	0.36	26.60	21.24	0.10
15989.9*	Modern Scenario	9.50	314.24	316.15	314.85	316.15	0.000019	0.34	28.19	22.00	0.10
15970.0*	Modern Scenario	9.50	314.18	316.15	314.78	316.15	0.000016	0.32	30.01	22.96	0.09
15950.1*	Modern Scenario	9.50	314.12	316.15	314.72	316.15	0.000014	0.30	32.13	23.83	0.08
15930.2*	Modern Scenario	9.50	314.06	316.15	314.65	316.15	0.000011	0.28	34.52	24.68	0.07
15910.3*	Modern Scenario	9.50	314.00	316.15	314.59	316.15	0.000009	0.26	37.20	25.58	0.07
15890.4*	Modern Scenario	9.50	313.94	316.15	314.52	316.15	0.000008	0.24	40.28	27.00	0.06
15870.5*	Modern Scenario	9.50	313.88	316.15	314.45	316.15	0.000006	0.22	43.68	27.93	0.06
15850.68	Modern Scenario	9.50	313.82	316.15	314.35	316.15	0.000005	0.20	47.23	28.56	0.05
15647.55	Modern Scenario	9.50	313.73	316.15	314.27	316.15	0.000006	0.22	42.72	26.44	0.06
15247.65	Modern Scenario	9.50	313.57	316.15	314.27	316.15	0.000004	0.20	47.63	27.65	0.05
14248.83	Modern Scenario	9.50	313.54	316.14	314.24	316.14	0.000006	0.23	41.83	24.72	0.06
13285.95	Modern Scenario	9.50	313.59	316.13	314.10	316.14	0.000007	0.22	42.31	26.98	0.06
12287.88	Modern Scenario	9.50	313.66	316.13	314.16	316.13	0.000005	0.22	43.76	25.31	0.05
11295.16	Modern Scenario	9.50	313.64	316.12	314.20	316.12	0.000005	0.21	44.39	25.65	0.05
10311.71	Modern Scenario	9.50	313.11	316.12	313.68	316.12	0.000003	0.18	53.93	27.28	0.04
9311.418	Modern Scenario	9.50	313.58	316.12	314.10	316.12	0.000005	0.21	45.94	27.42	0.05
8413.406	Modern Scenario	9.50	314.00	316.11	314.40	316.11	0.000004	0.17	54.78	88.61	0.04
8363.67*	Modern Scenario	9.50	314.03	316.11	314.44	316.11	0.000004	0.18	52.85	87.65	0.05
8313.93*	Modern Scenario	9.50	314.05	316.11	314.48	316.11	0.000004	0.18	52.69	86.97	0.05
8264.20*	Modern Scenario	9.50	314.08	316.11	314.52	316.11	0.000005	0.18	51.83	86.42	0.05
8214.47*	Modern Scenario	9.50	314.10	316.11	314.55	316.11	0.000005	0.19	50.94	85.70	0.05
8164.74*	Modern Scenario	9.50	314.13	316.11	314.59	316.11	0.000005	0.18	51.94	83.85	0.05
8115.00*	Modern Scenario	9.50	314.16	316.11	314.62	316.11	0.000005	0.19	51.28	81.17	0.05
8065.27*	Modern Scenario	9.50	314.18	316.11	314.65	316.11	0.000005	0.19	50.70	80.41	0.05
8015.54*	Modern	9.50	314.21	316.11	314.67	316.11	0.000005	0.19	51.08	83.84	0.05

	Scenario										
7965.80*	Modern Scenario	9.50	314.23	316.11	314.69	316.11	0.000005	0.18	51.74	80.65	0.05
7916.073	Modern Scenario	9.50	314.26	316.11	314.70	316.11	0.000005	0.18	52.18	81.40	0.05
7416.061	Modern Scenario	9.50	314.00	316.11	314.64	316.11	0.000002	0.11	89.56	109.49	0.03
6918.098	Modern Scenario	8.54	313.83	316.11	314.33	316.11	0.000001	0.09	100.19	174.33	0.02
6616.848	Modern Scenario	8.48	314.15	316.11	314.48	316.11	0.000002	0.12	73.54	129.75	0.03
6576.857	Modern Scenario	8.48	314.15	316.11	314.47	316.11	0.000002	0.11	76.26	131.80	0.03
6406.850	Modern Scenario	8.40	313.89	316.11	314.34	316.11	0.000001	0.10	87.49	157.32	0.02
5681.308	Modern Scenario	8.32	313.64	316.10	314.18	316.11	0.000004	0.19	44.66	28.74	0.05
5639.827	Modern Scenario	8.32	313.63	316.10	314.17	316.11	0.000004	0.19	44.24	27.22	0.05
5563.450	Modern Scenario	8.27	313.43	316.10	313.97	316.11	0.000003	0.16	51.13	27.87	0.04
5178.663	Modern Scenario	8.22	313.27	316.10	313.87	316.10	0.000003	0.16	51.94	28.55	0.04
5106.115	Modern Scenario	8.22	313.27	316.10	313.88	316.10	0.000003	0.17	48.01	26.03	0.04
4957.299	Modern Scenario	8.17	313.45	316.10	313.90	316.10	0.000002	0.15	53.41	27.80	0.04
4680.289	Modern Scenario	8.09	313.59	316.10	314.02	316.10	0.000003	0.16	51.58	31.40	0.04
4619.007	Modern Scenario	8.09	313.48	316.10	313.95	316.10	0.000003	0.16	51.17	27.27	0.04
4565.787	Modern Scenario	8.03	313.24	316.10	313.75	316.10	0.000002	0.13	59.72	28.47	0.03
4087.147	Modern Scenario	7.92	313.44	316.10	313.96	316.10	0.000002	0.14	57.23	36.10	0.03
4017.405	Modern Scenario	7.87	313.41	316.10	313.82	316.10	0.000002	0.12	63.23	34.55	0.03
3566.712	Modern Scenario	7.69	313.32	316.10	313.74	316.10	0.000002	0.13	57.19	33.00	0.03
3414.002	Modern Scenario	7.63	313.34	316.10	314.03	316.10	0.000002	0.14	54.29	34.53	0.04
2962.440	Modern Scenario	7.45	313.56	316.10	314.04	316.10	0.000002	0.14	51.74	28.41	0.03
2759.035	Modern Scenario	7.39	313.71	316.10	314.38	316.10	0.000005	0.19	38.92	28.04	0.05
2568.159	Modern Scenario	7.39	313.31	316.10	313.76	316.10	0.000002	0.13	55.98	31.42	0.03
2368.406	Modern Scenario	7.14	313.52	316.10	313.87	316.10	0.000002	0.14	49.88	26.95	0.03
2163.296	Modern Scenario	7.14	313.41	316.10	313.82	316.10	0.000002	0.14	49.97	26.93	0.03
1965.290	Modern Scenario	7.06	313.11	316.10	313.57	316.10	0.000001	0.12	60.58	30.22	0.03
1571.255	Modern Scenario	7.00	313.96	316.09	314.29	316.10	0.000003	0.15	45.58	28.20	0.04
1411.310	Modern Scenario	7.00	313.96	316.09	314.29	316.10	0.000003	0.15	45.48	28.15	0.04
1213.921	Modern Scenario	6.95	313.96	316.09	314.30	316.09	0.000004	0.19	37.07	22.71	0.05
1058.804	Modern Scenario	6.81	313.96	316.09	314.30	316.09	0.000003	0.15	44.48	27.53	0.04
1039.854	Modern Scenario	6.80	314.08	316.09	314.56	316.09	0.000020	0.37	18.53	12.30	0.10
926.992	Modern Scenario	6.76	314.06	316.09	314.53	316.09	0.000014	0.31	22.14	15.13	0.08
926.990		Int Struct									
917.799*	Modern	6.76	314.06	314.89	314.54	314.95	0.000469	1.10	6.12	8.65	0.42

	Scenario										
908.606*	Modern Scenario	6.76	314.06	314.88	314.54	314.95	0.000480	1.11	6.07	8.64	0.42
899.413*	Modern Scenario	6.76	314.06	314.88	314.54	314.94	0.000493	1.12	6.02	8.62	0.43
890.22*	Modern Scenario	6.76	314.06	314.87	314.54	314.94	0.000507	1.13	5.96	8.60	0.43
881.027*	Modern Scenario	6.76	314.06	314.87	314.54	314.93	0.000522	1.14	5.91	8.58	0.44
871.834*	Modern Scenario	6.76	314.06	314.86	314.54	314.93	0.000535	1.15	5.85	8.56	0.45
862.641*	Modern Scenario	6.76	314.06	314.85	314.54	314.92	0.000552	1.17	5.79	8.54	0.45
853.448*	Modern Scenario	6.76	314.06	314.85	314.54	314.92	0.000569	1.18	5.73	8.52	0.46
844.255*	Modern Scenario	6.76	314.06	314.84	314.54	314.91	0.000589	1.19	5.67	8.49	0.47
835.062*	Modern Scenario	6.76	314.06	314.83	314.54	314.91	0.000610	1.21	5.60	8.47	0.47
825.869	Modern Scenario	6.76	314.06	314.83	314.54	314.90	0.000625	1.22	5.56	8.45	0.48
642.462	Modern Scenario	6.76	313.67	314.81	314.15	314.84	0.000154	0.75	8.95	9.60	0.25
41.961	Modern Scenario	6.76	313.64	314.70	314.12	314.73	0.000200	0.83	8.18	9.36	0.28

VI. Crop and irrigation water requirements

Recap Net Irrigation Water Requirement

Month	Precipitation (mm/m)	Rice Etm(mm/m)	IWR(mm/m)	Maize Etm(mm/m)	IWR(mm/m)	Sorghum Etm(mm/m)	IWR(mm/m)	Tomato Etm(mm/m)	IWR(mm/m)	Totals IWR(mm/m)
May	31	51.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Jun	30	69.4	0.0	170.6	51.3	0.0	51.3	0.0	0.0	170.6
Jul	31	203.0	145.7	4.7	109.3	0.0	109.3	0.0	0.0	4.7
Aug	31	256.4	130.2	0.0	156.2	0.0	130.2	0.0	0.0	0.0
Sep	30	129.4	141.8	72.4	67.5	0.0	74.3	0.0	0.0	72.4
Oct	31	45.9	155.0	171.1	0.0	0.0	0.0	0.0	0.0	171.1
Nov	30	0.0	0.0	180.0	0.0	0.0	0.0	97.2	97.2	277.2
Dec	31	0.0	170.5	294.5	51.2	51.2	0.0	148.3	148.3	494.0
Jan	31	0.0	192.2	316.2	144.2	144.2	0.0	221.0	221.0	681.4
Feb	28	0.0	214.6	326.6	245.3	245.3	0.0	163.5	163.5	735.4
Mar	31	0.0	241.8	365.8	120.9	120.9	0.0	0.0	0.0	486.7
Apr	30	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
D. Season		819	1483	561	561	0	630	630		
R. Season			573	419	384	0	365	0	0	
Year tot			1392	1902	946	561	365	0	630	630
Total dry season and all crops										
IWR(mm)			2675							
Total rainy season and all crops										
IWR(mm)			419							

Current Scenario- Canal Efficiency = 60%

Current Scenario with not lined secondary canal Efficiency =60%

Dry Season Areas (ha) percentages for each block

Rice 30%		Maize 16%		Tomato 54%		Nota : conveyance efficiency=60% for the non lined secondary canals for discharge computation. Irrigation 12 hours/24											
Secondary Block	CSK1	CSK2	CSK3	CSK4	CSK5	CSK6	CSK7	CSK8	CSK9	CSK10	CSK11	CSK12	CSK13	CSK15	CSK16	CSK17	
GIS Block Total Area A (ha)	22.7	10.7	21.4	27.8	41.7	57.3	35.1	103.6	23.4	66.0	5.3	9.7	80.7	27.5	70.2	16.8	
Irrigation Water Requirement (m3/month)																	
Nov	24354.45	11492.94	22936.59	29756.91	44711.45	61355.00	37634.99	111062.72	25043.56	70706.68	5668.24	10437.32	86530.37	29477.19	75217.47	17951.03	
Dec	40445.74	19086.47	38091.08	49417.66	74252.86	101893.00	62500.90	184443.25	41590.14	117423.46	9413.31	17333.38	143702.06	48953.14	124914.59	29811.49	
Jan	54340.21	25643.32	51176.64	66394.29	99761.21	136896.68	83972.07	247805.71	55877.76	157762.37	12647.10	23287.98	193068.56	65770.19	167826.96	40052.74	
Feb	51781.68	24435.94	48767.07	63268.21	95064.10	130451.10	80018.36	236138.14	53246.84	150334.36	12051.63	22191.50	183978.21	62673.49	159925.08	38166.92	
Mar	29771.82	14049.41	28038.57	36375.98	54656.99	75002.71	46006.46	135767.34	30614.20	86434.56	6929.07	12758.98	105778.05	36034.05	91948.73	21944.02	
Total (m3)	200693.90	94708.09	189009.94	245213.06	368446.62	505598.49	310132.79	915217.16	206372.50	582661.41	46709.35	86009.15	713057.25	242908.06	619832.84	147926.20	
Pick Q(liters/s)	70	33	66	85	128	176	108	319	72	203	16	30	248	85	216	52	
Q if irrig 3days/7	163	77	154	199	299	411	252	744	168	473	38	70	579	197	504	120	
Q specific (l/s/ha)	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	
OPIB Block Total Area A (ha)	21.8	27.4	20.1	29.9	37.1	65.1	64.2	92.1	22.7	48.9	12.9	15.4	67.8	22.4	56.8	13.0	
OPIB Qnominal(l/s)	60	76	56	83	103	180	178	255	63	135	36	43	188	62	157	36	
OPIB Qmodule(l/s)	75	80	80	100	125	200	100	260	75	180	40	40	220	80	160	60	

Rice 30% Secondary Block		Eff(%)= 60% Nota : conveyance efficiency=60% for the non lined secondary canals for discharge computation. Irrigation 12 hours/24													
		Maize CSB1	16% CSB2	Tomato CSB3	54% CSB4	CSB5	CSB6	CSB7	CSB8	CSB9	CSB10	CSB11	CSB12	CSB13	CSB14
GIS Block Total Area A (ha)		20.1	6.6	7.9	111.7	91.7	65.3	108.2	71.4	94.9	8.7	62.2	112.7	79.7	200.5
		Irrigation Water Requirement (m3/month)													
Nov		21590.53	7077.53	8508.25	119759.59	98247.30	70027.22	115951.83	76479.94	101746.41	9318.46	66645.99	120822.72	85369.72	214849.66
Dec		35855.66	11753.74	14129.76	198886.25	163160.51	116295.07	192562.65	127011.19	168971.53	15475.28	110679.83	200651.80	141774.55	356803.50
Jan		48173.28	15791.54	18983.80	267210.36	219211.64	156246.34	258714.40	170643.80	227018.93	20791.56	148702.08	269582.44	190478.88	479377.50
Feb		45905.12	15048.02	18089.98	254629.16	208890.38	148889.71	246533.21	162609.29	216330.08	19812.62	141700.66	256889.55	181510.46	456806.72
Mar		26393.09	8651.84	10400.81	146398.73	120101.27	85603.96	141743.98	93492.02	124378.72	11391.24	81470.62	147698.34	104359.22	262640.48
Total (m3)		177917.68	58322.66	70112.60	986884.09	809611.11	577062.30	955506.08	630236.24	838445.67	76789.15	549199.18	995644.86	703492.83	1770477.85
Pick Q(liters/s)		62	20	24	344	282	201	333	219	292	27	191	347	245	616
Q if irrig 3days/7		145	47	57	802	658	469	776	512	681	62	446	809	572	1438
Q specific (l/s/ha)		3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1
OPIB Block Total Area A (ha)		12.9	8.4	17.4	101.8	85.9	75.7	95.7	68.8	103.6	8.6	56.6	94.0	85.4	163.3
OPIB Qnominal(l/s)		35.58	23.12	48.18	281.7	237.86	209.61	264.85	190.51	286.87	23.81	156.73	260.29	236.47	452.18
OPIB Qmodule(l/s)		60	100	100	320	240	220	320	200	300	40	180	300	240	460
0															
Rice 30% Secondary Block		Eff(%)= 0.6 Nota : conveyance efficiency=60% for the non lined secondary canals for discharge computation. Irrigation 12 hours/24													
		Maize CSB15	CSB16	16% Tomato CSB17	54% CSB18	CSB19	CSB20	CSB21	CSB22a	CSB22b	CSB23	CSB24	CSB25		
GIS Block Total Area A (ha)		124.6	200.3	97.9	72.5	39.0	102.7	58.6	72.9	89.0	90.9	186.6	49.8		
Nov		133548.13	214646.03	104868.28	77697.40	41798.56	110032.82	62838.23	78095.00	95428.72	97404.94	200018.36	53351.52		
Dec		221785.03	356465.34	174156.06	129033.03	69415.39	182732.87	104356.23	129693.33	158479.66	161761.60	332172.98	88601.53		
Jan		297975.65	478923.17	233984.52	173360.22	93261.91	245507.76	140206.11	174247.36	212922.76	217332.15	446285.57	119039.14		
Feb		283945.91	456373.78	222967.71	165197.81	88870.81	233948.38	133604.71	166043.17	202897.60	207099.38	425272.87	113434.35		
Mar		163254.36	262391.56	128195.02	94980.28	51096.17	134508.34	76815.87	95466.33	116655.74	119071.54	244510.13	65218.95		
Total (m3)		1100509.07	1768799.88	864171.59	640268.73	344442.83	906730.17	517821.17	643545.19	786384.49	802669.61	1648259.90	439645.48		
Pick Q(liters/s)		383	616	301	223	120	316	180	224	274	279	574	153		
Q if irriga 4days/7		671	1078	527	390	210	553	316	392	479	489	1004	268		
Q specific (l/s/ha)		3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1		
OPIB Block Total Area A (ha)		111.0	186.0	107.9	66.3	29.3	81.4	45.4	56.3	71.7	74.6	149.6	41.0		
OPIB Qnominal(l/s)		307	515	299	184	81	225	126	156	199	207	414	114		
OPIB Qmodule(l/s)		340	540	260	180	100	240	140	180	220	220	500	120		

Remark : the maximum IWR is located in january due to the 54% of tamato whint its requirements

Max 616 Min 20

Max 615.90 Min 119.94

Modern Scenario :- Canals Efficiency = 80%**Modern Scenario lined secondary canals Efficiency=80%**

Irrigation water requirement in mm as function of % cropping area, secondary canal and per month

Dry Season Areas (ha) percentages for each block

Rice	30%	Maize	16%	Tomato	54%	Nota : conveyance efficiency=80% for lined secondary canals for discharge computation. Irrigation 12 hours/24											
Secondary Block	CSK1	CSK2	CSK3	CSK4	CSK5	CSK6	CSK7	CSK8	CSK9	CSK10	CSK11	CSK12	CSK13	CSK15	CSK16	CSK17	
GIS Block Total Area A (ha)	22.7	10.7	21.4	27.8	41.7	57.3	35.1	103.6	23.4	66.0	5.3	9.7	80.7	27.5	70.2	16.8	
	Irrigation Water Requirement (m3/month)																
Nov	24354.45	11492.94	22936.59	29756.91	44711.45	61355.00	37634.99	111062.72	25043.56	70706.68	5668.24	10437.32	86530.37	29477.19	75217.47	17951.03	
Dec	40445.74	19086.47	38091.08	49417.66	74252.86	101893.00	62500.90	184443.25	41590.14	117423.46	9413.31	17333.38	143702.06	48953.14	124914.59	29811.49	
Jan	54340.21	25643.32	51176.64	66394.29	99761.21	136896.68	83972.07	247805.71	55877.76	157762.37	12647.10	23287.98	193068.56	65770.19	167826.96	40052.74	
Feb	51781.68	24435.94	48767.07	63268.21	95064.10	130451.10	80018.36	236138.14	53246.84	150334.36	12051.63	22191.50	183978.21	62673.49	159925.08	38166.92	
Mar	29771.82	14049.41	28038.57	36375.98	54656.99	75002.71	46006.46	135767.34	30614.20	86434.56	6929.07	12758.98	105778.05	36034.05	91948.73	21944.02	
Total (m3)	200693.90	94708.09	189009.94	245213.06	368446.62	505598.49	310132.79	915217.16	206372.50	582661.41	46709.35	86009.15	713057.25	242908.06	619832.84	147926.20	
Pick Q (liters/s)	52	25	49	64	96	132	81	239	54	152	12	22	186	63	162	39	
Q if irrig 3days/7	122	58	115	149	225	308	189	558	126	355	28	52	435	148	378	90	
Q specific (l/s/ha)	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	
OPIB Block Total Area A (ha)	21.8	27.4	20.1	29.9	37.1	65.1	64.2	92.1	22.7	48.9	12.9	15.4	67.8	22.4	56.8	13.0	
OPIB Qnominal(l/s)	60	76	56	83	103	180	178	255	63	135	36	43	188	62	157	36	
OPIB Qmodule(l/s)	75	80	80	100	125	200	100	260	75	180	40	40	220	80	160	60	

Dry Season Areas (ha) percentages for each block

Rice	30%	Maize	16%	Tomato	54%	Nota : conveyance efficiency=80% for lined secondary canals for discharge computation. Irrigation 12 hours/24									
Secondary Block	CSB1	CSB2	CSB3	CSB4	CSB5	CSB6	CSB7	CSB8	CSB9	CSB10	CSB11	CSB12	CSB13	CSB14	
GIS Block Total Area A (ha)	20.1	6.6	7.9	111.7	91.7	65.3	108.2	71.4	94.9	8.7	62.2	112.7	79.7	200.5	
	Irrigation Water Requirement (m3/month)														
Nov	21590.53	7077.53	8508.25	119759.59	98247.30	70027.22	115951.83	76479.94	101746.41	9318.46	66645.99	120822.72	85369.72	214849.66	
Dec	35855.66	11753.74	14129.76	198886.25	163160.51	116295.07	192562.65	127011.19	168971.53	15475.28	110679.83	200651.80	141774.55	356803.50	
Jan	48173.28	15791.54	18983.80	267210.36	219211.64	156246.34	258714.40	170643.80	227018.93	20791.56	148702.08	269582.44	190478.88	479377.50	
Feb	45905.12	15048.02	18089.98	254629.16	208890.38	148889.71	246533.21	162609.29	216330.08	19812.62	141700.66	256889.55	181510.46	456806.72	
Mar	26393.09	8651.84	10400.81	146398.73	120101.27	85603.96	141743.98	93492.02	124378.72	11391.24	81470.62	147698.34	104359.22	262640.48	
Total (m3)	177917.68	58322.66	70112.60	986884.09	809611.11	577062.30	955506.08	630236.24	838445.67	76789.15	549199.18	995644.86	703492.83	1770477.85	
Pick Q(liters/s)	46	15	18	258	211	151	250	165	219	20	143	260	184	462	
Q if irrig 3days/7	108	36	43	601	493	352	582	384	511	47	335	607	429	1079	
Q specific (l/s/ha)	2	2	2	2	2	2	2	2	2	2	2	2	2	2	
OPIB Block Total Area A (ha)	12.9	8.4	17.4	101.8	85.9	75.7	95.7	68.8	103.6	8.6	56.6	94.0	85.4	163.3	
OPIB Qnominal(l/s)	36	23	48	282	238	210	265	191	287	24	157	260	236	452	
OPIB Qmodule(l/s)	60	100	100	320	240	220	320	200	300	40	180	300	240	460	

Dry Season Areas (ha) percentages for each block

Rice	30%	Maize	16%	Tomato	54%	Nota : conveyance efficiency=80% for lined secondary canals for discharge computation. Irrigation 12 hours/24									
Secondary Block		CSB15	CSB16	CSB17	CSB18	CSB19	CSB20	CSB21	CSB22a	CSB22b	CSB23	CSB24	CSB25		
GIS Block Total Area A (ha)		124.6	200.3	97.9	72.5	39.0	102.7	58.6	72.9	89.0	90.9	186.6	49.8		
		Irrigation Water Requirement (m3/month)													
Nov		133548.13	214646.03	104868.28	77697.40	41798.56	110032.82	62838.23	78095.00	95428.72	97404.94	200018.36	53351.52		
Dec		221785.03	356465.34	174156.06	129033.03	69415.39	182732.87	104356.23	129693.33	158479.66	161761.60	332172.98	88601.53		
Jan		297975.65	478923.17	233984.52	173360.22	93261.91	245507.76	140206.11	174247.36	212922.76	217332.15	446285.57	119039.14		
Feb		283945.91	456373.78	222967.71	165197.81	88870.81	233948.38	133604.71	166043.17	202897.60	207099.38	425272.87	113434.35		
Mar		163254.36	262391.56	128195.02	94980.28	51096.17	134508.34	76815.87	95466.33	116655.74	119071.54	244510.13	65218.95		
Total (m3)		1100509.07	1768799.88	864171.59	640268.73	344442.83	906730.17	517821.17	643545.19	786384.49	802669.61	1648259.90	439645.48		
Pick Q (liters/s)		287	462	226	167	90	237	135	168	205	210	430	115		
Q if irrig 4days/7		503	808	395	293	157	414	237	294	359	367	753	201		
Q specific (l/s/ha)		2	2	2	2	2	2	2	2	2	2	2	2		
OPIB Block Total Area A (ha)		111.0	186.0	107.9	66.3	29.3	81.4	45.4	56.3	71.7	74.6	149.6	41.0		
OPIB Qnominal(l/s)		307	515	299	184	81	225	126	156	199	207	414	114		
OPIB Qmodule(l/s)		340	540	260	180	100	240	140	180	220	220	500	120		

Remark : the maximum IWR is located in January due to the 54% of tomato with its requirements

VII. Deficit irrigation scenarios computations

Dry Season - Current Scenario with 25% Water

	Rice	Maize	Tomato
Etm(mm/season)	819	561	630
Maximum Yield Ym(t/ha)	6	6	45
Yield Red. Rate β (%)	80%	80%	80%
Yield Facto Ky	1.30	1.25	1.05
Current cropping area propotion factor	25%		

Current Scenario with not lined Canals

Remark

Efficiency of Secondary Canals= 60% The efficiency plays only a role while transferring the required discharge from the field to the secondary intake. It is not used the deficit area computation below.

Dry Season Areas (ha) percentages for each block

	Rice 30%		Maize 16%		Tomato 54%		Nota : conveyance efficiency=60% for the non lined secondary canals for discharge computation. Irrigation 12 hours/24										Totals		Genera Totals	
Secondary Block	CSK1	CSK2	CSK3	CSK4	CSK5	CSK6	CSK7	CSK8	CSK9	CSK10	CSK11	CSK12	CSK13	CSK15	CSK16	CSK17				
GIS Block Total Area A (ha)	22.725	10.724	21.402	27.766	41.72	57.25	35.117	103.632	23.368	65.976	5.289	9.739	80.741	27.505	70.185	16.75	619.889	Current	Deficit Irrig	
Initial Current Actual Irrigated Area (ha)	5.68	2.68	5.35	6.94	10.43	14.31	8.78	25.91	5.84	16.49	1.32	2.43	20.19	6.88	17.55	4.19	154.97225	711.59	869.47	
Deficit managed Area (ha)	6.94	3.28	6.54	8.48	12.74	17.49	10.73	31.66	7.14	20.15	1.62	2.97	24.66	8.40	21.44	5.12	189.3548243			
Secondary Block	CSB1	CSB2	CSB3	CSB4	CSB5	CSB6	CSB7	CSB8	CSB9	CSB10	CSB11	CSB12	CSB13	CSB14						
GIS Block Total Area A (ha)	20.146	6.604	7.939	111.747	91.674	65.342	108.194	71.363	94.939	8.695	62.187	112.739	79.658	200.475	1041.702					
Current Actual Irrigated Area (ha)	5.04	1.65	1.98	27.94	22.92	16.34	27.05	17.84	23.73	2.17	15.55	28.18	19.91	50.12	260.4255					
Deficit managed Area (ha)	6.15	2.02	2.43	34.13	28.00	19.96	33.05	21.80	29.00	2.66	19.00	34.44	24.33	61.24	318.2042256					
Secondary Block	CSB15	CSB16	CSB17	CSB18	CSB19	CSB20	CSB21	CSB22a	CSB22b	CSB23	CSB24	CSB25								
GIS Block Total Area A (ha)	124.613	200.285	97.852	72.499	39.002	102.671	58.634	72.87	89.044	90.888	186.636	49.782	1184.776							
Current Actual Irrigated Area (ha)	31.15	50.07	24.46	18.12	9.75	25.67	14.66	18.22	22.26	22.72	46.66	12.45	296.194							
Deficit managed Area (ha)	38.06	61.18	29.89	22.15	11.91	31.36	17.91	22.26	27.20	27.76	57.01	15.21	361.9084245							

Dry Season - Modern Scenario with 50%Water

	Rice	Maize	Tomato
Etm(mm/season)	819	561	630
Maximum Yield Ym(t/ha)	6	6	45
Yield Red. Rate β(%)	80%	80%	80%
Yield Facto Ky	1.30	1.25	1.05
Current cropping area propotion factor	50%		

Curren Scenario with not lined Canals

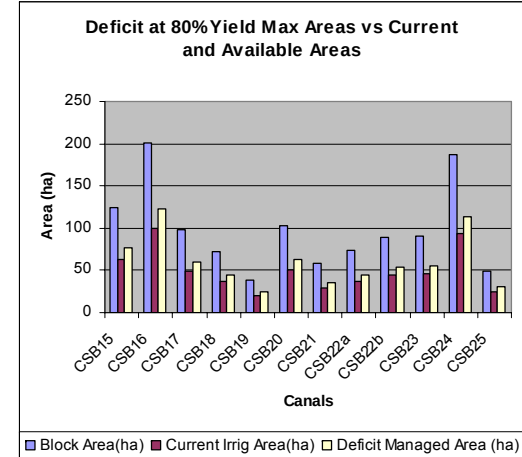
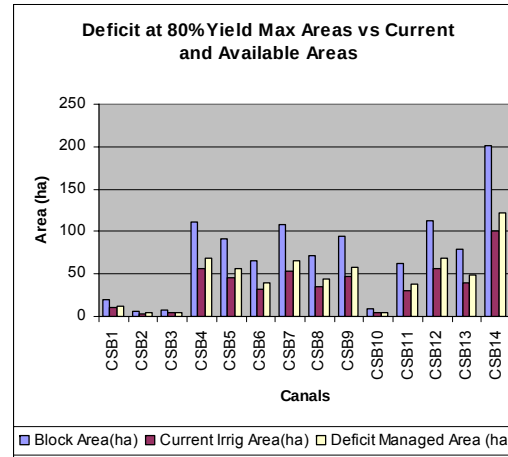
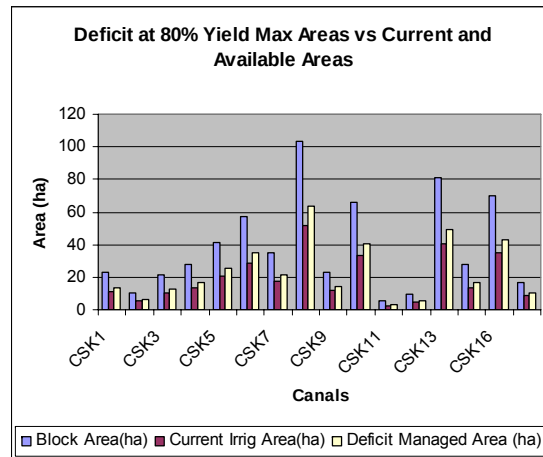
Efficiency of Secondary Canals=

Dry Season Areas (ha) percentages for each block

Remark

60% The efficiency plays only a role while transferring the required discharge from the field to the secondary intake. It is not used the deficit area computation below.

	Rice 30%	Maize 16%	Tomato 54%	Nota : conveyance efficiency=60% for the non lined secondary canals for discharge computation. Irrigation 12 hours/24												Totals	Total General
Secondary Block	CSK1	CSK2	CSK3	CSK4	CSK5	CSK6	CSK7	CSK8	CSK9	CSK10	CSK11	CSK12	CSK13	CSK15	CSK16	CSK17	
GIS Block Total Area A (ha)	22.725	10.724	21.402	27.766	41.72	57.25	35.117	103.632	23.368	65.976	5.289	9.739	80.741	27.505	70.185	16.75	619.889
Initial Current Actual Irrigated Area (ha)	11.36	5.36	10.70	13.88	20.86	28.63	17.56	51.82	11.68	32.99	2.64	4.87	40.37	13.75	35.09	8.38	309.9445
Deficit managed Area (ha)	13.88	6.55	13.08	16.96	25.49	34.98	21.45	63.31	14.28	40.31	3.23	5.95	49.33	16.80	42.88	10.23	378.7096487
Secondary Block	CSB1	CSB2	CSB3	CSB4	CSB5	CSB6	CSB7	CSB8	CSB9	CSB10	CSB11	CSB12	CSB13	CSB14			
GIS Block Total Area A (ha)	20.146	6.604	7.939	111.747	91.674	65.342	108.194	71.363	94.939	8.695	62.187	112.739	79.658	200.475			1041.702
Current Actual Irrigated Area (ha)	10.07	3.30	3.97	55.87	45.84	32.67	54.10	35.68	47.47	4.35	31.09	56.37	39.83	100.24			520.851
Deficit managed Area (ha)	12.31	4.03	4.85	68.27	56.01	39.92	66.10	43.60	58.00	5.31	37.99	68.88	48.67	122.48			636.4084512
Secondary Block	CSB15	CSB16	CSB17	CSB18	CSB19	CSB20	CSB21	CSB22a	CSB22b	CSB23	CSB24	CSB25					
GIS Block Total Area A (ha)	124.613	200.285	97.852	72.499	39.002	102.671	58.634	72.87	89.044	90.888	186.636	49.782					1184.776
Current Actual Irrigated Area (ha)	62.31	100.14	48.93	36.25	19.50	51.34	29.32	36.44	44.52	45.44	93.32	24.89					592.388
Deficit managed Area (ha)	76.13	122.36	59.78	44.29	23.83	62.72	35.82	44.52	54.40	55.53	114.02	30.41					723.816849



VIII. Crop characteristics

Table 30 : Crops growing periods and ,aximum yields

Crop		Vegetative	Flowering	Yield Formation	Ripening	Total growing period	Yield Max (t/ha)
Sorghum	Grow Priods	(I)	(II)	(III)	(IV)		
	Duration (days)	20	35	40	30	125	3.5 to 5
	Kc values	0.30	1.00		0.55		
	Root Depth Dr (m)	0.30		1.40	1.40		
	Depletion fact p	0.60		0.50	0.80		
	Yield resp factor Ky	0.20	0.40	0.55	0.20	0.90	
Maize	Grow Priods	(I)	(II)	(III)	(IV)		
	Duration (days)	25	40	40	30	135	6 to 8
	Kc values	0.30	1.20		0.50		
	Root Depth Dr (m)	0.30		1.00	1.00		
	Depletion fact p	0.50		0.50	0.80		
	Yield resp factor Ky	0.40	0.40	1.30	0.50	1.25	
tomatoes	Grow Priods	(I)	(II)	(III)	(IV)		
	Duration (days)	30	40	40	25	135	35 to 45
	Kc values	0.60		1.15	0.80		
	Root Depth Dr (m)	0.25		1.00	1.00		
	Depletion fact p	0.30		0.40	0.50		
	Yield resp factor Ky	0.50	0.60	1.10	0.80	1.05	
Rice	Grow Priods	(I)	(II)	(III)	(IV)		
	Duration (days)	50	20	35	20	125	6 to 8
	Kc values		1.00	1.05			
	Root Depth Dr (m)		n.a.				
	Depletion fact p		n.a.				
	Yield resp factor Ky	1.20	2.40	0.30			
	Note	For all crops, establishment period can be taken 10-30 days (de Laat, 2006)					
		An amount of 180 mm of water is assumed for land preparation and water layer of rice in june and november					

Sources : (OPIB [4]) (de Laat, 2006) (Smith, 1991) (Ghawi.I, 1989)

IX. Soil map digitization process

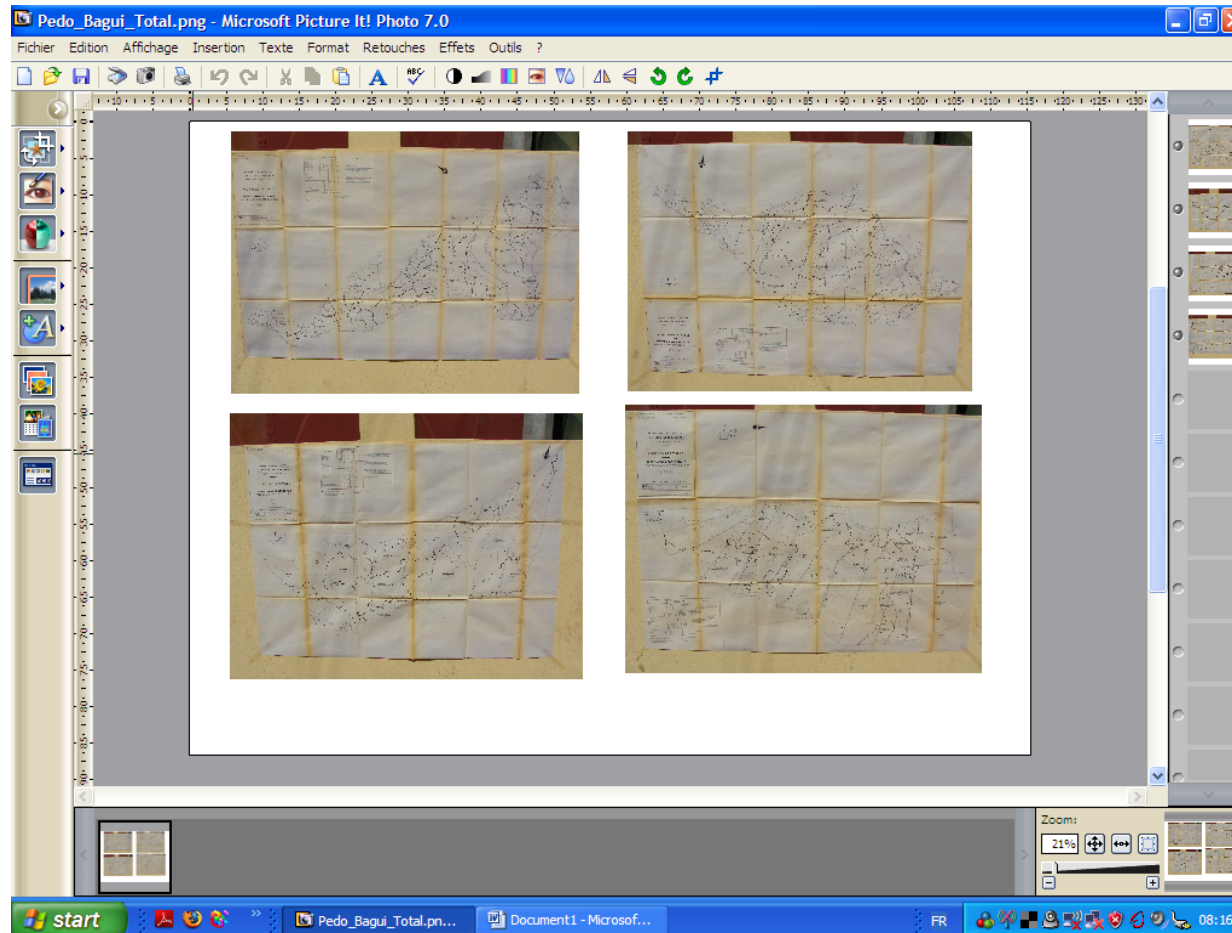


Figure 64: The BCEOM Baguineda 4 plans of soil map were at the scale 1:2,000

The map 4 pieces were pictured with high resolution of 8 mega pixels, approximately from the same distance to the operator in order to preserve the same scale for all. It can be noticed that the north arrows orientation are not parallel.

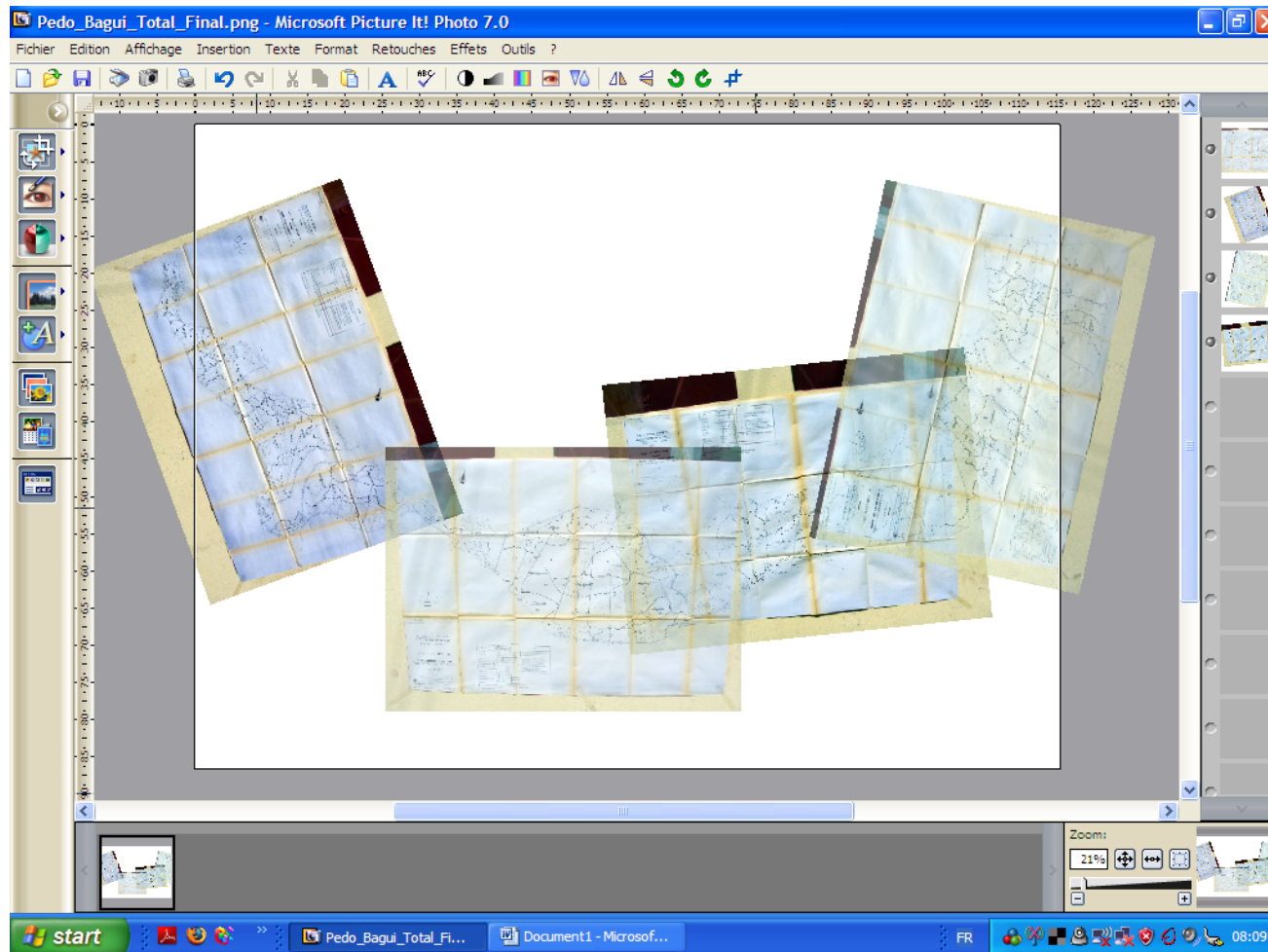


Figure 65: Joining the 4 plans of Baguineda soil map

The following actions were performed : i) automatic adjustment of the “color levels” to improve the picture reading quality, ii) rotation of each of the 4 pieces making parallel the north arrows; iii) making transparent piece 2 and piece 4; iv) superposing the pictures so that the canal network extremities match properly; v) cutting the extremities of the picture piece 1, piece 3 and piece 4 that were in front of piece 2 , and cutting piece 4 that was in front of piece 3; vi) making opaque all the 4 pieces and joining them into a single one piece.

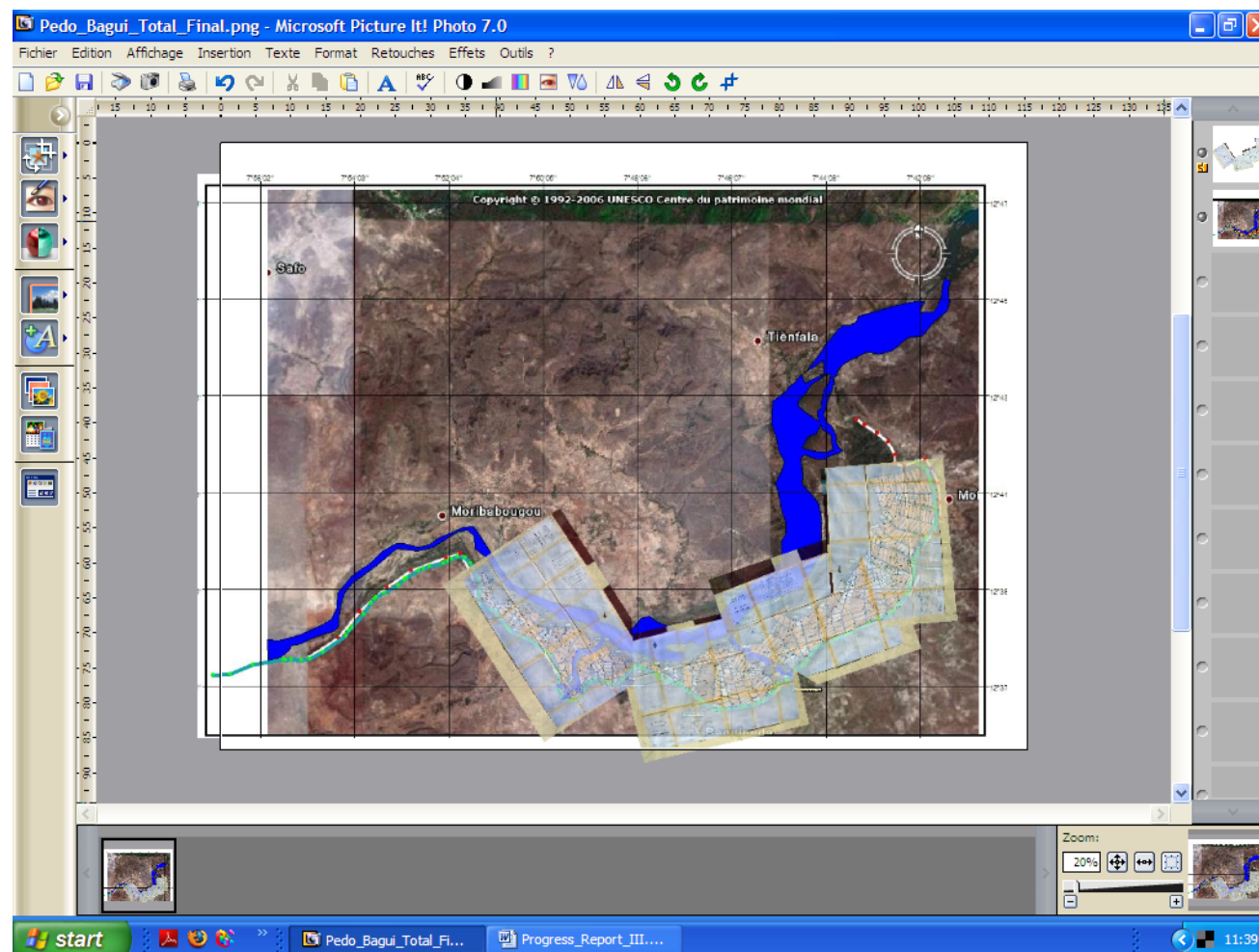


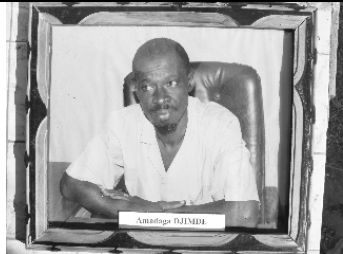
Figure 66: Scaling the pedological map

Afterwards, the picture is scaled using the map of Baguineda constructed in Arview 3.3. The north arrows are made parallel and the sizes fitting.

X. Directors of OPIB

Table 31: OPIB Directors before 1942 to nowadays

First and last names	Function starting date	Departure date	Picture
Seydou Bassié TOURÉ	2006	—	
Salikou SANOGO	2001	2006	
Dassé BOUARE	1996	2001	
Moussa KANTE	1989	1996	

First and last names	Function starting date	Departure date	Picture
Amadaga DJIMDE	1980	1989	 A black and white portrait of a man with a beard, wearing a light-colored shirt, sitting at a desk. A small label at the bottom of the photo reads "Amadaga DJIMDE".
Sambou TRAORE	1976	1976	 A black and white portrait of a man with a beard, wearing a dark jacket over a light shirt. A small label at the bottom of the photo reads "Sambou TRAORE".
Bocar Sada DIALLO	1968	1976	
Nansiamma KONATE	1965	1968	 A black and white portrait of a man with short hair, wearing a suit and tie. A small label at the bottom of the photo reads "Nansiamma KONATE".
Bakary COULIBALY	1965	1965	

First and last names	Function starting date	Departure date	Picture
Amadou BAH	1964	1965	
Kantara CISSOKO	1963	1964	
DESTRILLO	1962	1963	
BEROGUIN	1961	1962	
BOUASSET	1945	1961	
DELLONE	1943	1945	
MATHIEU	1942	1943	
PICATEAU		1942	