THE ROUGHNESS COEFFICIENT : AN INDIRECT WITNESS TO OBSERVE A CANAL?

A methodology based on the use of a simulation model of flow in irrigation canals.

LE COEFFICIENT DE RUGOSITÉ : UN TÉMOIN INDIRECT POUR OBSERVER UN CANAL ?

Une démarche fondée sur l'utilisation d'un modèle de simulation d'écoulement dans les canaux d'irrigation

by

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FRENCH / ENGLISH GLOSSARY
GLOSSAIRE FRANCAIS / ANGLAIS

accuracy	précision
actually	en fait
calibration	calage
cross regulator	régulateur en travers
cross structure	ouvrage en travers
dam	barrage
discharge	débit
downstream	(à l')aval
elevation	cote
flow	écoulement
free flow	écoulement dénoyé
gate	vanne
head	charge
head loss	perte de charge
headworks	ouvrages de tête
hydraulic radius	rayon hydraulique
inaccuracy	imprécision
maintenance	entretien

offtake	prise
open channel flow	écoulement à surface libre
pipe flow	écoulement en charge
raw data	données brutes
reach	bief
roughness	rugosité
seepage	infiltration
siltation	sédimentation
sluice	vanne à glissière
steady flow	écoulement permanent
submerged flow	écoulement noyé
tail end	extrémité
tract	sous-unité du canal
unsteady flow	écoulement non permanent
upstream	(à l')amont
water level	tirant d'eau
wetted perimeter	périmètre mouillé

ACRONYMES / ABREVIATIONS

DC	Distributory Channel	Canal secondaire
D/S	downstream	aval ou à l'aval
FC	Field Channel	Canal tertiaire
GR	Gate Regulator	Régulateur à vanne
RBMC	Right Bank Main Canal	Canal Principal Rive Droite
SIC	Simulation of Irrigation Canals	Logiciel de simulation d'écoulements
SFP	Steady Flow Period	Période d'Ecoulement Permanent
U/S	upstream	amont ou à l'amont

TABLE OF CONTENTS

Page

RÉSUMÉ EN FRANCAIS i

ABSTRACT IN ENGLISH vii

A. OBJECTIVES AND BACKGROUND OF THE STUDY 1

1. OBJECTIVES

2. GENERAL FEATURES OF THE KIRINDI OYA IRRIGATION AND SETTLEMENT SCHEME 3

3. MANAGEMENT OF A MAIN CANAL AND SIMULATION MODEL OF FLOW 7

4. PRINCIPAL FEATURES OF SIC MODEL 8

5. SIC, A TOOL IN A WIDER IRRIGATION MANAGEMENT INFORMATION SYSTEM 10

B. METHODOLOGY OF THE STUDY : THE STRICKLER COEFFICIENT, AN INDIRECT WITNESS TO OBSERVE A CANAL ? 13

1. PHYSICAL MEANING OF THE STRICKLER COEFFICIENT 15

1.1 HYDRAULIC BACKGROUND

a. Explanation of Manning Strickler formula

b. Conditions of flow in most irrigation canals 17

c. Limitations in the use of Manning-Strickler formula 18

d. Strickler coefficient K calibration in SIC

1.2 RESTRICTED MEANING OF K : INDICATOR OF ROUGHNESS IN A CANAL 23

1.3 WIDER MEANING : INDICATOR OF PHYSICAL STATUS OF A CANAL 24

2. FROM FIELD COLLECTED RAW DATA TO CALIBRATED SETS OF STRICKLERS 25

2.1 ISOLATING STEADY FLOW PERIODS IN THE DATA : PROGRAM SPF

a. Necessary conditions at each boundary cross section

b. Necessary conditions for the reach 26

2.2 EXTRACTING AND SHAPING USEFUL HYDRAULIC DATA : PROGRAM SFP 33

2.3 OBTAINING SETS OF STRICKLER : SIC CALIBRATION MODULE

3. FROM CALIBRATED SETS OF STRICKLER TO INDIRECT INFORMATION ABOUT THE PHYSICAL STATUS OF A CANAL 34

3.1 EXPECTING TRENDS AND JUMPS IN SETS OF K

a. Evolution of K through time : qualitative and quantitative approaches

b. Appropriated data analysis techniques : Robust methods 40

c. Confront the trends with accuracy on K 42

3.2 SIMULATING SILTATION/EROSION IN THE CANAL 43

a. Simulation and accuracy of K

b. Simple transformations 44

c. Testing a scenario 45

d. Implementing a simulation 47

C. TEST OF THE METHODOLOGY ON KO RBMC 49

1. GETTING ACCURACIES ON FIELD MEASUREMENTS AND CALCULATED PARAMETERS

1.1 WATER LEVEL MEASUREMENT ACCURACIES U/S AND D/S CROSS STRUCTURES

a. Data Collecting

b. Data Analysis 52

1.2 DISCHARGE ACCURACY AT THE CROSS STRUCTURES 55

1.3 CALIBRATED STRICKLER VALUES ACCURACY 56

a. Interest

b. Protocol

c. Results 59

2. CALIBRATION OF STRICKLER COEFFICIENTS 63

2.1 1988'S SET OF DATA 63

2.2 MAHA 1991-1992'S SET OF DATA 64

a. Preliminary remarks

b. Main results 65

c. Complementary results 69

BIBLIOGRAPHY 75

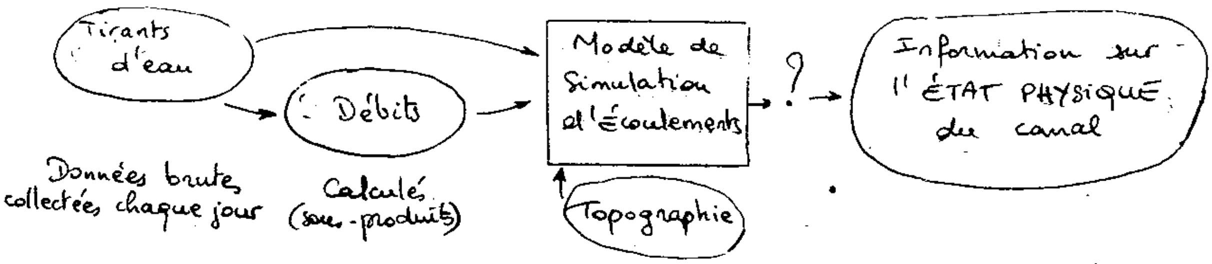
ANNEXES

RÉSUMÉ

1. Est-il possible d'extraire de l'information concernant l'évolution au cours du temps de l'état physique d'un canal d'irrigation en utilisant :

- des données recueillies facilement sur le terrain : mesures de niveaux d'eau dans différentes sections en travers (et des débits comme l'un de leurs sous-produits) ;

- un modèle de simulation de flot ?



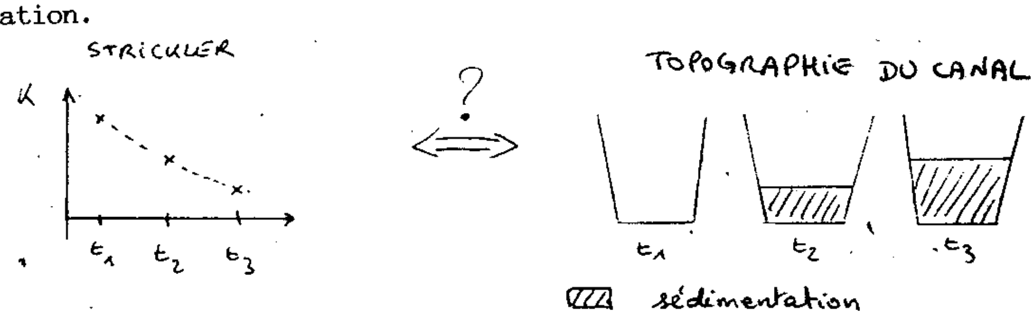
Si c'est le cas, la prévision d'un état futur du canal pourrait être possible et le planning de l'entretien du canal facilité.

Dans le présent document, une méthodologie pour répondre à cette question est mise au point et testée sur un canal situé dans le sud du Sri Lanka : le Canal Principal Rive Droite de Kirindi Oya (KO RBMC), où l'équipe de Modélisation et de Simulation de la Division Recherche de l'IIMI expérimente plusieurs améliorations dans la gestion de canaux depuis 1991. La présente étude est fondée sur l'utilisation du logiciel SIC (Simulation of Irrigation Canals) développé par le CEMAGREF.

2. La méthodologie consiste à :

- Condenser le comportement hydraulique du système physique (l'eau dans un canal d'irrigation) en un paramètre physique spécifique : le coefficient de rugosité de Strickler, K. K contient en général une information concernant les frottements du canal et sa résistance aux écoulements, mais est ici chargé d'un sens plus large, comprenant les transformations de la topographie et les imprécisions sur les mesures de terrain. Cette étape est rendue possible par l'existence d'un module de calage de Strickler dans SIC ;

- Analyser l'évolution de K dans le temps et essayer de la corréler avec l'évolution de l'état physique du canal, en particulier sa topographie : érosion, sédimentation.



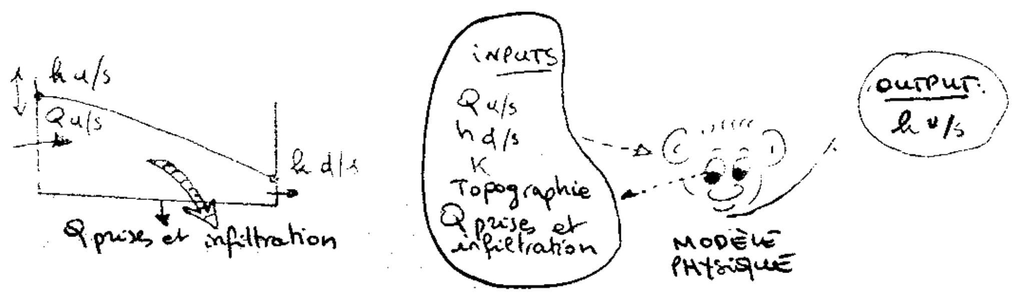
Dans les conditions de fonctionnement recherchées par les gestionnaires du canal, le comportement hydraulique du système physique peut être décrit par l'équation dynamique de l'écoulement comme suit :

f (variables hydrauliques, variables topographiques) = 0

Sur un bief, c'est-à-dire une portion de canal limitée par deux sections en travers :

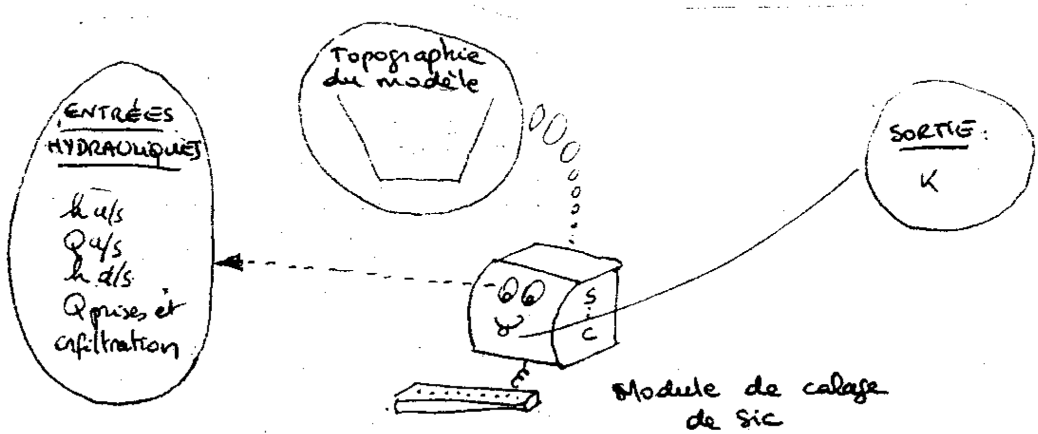
f [Qu/s, Qprises et infiltration, hu/s, hd/s, K, topographie (pente du lit, géométrie des sections en travers)] = 0

Sur KO RBMC, pour chaque bief situé entre deux régulateurs, le système physique réagit aux entrées hydrauliques fixées par les gestionnaires du canal (Qu/s, hd/s, Qprises) de la manière suivante :



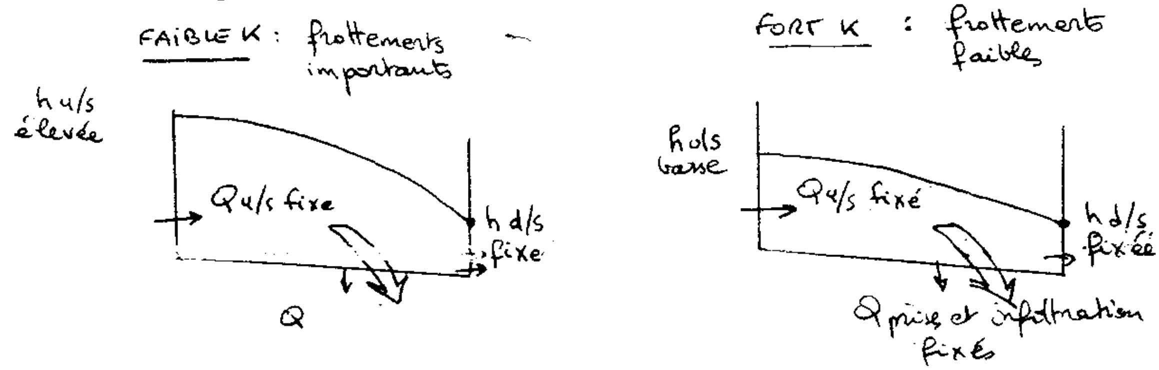
Ce comportement peut être prédit par une simulation de l'écoulement.

Le module de calage de SIC agit de façon différente :



Il est utilisé en considérant les données topographiques comme des constantes (fixées une fois pour toutes dans le modèle), les données hydrauliques comme entrées, K comme résultat.

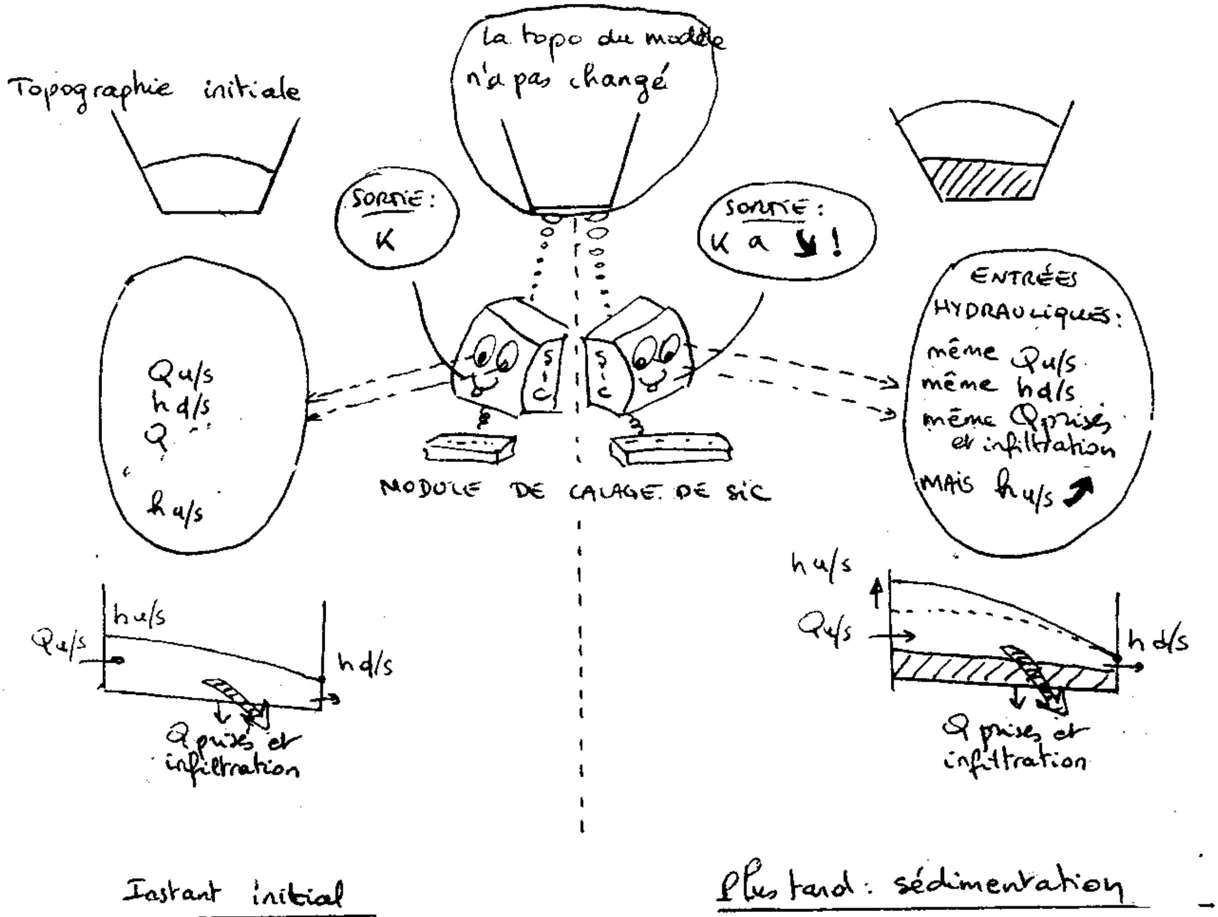
Si la topographie réelle ne change pas, K représente seulement la rugosité et ne devrait pas dépendre des conditions hydraulique de l'écoulement. Etant donné un jeu de conditions de contrôle hydraulique (Qu/s, hd/s, Qprises et infiltration), K et hu/s sont qualitativement corrélés de la manière suivante :



Si la topographie varie avec le temps, le module de calage de SIC ne le "voit" pas et pour le même jeu de données de contrôle (Qu/s, hd/s,Qprises et infiltration) :

- le système physique va réagir en changeant hu/s ;

- le module de calage de SIC va réagir en changeant la valeur de K.



Une tendance à la baisse de K dans le temps doit pouvoir être rapportée à de la sédimentation, une tendance à la hausse à de l'érosion.

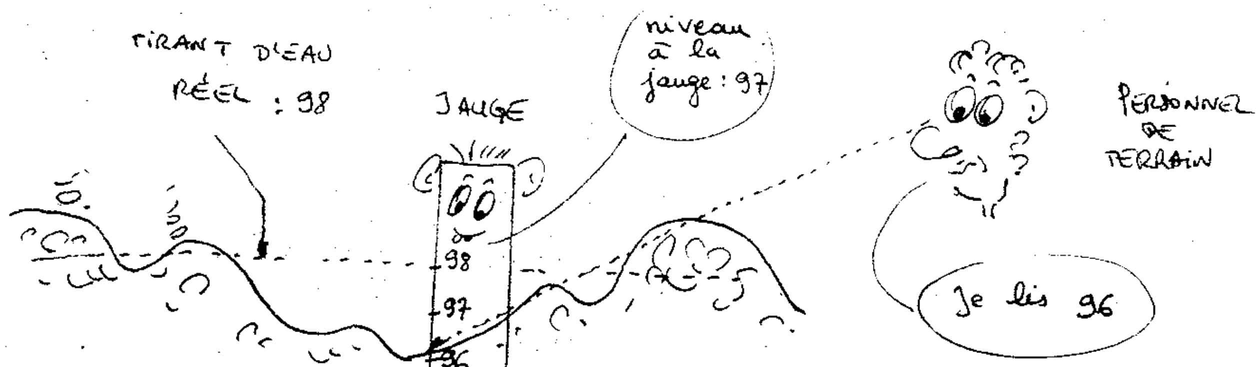
3. Les données recueillies sur le terrain sont stockées dans une base de données. Pour des raisons hydrauliques, pour caler des valeurs sensées de K, il faut choisir les seuls enregistrements correspondant à des périodes où l'écoulement dans le canal est permanent, en d'autres termes où les tirants d'eau et les débits sont stables. Déterminer des périodes d'écoulements permanents (SFP) dans les données est une étape préliminaire. Elle est réalisée grâce à un programme écrit en langage de programmation DBASEIII+.

Cette étape n'est plus un problème d'hydraulique mais un problème de gestion des imprécisions sur les données recueillies sur le terrain : la stabilité d'un paramètre est une notion relative aux imprécisions de mesure.

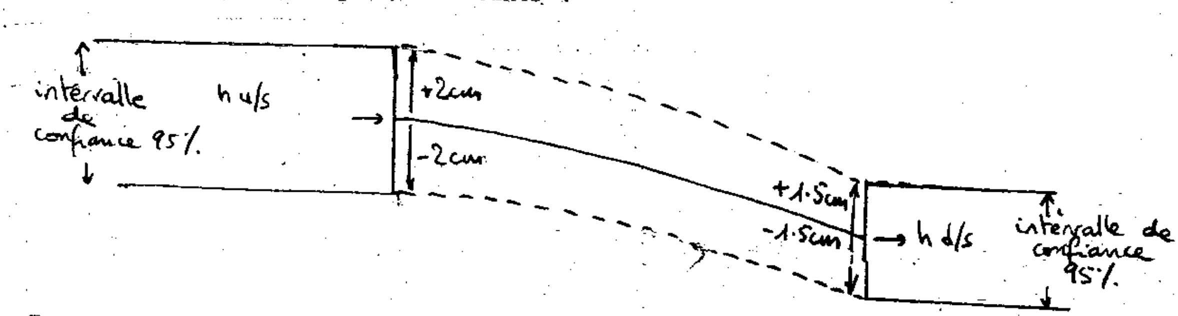
Dans le cas des mesures de tirants d'eau en travers d'une section, deux sources d'imprécision se combinent :

- Le tirant d'eau en travers d'une section est une variable aléatoire à cause de la turbulence de l'écoulement, en particulier à proximité de sections singulières comme les régulateurs. Un niveau relevé à une jauge est une estimation statistique de cette variable aléatoire ;

- La lecture d'une jauge par le personnel de terrain est source d'imprécision puisque la jauge est une échelle discrète.



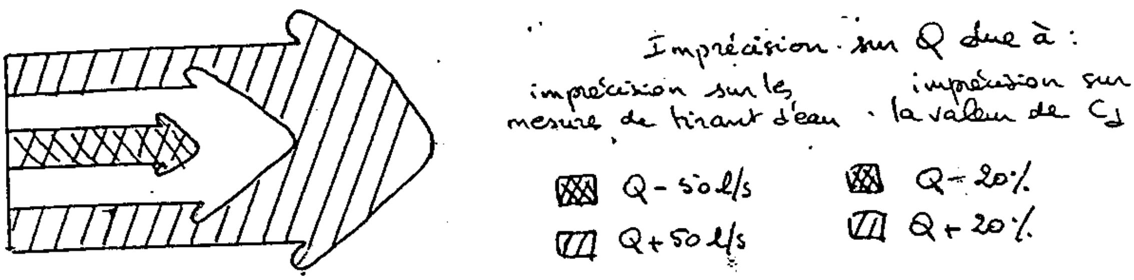
En fait, le raisonnement porte non sur des valeurs, mais sur des intervalles de confiance. Par exemple, sur RBMC :



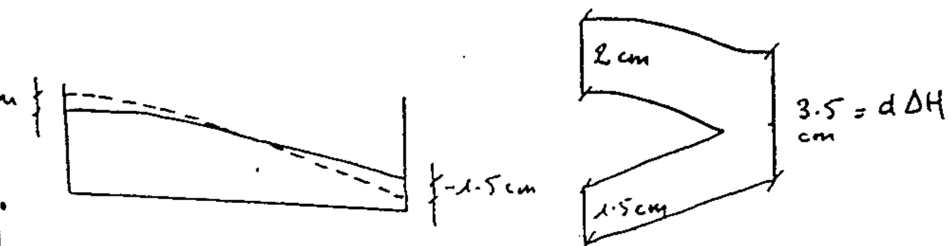
Dans le cas des débits Q, calculés en utilisant les tirants d'eau hu/s et hd/s d'un ouvrage, les ouvertures des vannes w et les coefficients de débit Cd par l'intermédiaire de lois du type Q=Cd f(hu/s,w,hd/s), deux sources d'imprécision ont aussi été prises en considération :

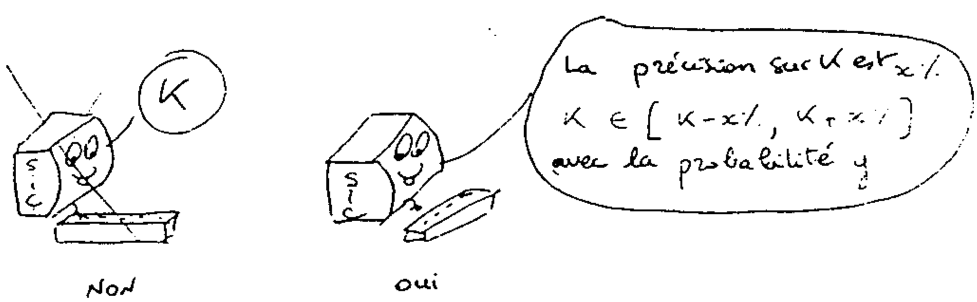
- l'imprécision sur les mesures de tirants d'eau ;

- l'imprécision sur les coefficients de débit, particulièrement sensible lorsque une valeur arbitraire est fixée alors que Cd dépend des conditions de l'écoulement. Sur KO RBMC, ces deux sources ont été quantifiées séparément :

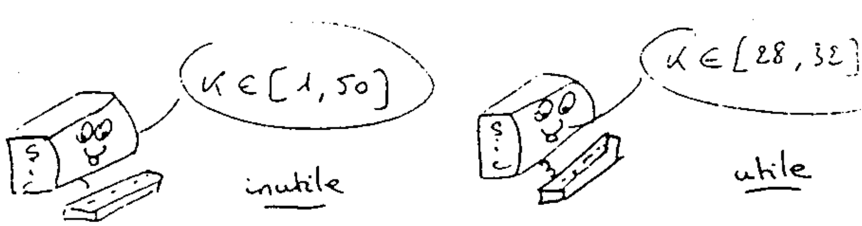


4. Lorsque les données hydrauliques représentant une SFP ont été sélectionnées, on peut utiliser le module de calage de Strickler de SIC. Le résultat du calage n'est pas une VALEUR de K mais un INTERVALLE DE CONFIANCE. Ses limites dépendent largement de la précision sur la perte de charge DH dans le bief : selon notre traitement des données, dK/K=-dDH/DH pour une gamme donnée de débits.



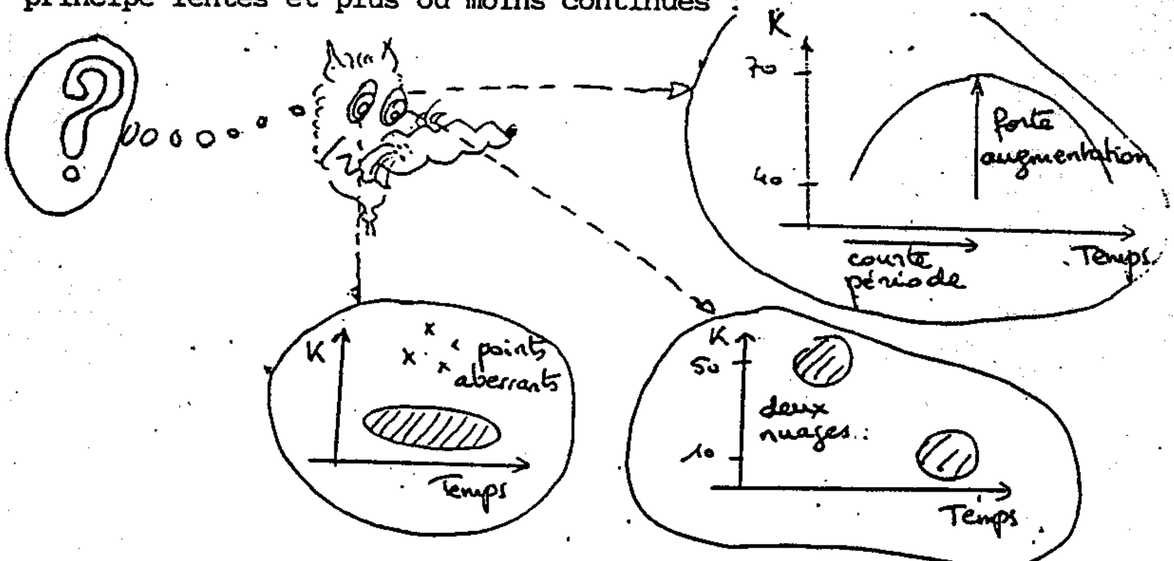


Par conséquent, selon les valeurs de K, DH et dDH, le résultat du calage peut être ou non utile. Par exemple, si une valeur de 30 a été calée, cela peut signifier :



5. Le traitement des données sur 14 biefs de RBMC, recueillies pendant 4 mois lors de la saison principale de culture (sept 1991-mai 1992), a conduit à des jeux de Strickler. La taille d'échantillon de 7 d'entre eux a permis une analyse statistique fondée sur des méthodes de régression multiple dites "robustes".

Les graphes de K en fonction du temps (T) ont abouti à de surprenants résultats : de très fortes variations de K sur des périodes courtes, l'existence de nuages de point distincts et de points aberrants qui, de toute évidence, ne peuvent pas être expliqués seulement par des modifications de topographie qui sont en principe lentes et plus ou moins continues :



En fait, des variables hydrauliques (Qu/s, hu/s) ont expliqué la plus grande partie de la variabilité de K. En éliminant l'effet de ces variables, l'absence de corrélation entre K et T a été mis en évidence.

~~K(T)~~ NON — RBMC Sept 91-Mai 92 — K(Q(T)) ou K(hu/s(T)) oui

6. Comme un jeu de Strickler a pu être calé avec des données hydrauliques recueillies en 1988, une tentative pour comparer la valeur de 1988 et le jeu de données de 1991-1992 a été menée. Les intersections des intervalles de confiance sur K ne sont pas vides, sauf pour un bief. Globalement, on ne peut mettre en évidence aucun changement significatif de K entre les données de 1988 et celles de 1992.

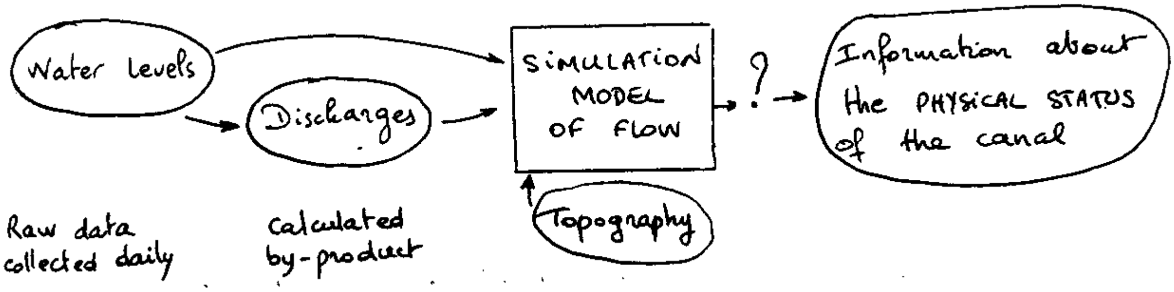
7. Ayant été conçue pour permettre un usage général sur n'importe quel canal d'irrigation, la méthodologie est prête pour être testée ailleurs. Ceci serait nécessaire pour vérifier sa capacité à détecter des changements significatifs de topographie (sédimentation ou érosion se sont montrés non détectables sur la période de 4 mois étudiée), et pour expliquer si la dépendance des Stricklers calés vis-à-vis de paramètres hydrauliques (Qu/s, hu/s) est spécifique à RBMC ou au module de calage de SIC.

ABSTRACT

1. Is it possible to extract information about the evolution through time of the physical status of an irrigation canal using :

- data easily collected on the field : water level measurements in several cross sections (and discharges as one of their by-products) ;

- a simulation model of flow ?



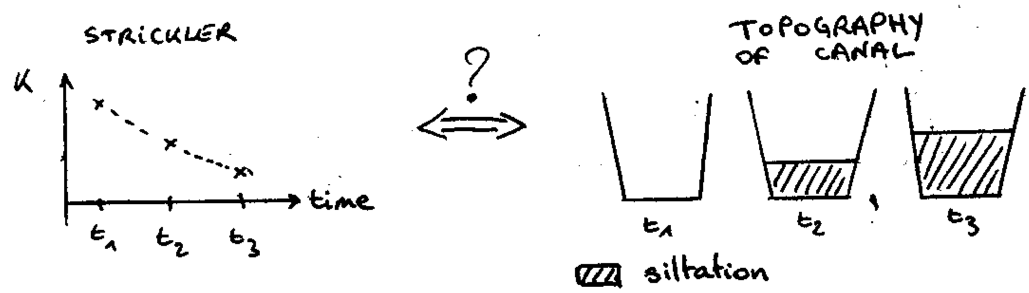
If it is the case, prediction of the future status of the canal should become possible and maintenance planning facilitated.

In the present document, a methodology to answer this question is elaborated and tested on a canal located in the South of Sri Lanka : Kirindi Oya Right Bank Main Canal (KO RBMC), where the Simulation Modelling team of IIMI's Research Division has been experimenting several improvements in the management of canals since 1991. The present study is based on the use of the software SIC (Simulation of Irrigation Canals) developed by CEMAGREF, a French public-funded research institute.

2. The methodology consists in :

- Condensing the hydraulic behavior of the physical system (water in an irrigation canal) into a specific physical parameter : the Strickler's coefficient of roughness, K. K usually carries information about canal friction and resistance to flow, but is here burdened with a wider meaning, including transformations of topography and inaccuracies on the field measurements. This stage is possible thanks to a Strickler calibration module in SIC.

- Analyzing the evolution of K through time and try to correlate it with the evolution of the physical status of the canal, particularly its topography : erosion, siltation.



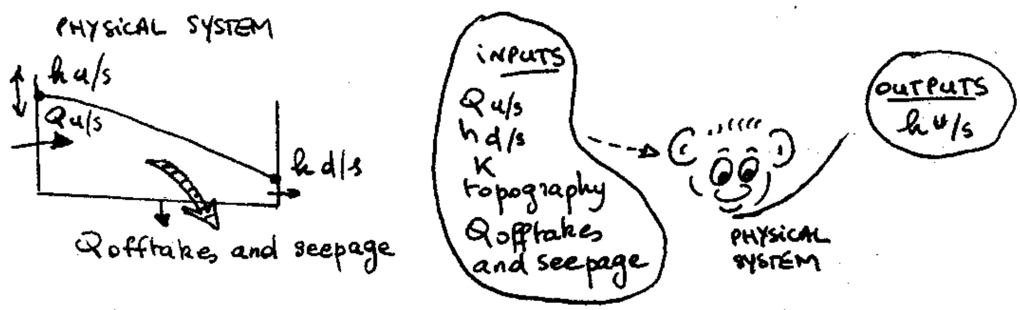
In the managers'target conditions of functioning of the canal, the hydraulic behavior of the physical system can be described by the dynamic equation of flow as :

f (hydraulic variables, topographic variables) = 0

In a reach, i.e. a portion of the canal delimited by two boundary cross sections :

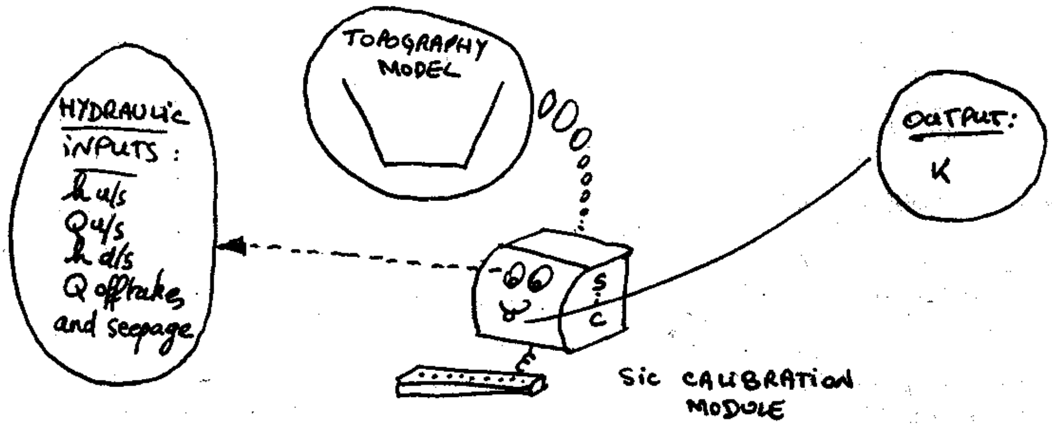
f [Qu/s, Qofftakes and seepage, hu/s, hd/s, K, topography (bed slope, cross section geometry)] =0

In KO RBMC, on each reach located between two cross regulators, the physical system reacts to hydraulic inputs fixed by the managers of the canal (Qu/s, hd/s, Qofftakes) in the following way :



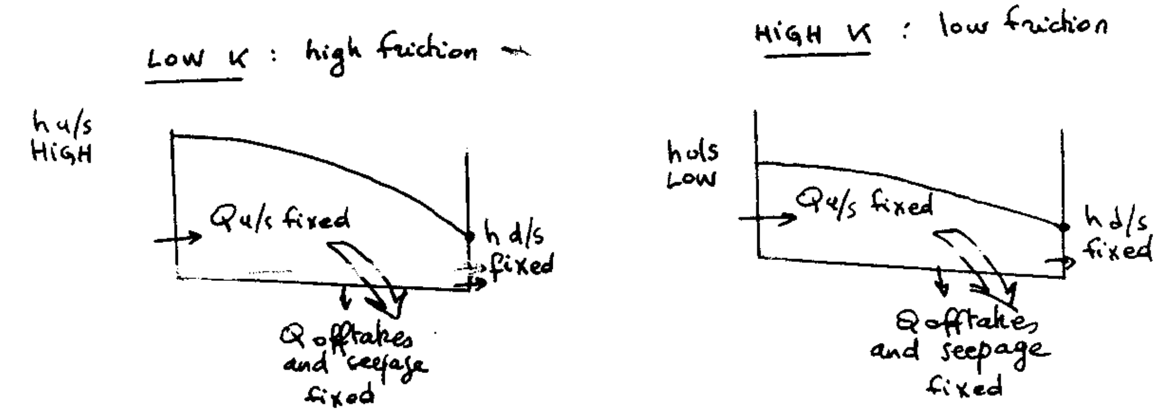
This behavior can be predicted by the simulation of flow.

SIC Strickler calibration module operates in a different way :



It is used considering topographic data as constants (fixed once for all in the model), hydraulic data as inputs, K as an output.

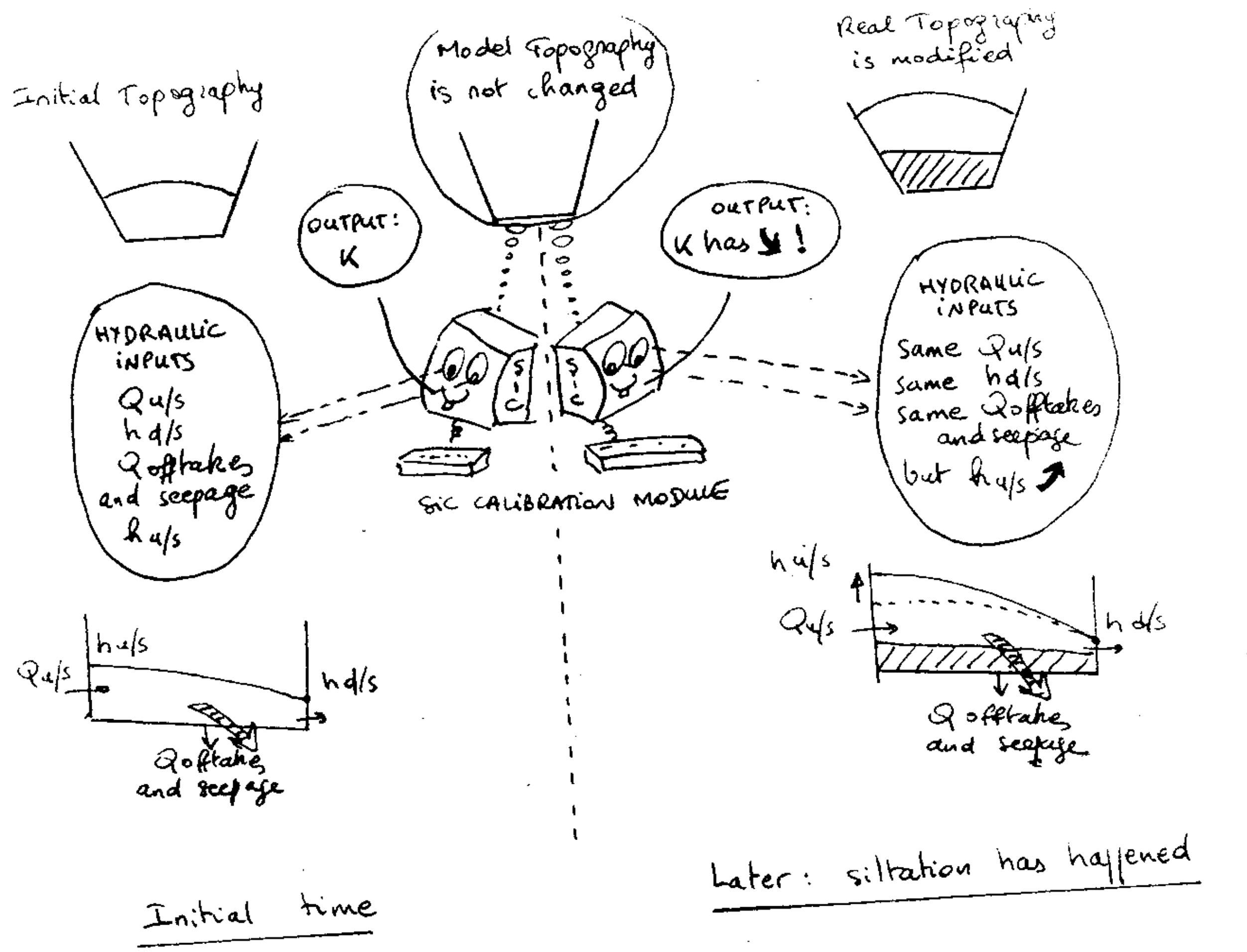
If the real topography does not change, K stands only for the roughness and is expected to be independant on hydraulic conditions of flow. Given a set of hydraulic control conditions (Qu/s, hd/s, Qofftakes and seepage), K and hu/s are qualitatively correlated in the following way :



If the real topography is modified through time, SIC calibration module cannot "see" it, and for the same hydraulic control conditions (Qu/s, hd/s, Qofftakes and seepage) :

- the physical system will react changing hu/s ;
- SIC calibration module will react changing the value of K.

In that case, K stands both for roughness and changes in topography. For instance, if a phenomenon of siltation happens :



A downward trend of K through time should be related with siltation, an upward trend with erosion.

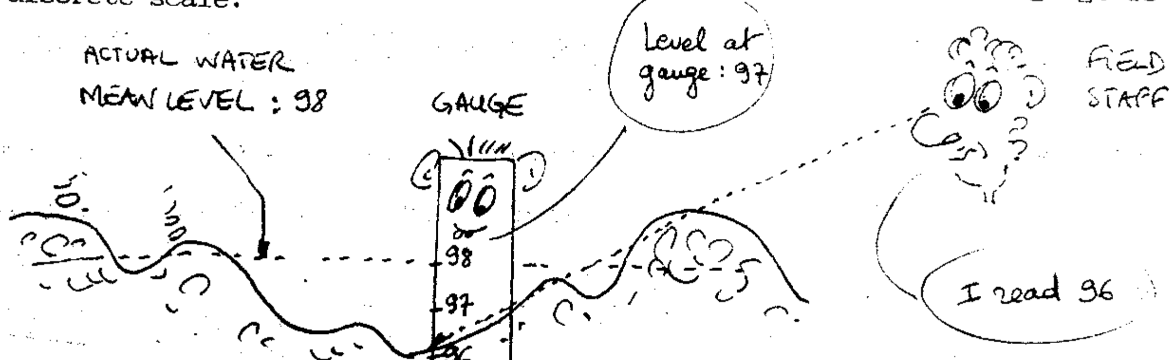
3. The field-collected raw data are stored in a database. Because of hydraulic reasons, to calibrate meaningful values of Strickler, it is necessary to select only the records corresponding to periods where the flow in the canal is in STEADY conditions, i.e. stable water levels and discharges. Determining Steady Flow Periods (SFPs) in the data is a preliminary step. It is achieved thanks to a program written in DBASEIII+ programmation language.

This stage is not any more a hydraulic problem but a problem of management of the inaccuracies on the field-collected data : the stability of a parameter is a notion relative to the inaccuracies of the measurements.

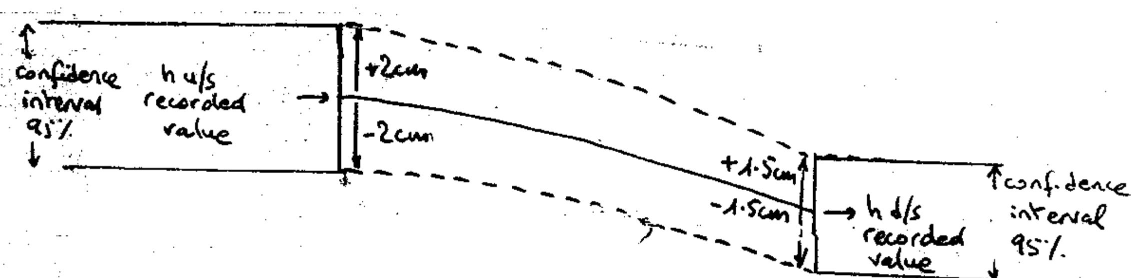
In the case of water level measurements across a section, two sources of inaccuracy interfere :

- The water level across a section is a random variable because of natural turbulence, particularly close to to singular sections such as cross regulators. A level at a gauge is an estimate of this random variable ;

- The reading of a gauge by field staff brings inaccuracy as the gauge is a discrete scale.



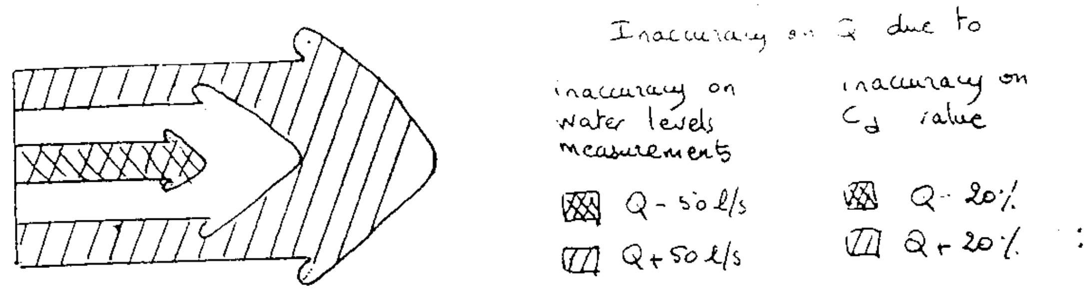
Actually, the reasoning rests not on values, but on confidence intervals. For instance, on KO RBMC :



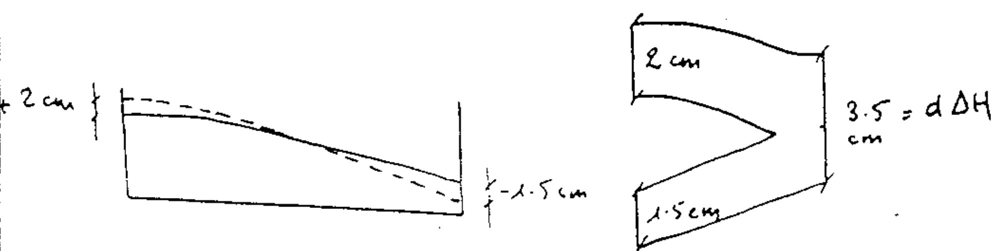
In the case of the discharges Q, computed using water levels hu/s and hd/s, opening of gates w and discharge coefficients Cd through laws such as Q=Cd.f(hu/s,w,hd/s), two sources of inaccuracy were also considered :

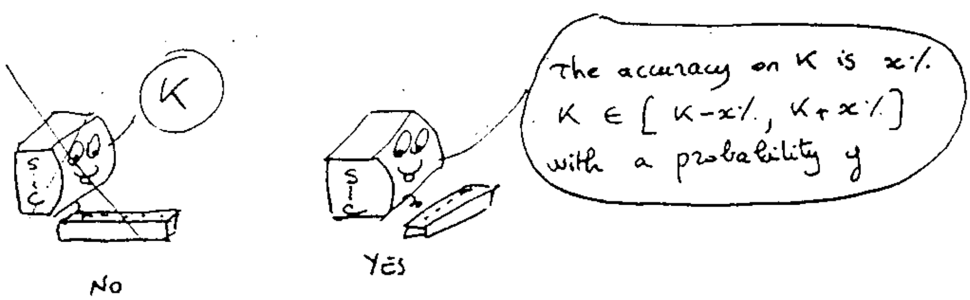
- inaccuracy on water level measurements ;

- inaccuracy on discharge coefficients, particularly sensitive when an arbitrary fixed value is used whereas Cd depends on the flow conditions. On KO RBMC, these two sources were quantified separately :

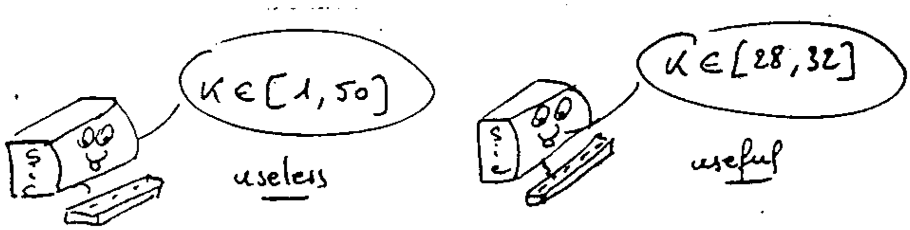


4. When hydraulic data standing for a SFP are selected, it is possible to use SIC Strickler calibration module. The result of a calibration is not a VALUE of K, but a CONFIDENCE INTERVAL. Its boundaries largely depend on the accuracy on the head loss DH in the reach : in our process, dK/K=-dDH/DH for a given range of discharges.



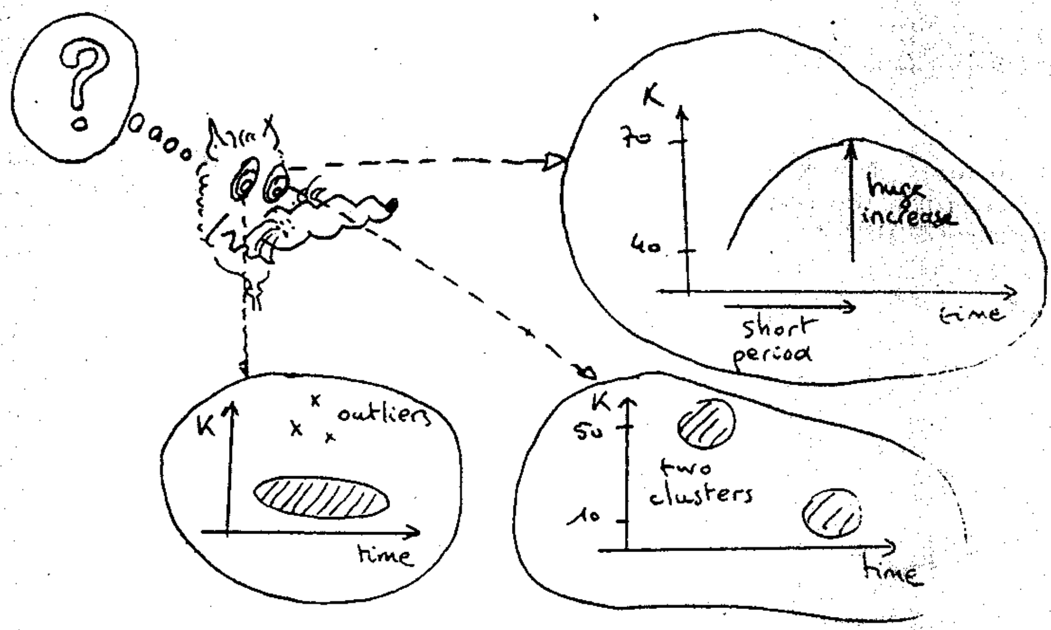


Consequently, following the values of K, DH and dDH, the output of SIC calibration module can be either useful or useless. For instance, if a value 30 was calibrated, it should mean :

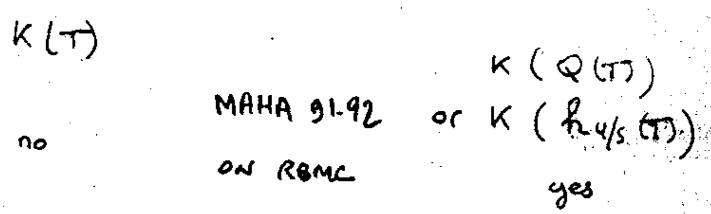


5. The process of data on 14 reaches of KO RBMC, collected during 4 months out of the main cultivation season (Sept 1991-May 1992), lead to calibrated sets of Stricklers. The sample size of 7 among these allowed statistical analysis, based on robust multiple regression methods.

Plotting K vs time (T) ended up to surprising results : huge variations of K in a short time, existence of separate clusters and of outliers that obviously could not be explained by modifications of topography which are slow and more or less continuous :



Actually, hydraulic variables (Qu/s, hu/s) explained most of the variability in K. Removing the effects of these variables allowed to underline a lack of correlation between K and T. In other words, K did not vary significantly during the season.



6. As a set of Stricklers could be calibrated with hydraulic data collected in 1988, en attempt to carry out a comparison between 1988 and 1991's sets of K was considered. Unfortunately, too wide confidence intervals on the values of 1988 made it impossible that comparison , except on 2 reaches where no significant evolution was underlined.

7. As it was elaborated to allow a general use in any irrigation canal, the methodology is ready to be tested in other locations. This should be necessary to check its capacity to detect significant changes in the topography (siltation on erosion proved to be minor in RBMC within a period of 4 months), and to investigate further if the dependance of K on hydraulic parameters (Q, hu/s) is RBMC-specific or SIC calibration module-specific.

A. OBJECTIVES AND BACKGROUND OF THE SURVEY

1. OBJECTIVES

When a manager of a canal irrigation needs to plan maintenance operations (removing weeds in the banks or in the bed, desilting the bed), he can use several tools to identify where the action is a priority :

- visual inspection, possibly combined with sonar measurements, to determine the maximum density of vegetation along the canal ;[1]
- comparative topography surveys between two dates, to directly measure the changes in the cross sections of the canal : bank erosion, bed siltation.[2]

Yet, in some canals, such topography surveys are not possible as there is water in the canal all year long. Then it becomes highly hypothetical to locate and quantify the evolution of the physical status of the canal. In these conditions, action can hardly be optimized.

When a direct investigation is not possible, one possible solution should be to find a physical parameter which would indirectly give qualitative and quantitative information on weed growth, erosion and siltation.

Moreover, if the evolution of the physical status of the canal can be quantitatively linked with the evolution of that indirect witness, forecast should become possible and the planning of maintenance should rely on an improved knowledge of the behavior of the canal.

The present survey aims at answering :

Can the Strickler coefficient of roughness, K, be an indirect witness to observe the physical evolution of an irrigation canal ?

Based on the experience of the Kirindi Oya Right Bank Main Canal (KO RBMC), in the South of Sri Lanka, and on the use of a mathematical model of simulation of flow in irrigation canals, the Simulation Modelling team of the International Irrigation Management Institute's Research Division asked me to elaborate a methodology and various tools to answer that question and test it on KO RBMC.[3]

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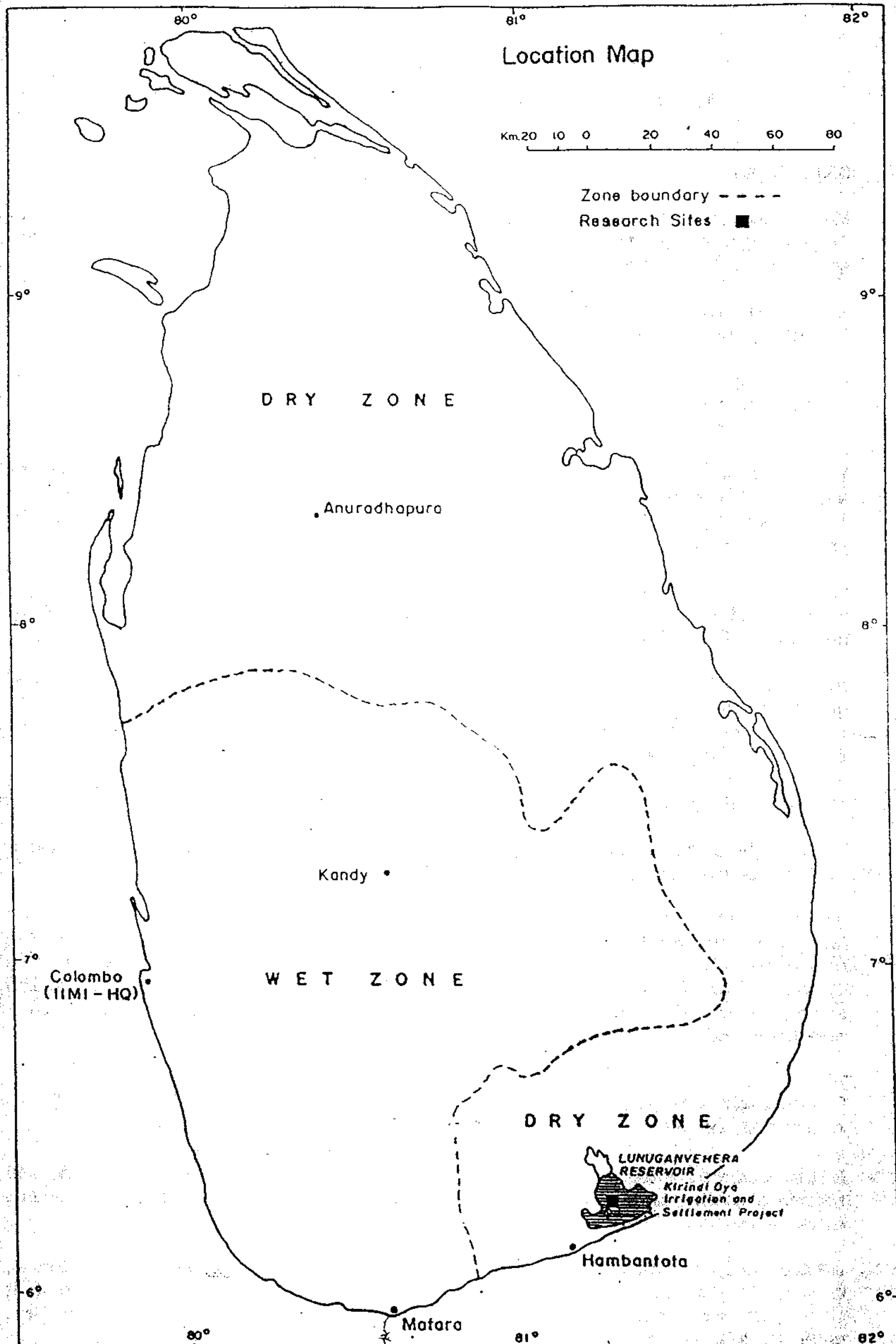
1 For aquatic weeds management problem, see in particular, publications of BRABBEN, T.E., from Hydraulics Research, Wallingford, UK, and KHATTAB, A.F., from Research Institute of Weed Control and Channel Maintenance, Cairo, Egypt.

2 Quantitative design and performance predictions methods for canal sediment control structures such as Vortex tube and tunnel type sediment extractors can be found in the publications of LAWRENCE, P., and ATKINSON, E. from Hydraulics Research, Wallingford, UK.

3 In BRABBEN, T.E., 1986, "Monitoring the effect of aquatic weeds in Egyptian Irrigation Systems", Hydraulics Research, Wallingford, UK, an attempt to link the change in the roughness parameter with the annual life cycle of weed growth is conducted, but the basic data are not numerous enough to clarify the relationship between weed growth and Strickler's coefficient. No article was found about how to calculate siltation or erosion with the Strickler's coefficient.



Location Map
Km.20 10 0 20 40 60 80
Zone boundary
Research Sites
80°
81°
82°
9°
8°
7°
6°
DRY ZONE
Anuradhapura
Kandy
Colombo
(IIMI - HQ)
WET ZONE
DRY ZONE
LUNUGANVEHERA
RESERVOIR
Kirindi Oya
Irrigation and
Settlement Project
Hambantota
Matara

2. GENERAL FEATURES OF THE KIRINDI OYA IRRIGATION AND SETTLEMENT SCHEME

. Location:

The project area is in the dry zone of the island, in its south east quadrant about 260 km from COLOMBO. It is located on both banks of the KIRINDI OYA river between the LUNUGANWEHERA tank in the north and coastal lagoons in the south.

The scheme consists of the previously developed ELLAGALA and BADAGIRIYA areas and two new areas, the right and left bank area.

The major source of irrigation water for the project is the 200 million m^3 LUNUGANWEHERA Reservoir. The five old tanks located in the ELLAGALA area are now obtaining most of their supply from this main Reservoir via the Left Bank Main Canal (LBMC). The BADAGIRIYA tank also receives water from the LUNUGANWEHERA reservoir via the Right Bank Main Canal (RBMC).

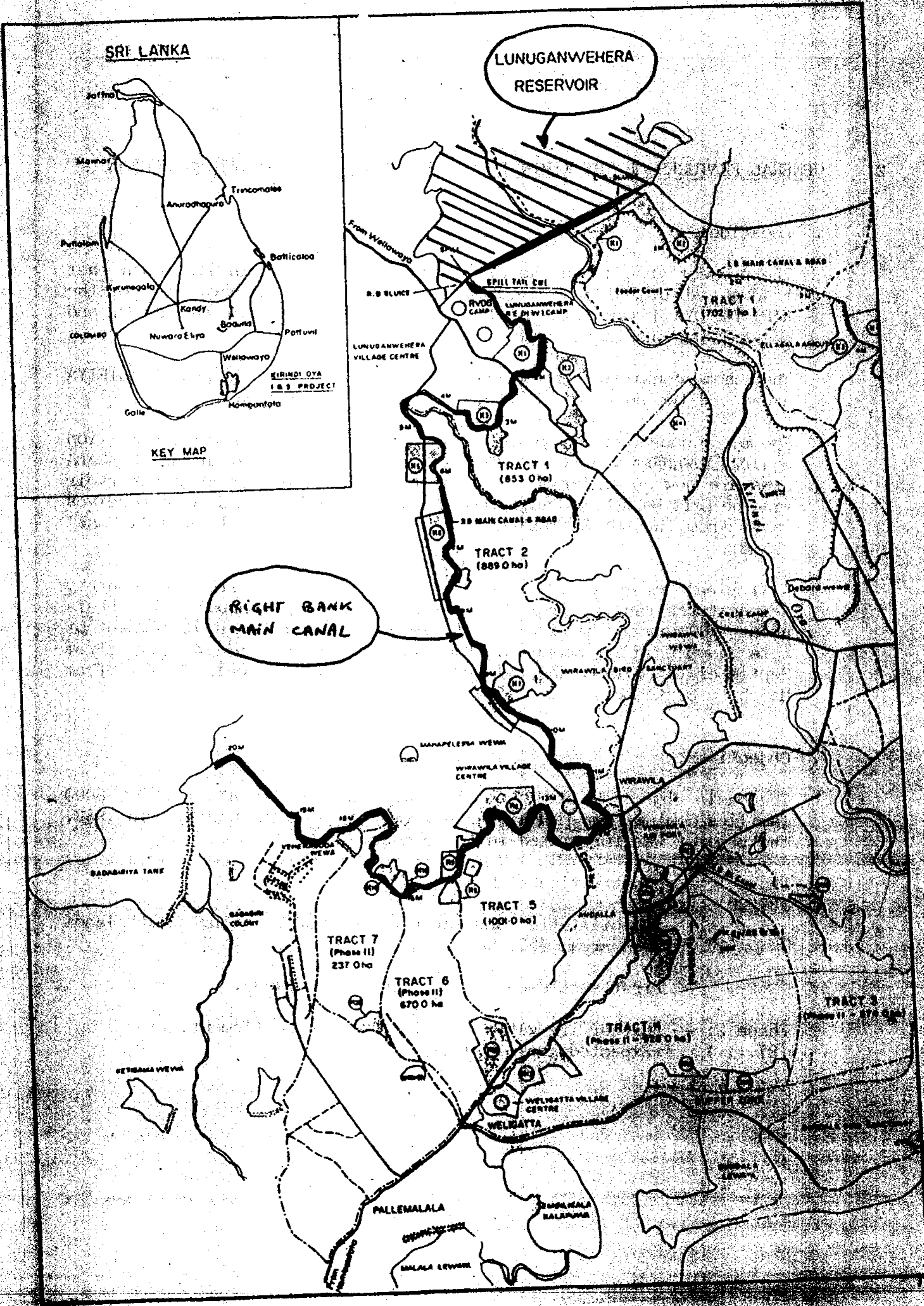
A tropical monsoonal climate prevails in the area with mean monthly temperatures ranging from 26^0C to 28^0C. The mean annual rainfall is about 1,000 mm and has a distinct bimodal pattern; about 75 percent of this precipitation occurs during the wet season called Maha (from September to March); the balance during the season called Yala (from March to September).

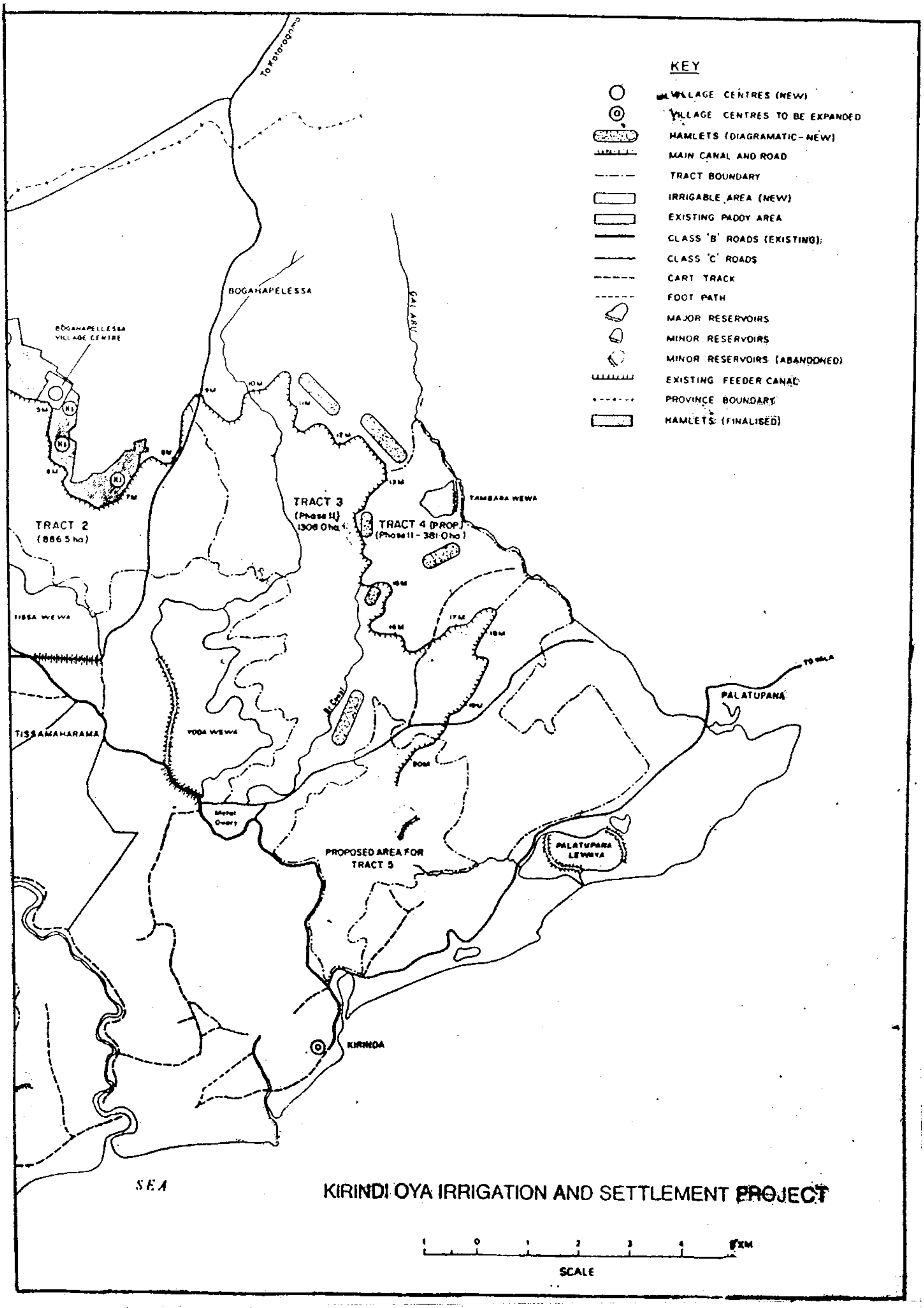
. Objectives:

The basic objective of the project was the settlement of about 8000 families coming from different areas (mostly from the South). In 1982, the project was formulated in two phases.

Phase 1: (87/89)
- construction of headworks
- rehabilitation and augmentation of existing paddy lands (old area) 4500 ha.
- first settlement in 4000 ha of new lands.

Phase 2: (87....)
- further irrigation development new settlement. (Expected area 4000 ha)


SRI LANKA
Jaffna
Mannar
Trincomalee
Anuradhapura
Puttalam
Batticaloa
Kurunegala
Kandy
Badulla
COLOMBO
Nuwara Eliya
Pottuvil
Wellawaya
KIRINDI OYA I & S PROJECT
Galle
Hambantota
KEY MAP
LUNUGANWEHERA RESERVOIR
From Wellawaya
SPILL TAIL CHL
R.B SLUICE
RVDB CAMP
LUNUGANWEHERA VILLAGE CENTRE
L.B MAIN CANAL & ROAD
TRACT 1
TRACT 1 (853.0 ha)
R.B MAIN CANAL & ROAD
TRACT 2 (889.0 ha)
RIGHT BANK MAIN CANAL
MAHAPELESSA WEWA
WIRAWILA VILLAGE CENTRE
WIRAWILA
BADAGIRIYA TANK
TRACT 5 (1001.0 ha)
TRACT 7 (Phase II) 237.0 ha
TRACT 6 (Phase II) 670.0 ha
WELIGATTA VILLAGE CENTRE
WELIGATTA
PALLEMALALA



KIRINDI OYA IRRIGATION AND SETTLEMENT PROJECT

Present problems:[4]

Kirindi Oya presents a special problem not faced in most other Sri Lankan irrigation settlement schemes : it is a severe water short system. During the design stage, the hydraulic estimates for the average annual reservoir yield were overestimated and have been revised downward from 375 million m^3 in 1977 to 240 in 1990, there has been a more severe drought for 5 years.

This problem is all the more acute as the present cropping pattern in most of the irrigated areas (rice mono cultivation during both Yala and Maha seasons) requires much more water than the cropping pattern that was planned when the project was designed. "This cropping pattern yields a high standard in terms of economic performance, but is not sustainable on the whole area, as the Kirindi Oya scheme was technically based (and economically justified) on the assumption that farmers would grow a lot of non-rice crops (the objective was a 170% cropping intensity with diversified crops)."

This water shortage situation leads to major water management problems:

- inability to implement the whole Phase II of the project;
- on already irrigated areas, inequity in water allocation between old settlers who tend to use more than their allotted share of water and newcomers, who have to share the balance.

Different management improvements have been sought for several years by the IIMI SLFO[5] and were recommended such as : institutional management capacities strengthening, turnover of responsibilities to farmer organizations, conditions of implementation of a crop diversification program, water management efficiency during land preparation and crop owing methods.

IIMI's Research Division, based at IIMI HQ[6], Colombo, was also involved in tackling these problems, through the aspect of the improvement of <u>main canal</u> management, as it is described in the next paragraph.

[4] IIMI, June 1990. "Kirindi Oya Irrigation and Settlement Project - Irrigation management and crop diversification, synthesis of findings and recommendations." Volume 1.

[5] IIMI : International Irrigation Management Institute.
SLFO : Sri Lanka Field Operations

[6] IIMI Head Quarters

3. MANAGEMENT OF A MAIN CANAL AND SIMULATION MODEL OF FLOW

IIMI's current research on the operation of "Main Systems" is based on the hypothesis that the control of the conveyance and primary distribution of water in main and branch canals could have a profound impact on efforts to improve management at lower levels. In fact an inflexible and unreliable primary water supply regime could negate many of the efforts exerted by irrigation agencies and farmers' organizations to achieve a reliable and equitable water supply below turnouts.

Since operational practices are often conditioned by the particular design features for water level control in the main canal and discharge control at their offtakes, IIMI's research priorities in this area include analyzing the impact of design choices on the management and manageability of main canals.

Such research cannot be easily carried out in the field. Mathematical models that simulate the real system provide a convenient alternative to field research in investigating the behavior of irrigation canals under a variety of design/management scenarios without affecting normal canal operations. For example, such models could be used to assess the impact of any operational maneuver before actual intervention on the field.

IIMI, in consultation with the Sri Lanka Irrigation Department[7], identified the Kirindi Oya Right Bank Main Canal (KO RBMC) as an appropriate site for a pilot application of a mathematical flow simulation model. For the implementation of this research project IIMI was able to secure financial assistance from the Government of France to supplement its own core funds, and associated itself with CEMAGREF[8], a public-sector applied research center in France which is providing additional expertise in computational hydraulics and computer technology.

The RBMC is meant to irrigate approximately 5000 hectares of land. The development of a little over half of this area was completed in mid-1986 under Phase I of the project. The Irrigation Department is in charge of managing the system, as well as the development of facilities under Phase II.

The RBMC is 32 kilometers (km) long and is designed to carry a discharge of 13 m^3/s at its head. The canal is unlined throughout its length and was designed with trapezoidal cross sections. The cross sections have however evolved over time into more irregular shapes primarily due to erosion and cattle damage. In addition, siltation has occurred in many places on the canal bed.

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7 The public sector institution in charge of the management of several irrigated schemes in Sri Lanka.

8 CEMAGREF: Centre National du Machinisme Agricole, du Génie Rural, des Eaux et des Forêts.

A total of 42 distributary and field canals (DCs and FCs) take off directly from the RBMC. The irrigated paddy area is divided in Tracts. Presently five of them are operational : Tracts 1, 2, 5, 6 and 7. It is further characterized by the presence of 18 gated cross-regulators, of the undershot type, along its length. The coordinated operation of these regulators (each regulator having 2-5 manually operated sliding gates) is a key element in achieving effective control of water levels in the main canal, and hence of the primary distribution of discharges into the secondary and tertiary canals that take off from the RBMC. Ineffective operation of the control facilities could result in unreliable and inequitable water supply.

In the context of this relatively water-scarce environment and its particular design features, it is hoped that the use of a mathematical flow simulation model of the Kirindi Oya RBMC would contribute to the identification of alternative management practices leading to improved distribution of water.

4. PRINCIPAL FEATURES OF SIC[9] MODEL[10]

Overview:

The SIC (Simulation of Irrigation Canals) software is a mathematical model which can simulate the hydraulic behavior of most of the irrigation canals, under steady and unsteady flow conditions. The main purposes of the model are :

1) To provide a research tool to gain an in-depth knowledge of the hydraulic behavior of the main canal.

2) To identify, through the model, appropriate operational practices at regulating structures in order to improve the present canal operations.

3) To evaluate the influence of possible modifications to some design parameters in order to improve and maintain the capacity of the canal to satisfy the discharge and water elevation targets.

4) To set automatic operational procedures and evaluate their efficiency. (Such procedures will have to be written by advanced model users.)

9 Simulation of Irrigation Canals.

10 See "Simulation of Irrigation Canals, User's Guide", Version 1.1, December 1991, CEMAGREF, Montpellier, France.

Steady flow computations can be performed on any type of hydraulic networks, but unsteady flow computation only on non-looped[11] canal configurations.

The model is built around three main computer programs (TALWEG, FLUVIA and SIRENE) that respectively carry out the topography generation, the steady flow computation and the unsteady flow computation.

The SIC software is therefore divided into three main units that can be run either separately or in sequence.

Unit I is designed to generate the topography files used by the computation programs of Units II and III. Unit I allows the user to input and verify the data obtained from a topographical survey of the canal.

Unit II is designed to perform the steady flow computation. It allows to study the water surface profile for any given combination of offtake discharges and cross regulator gate openings. Unit II also allows to determine offtake gate openings and adjustable regulator gate settings required to satisfy a given water distribution plan whilst simultaneously maintaining a set of target water levels.

Unit III is designed to carry out the unsteady flow computation. It allows the user to test various scenarios of water demand schedules and operations at the head works and control structures. Starting from an initial steady flow regime, it will help the user to look for the best way to attain a new water distribution plan. The efficiency of the operational strategy may be evaluated via a set of water delivery indicators computed at the offtakes.

- Input data requirements:[12]

Since the model is a mathematical representation of the real system, it would only be as good as the quantity and quality of the information that is fed into it to describe the reality. The model should thus incorporate, as accurately as possible, all important physical and hydraulic features of the system.

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11 A model is looped when there is at least one point in the model where neither the discharge nor the water level are known by the model a priori (e.g. if a canal divides in two sub-canals with no regulation structure). Several iterations are necessary to calibrate both parameters.

12 **Hardware requirements:** The SIC software is designed to run on an IBM PC-AT or PS/2 compatible microcomputer under MS/DOS operating system. It needs a mathematical coprocessor and an EGA screen. The RAM must be at least 1 MB and about 2 MB of space is required on the hard disk for the three units. The software also has graphics output capability on HP compatible plotters (HPGL language) in A4 or A3 format.

The present model of KO RBMC is limited to the first 25 km of the RBMC corresponding to tracts 1, 2 and 5. The input data, both physical and hydraulic, therefore only concern this stretch of main canal. However, the model can easily accommodate eventual extensions by modification of its topography unit.

The physical information was gathered in the course of a topographical survey. This included (a) the locations and descriptions of all cross-regulators, offtakes and other singularities on the RBMC, (b) longitudinal profile of the canal bed, and (c) cross sections of the canal at appropriate intervals (100 meter intervals were used in the RBMC), trying as far as possible to capture all hydraulically significant features.

The hydraulic information required includes (a) roughness coefficients for the different reaches of the canal, (b) head-discharge relationships and discharge coefficients for the offtakes and regulators, and (c) seepage losses along the canal. Estimates of some of these parameters were obtained in the course of a measurement campaign in May 1988.

One of the sub-units of Unit II is a Strickler calibration module, that is extensively used in the present survey.

5. SIC, A TOOL IN A WIDER IRRIGATION MANAGEMENT INFORMATION SYSTEM

The primary objective of the research conducted on the KO RBMC in collaboration with the Irrigation Department is to investigate the potentialities for using a simulation model of flow as a routine decision support tool for the managers of manually operated main canals.

It appeared rapidly that the operational introduction of this simulation tool had severe management implications in terms of communication needs and monitoring facilities.

The developing of a simple Management Information System (MIS) integrating the simulation tool for specific processing, is presently experimented by Jacques Rey and Manju Hemakumara (IIMI-HQ, Research Division).

The main modules are the simulation model RBMC and routine written under DOS, DBASE III+, LOTUS 123, PASCAL.

The prototype decision support tool gathers all the raw information in a database regularly fed. The collected data are mostly water levels at structures and structures operations. Various by-products are processed and stored to follow the trajectories of key parameters. The scope of management activities achievable through the use of the MIS should be :

- Command operations : work out operational plan for planning or control of water deliveries : how a given target could be achieved ?

- Observe water : water issues, volume, filling requirements : what is the present photography of the canal ? This is a basic requirement to command operations.

- Evaluate operations : Assess the quality of management : Can the decision making process be improved ?

- Observe canal : Get information about the physical status of the canal (topography, vegetation, seepage, Strickler coefficient) : what are the main needs in maintenance ?

The present survey aims at studying and formalizing that last point, finding out a method and some tools : (1) elaborated and tested on KO RBMC and (ii) that should be easily generalized to any canal.

B. METHODOLOGY OF THE SURVEY, THE STRICKLER COEFFICIENT, AN INDIRECT WITNESS TO OBSERVE A CANAL ?

Two different stages can be identified :

1. **From raw data to calibrated Stricklers** - Process the raw hydraulic data (discharges and water elevations) collected on the field during several months or seasons. This stage is centered around database management and use of a calibration module. This involves :

   - Defining steady flow periods (SFPs) to be allowed to use Manning-Strickler formula. This involves :

     - Doing a complementary survey of the accuracies on measurements and hydraulic calculated parameters ;

     - Dividing the model of the canal studied into shorter sub-models ("reaches"[1]) to facilitate the processing of data ;

   - Shaping the inputs necessary to run SIC calibration module, i.e. building (.FLU) files containing hydraulic data directly readable by the simulation model of flow ;

   - Calculating sets of calibrated Stricklers ;

2. **From calibrated Stricklers to canal status** -

   - Analyze these sets to underline trends or jumps. This involves to determine the good data analysis tools adapted to the data. This stage is centered around the use of data analysis software.

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1 Notice that "reach" designates two different notions :

- in our survey, on R8MC a reach is a portion of canal delimited by two boundary cross sections of the main canal.

- in SIC terminology, a reach is a portion of the model delimited by two nodes, one node being an offtake, one gate regulator not being a node.

- Try to correlate possible trends or jumps with observed physical changes in the physical status of the canal. This stage associates the calibration module and field observations. It involves a complementary topography survey in some reaches as a validation step of the methodology.

. Required raw data and software :

In order to be correctly processed, the raw data, i.e. water elevations U/S and D/S the cross structures in the canal as well as discharges through these structures and at each offtake, should be stored in a database[2]. Presently, as the main module of the survey program SFP is a DBASE III+ program, to run it requires this software. Other software requirements are :

- a spreadsheet to collect and plot the calibrated values of K[3] and to modify semi-automatically the topographic data of a reach, in order to simulate the changes in the topography ;

- a file editor to modify program SFP and list (.TXT) files of results after the search of SFPs[4] ;

- a data analysis software including robust analysis multiple regression[5].

---

2 For KO RBMC, raw data are stored in a data file structured as follows for each record:
  - identification of structure : name of tract, name of structure ;
  - data and time of readings ;
  - readings of gauges U/S and D/S structure ;
  - calculated discharge through the structure.

  Readings of gauges are converted in water elevation, using separate data files containing absolute references of structures and gauges.

  Discharges stored in the data file were computed using files containing readings of gauges and cross structure description (openings of the gates).

3 LOTUS 123 2.0 and ALLWAYS (for graphics) for instance.

4 PFEDIT 4.01 for instance.

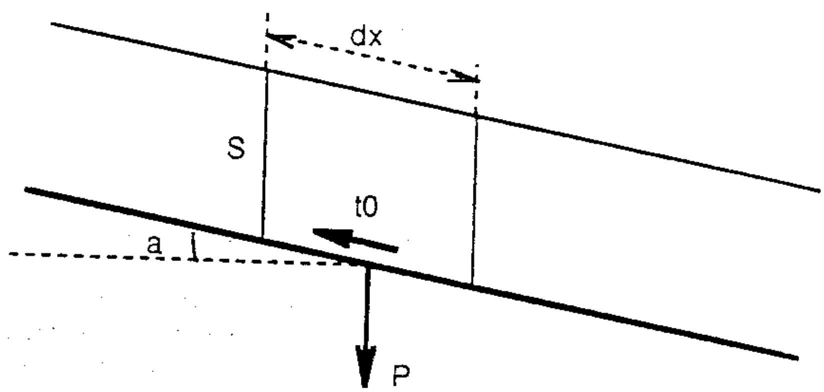
5 SOLO 4.0 for instance.

1. PHYSICAL MEANING OF THE STRICKLER COEFFICIENT

1.1 Hydraulic Background:

a. Explanation of Manning Strickler formula[6]

i. Chezy's Formula:



Let us consider a uniform-flow[7] in a channel with a constant section S. The dynamic equation of the uniform flow can be written for a "slice of flow" :

$F_{gravity} + F_{friction} = 0$ (1)

Let us develop (1) for a slice of length dx :

. weight : P = w A dx
    w : unit weight of water
    g : acceleration of gravity
  Longitudinal component of P is :
    F = P sin a # P S_0 if a is small
  (S_0 : bed slope of the canal)

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6 See POLGE de COMBRET, J., DEMMERLE, D. December 1990. L'Hydraulique numerique au service de l'Amendgement de Rivieres. Diadème Ingenierie - ENGREF.

7 The depth of flow is the same at every section of the channel, at any time.

. Flow resistance : in turbulent[8] flow conditions, flow resistance per unit area T is proportionate to V^2, V being the mean velocity :

$$T = \alpha V^2.$$

Resulting force F' is :

$$F' = T\,dx\,P$$

P being the wetted perimeter.

The dynamic equation equality between F and F' is consequently:

$$w\,g\,A\,S_0 = \alpha\,V^2\,P \text{ or } V = C\,(R_H\,S_0)^{½}$$

R_H = hydraulic radius = A/P
C : Chézy's resistance factor

ii. Manning Strickler's Formula:

Flow resistance is actually due to velocity V_0 in the neighborhood of the contact of water with the canal bed (boundary friction). Chézy's formula can actually be written as :

$$V_0 = C\,(R_H\,S_0)^{½} \qquad (1)$$

Moreover, experience shows that, for an equal velocity in the neighborhood of the canal bed, i.e. on the whole wetted perimeter, mean velocity varies approximately like $R_H^{1/6}$:

$$V = \beta\,V_0\,R_H^{1/6} \qquad (2)$$

Combining (1) and (2) gives

$$V = \beta\,C\,(R_H\,S_0)^{½}\,R_H^{1/6}$$

i.e. Manning Strickler's formula :

$$V = K\,R_H^{2/3}\,S_0^{½} \text{ or } Q = K\,A\,R_H^{2/3}\,S_0^{½},$$

Q discharge in the section

K is the Strickler's coefficient.[9]

8 a flow is turbulent if the viscous forces are weak relative to the inertial force.

9 n = 1/K is the Manning's coefficient.

b. Conditions of flow in most irrigation canals

The steady flow regime represents the objective of most of the managers of irrigation canals : the physical parameters describing the conditions of flow do not vary through time.

Generally uniform flow is not the actual regime, as the depth of water levels vary along the length of the canal, due to the presence of cross structures and lateral offtakes. The target flow is said "gradually varied", as the depth does not change abruptly over a comparatively short distance.

The target flow is <u>steady</u> and <u>gradually varied</u>.

The theories of gradual flow hinge on a basic assumption[10] : the head loss at a section is the same as for a uniform flow having the velocity and hydraulic radius of the section. Thus, the uniform flow Manning-Strickler's formula may be used to evaluate the energy slope of a gradually varied flow at a given section, and the corresponding coefficient of roughness developed primarily for uniform flow is applicable to the varied flow :

Uniform Flow	Gradually varied flow
$H = z + h + V^2/2g$	$H = z + h + V^2/2g$
$dH/dx = dz/dx$ or $S_f = S_0$	$dH/dx = dz/dx + dh/dx + d(V^2/2g)/dx$
$V = K\, R_H^{2/3} \sqrt{S_f} = K\, R_H^{2/3} \sqrt{S_0}$	$V = K\, R_H^{2/3} \sqrt{S_f}$

- z : vertical distance of the channel above the datum
- h : depth of flow in the section
- H : total head
- S_f : energy slope
- S_0 : bed slope

10 See CHOW, 1973. Open channel hydraulics. McGraw Hill International Edition, New York.

c. Limitations in the use of Manning-Strickler's formula

i. Rapidly varied flow:

On the other hand, in rapidly varied flow conditions, i.e. rapidly varied steady flow,[11] the previous assumption is not verified as the boundary friction, that plays a primary role in gradually varied flow, is comparatively small and in most cases insignificant in front of the high turbulence characterizing the flow. SIC program compute only subcritical flow and do not tackle problems with rapidly varied flows in a reach.

ii. Unsteady flow:

Moreover, flood waves and waves due to slow operations of controlling structures such as the gates and sluices are typical examples of gradually varied unsteady flow. In that case, the effect of channel friction is usually appreciable, the Strickler's coefficient can still be defined as for steady flow conditions - but the Manning-Strickler's formula is not true anymore, as the dynamic equation cannot be written any more for a "slice of water" :

$$F_{gravity} + F_{friction} = 0 \quad \text{(uniform flow)}$$

but

$$w\, dV/dt = F_{gravity} + F_{pressure} + F_{friction}$$

which is the most general expression.

d. Strickler coefficient K calibration in SIC[12]

SIC solves problems (water surface profile calculating, discharge coefficient calibration, Strickler coefficient calibration) under subcritical gradually varied steady flow conditions in a reach.

---

[11] Rapidly varied flow has very pronounced curvature of the streamlines. The change in curvature may become so abrupt that the flow profile is virtually broken, resulting in state of high turbulence; this is rapidly varied flow of discontinuous profile, of which the hydraulic jump is an example. (CHOW, 1973, op.cit)

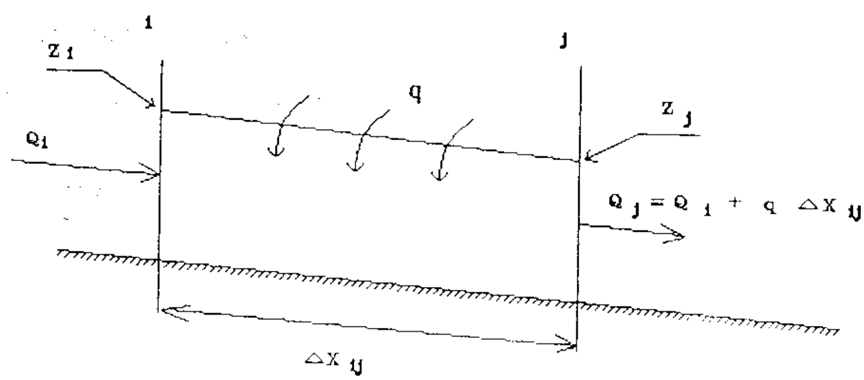
[12] See CEMAGREF, December 1991. SIC - Simulation of irrigation canals. Version 1.1. Theoretical concepts. Irrigation Division - CEMAGREF, Montpellier, France.

i. Hypotheses

Classical hypotheses of unidimensional hydraulics in canals are applied :

- Flow direction is rectilinear enough so that the free surface can be considered horizontal in a cross section ;
- Transversal velocities are negligible and pressure distribution is hydrostatic ;
- Friction forces are taken into account through the Manning-Strickler coefficient.

ii. Differential equation of the water surface profile



The equation of the water profile in a reach can be written as follows, considering a lateral inflow/outflow :

$$dH/dx = -S_f + \alpha\, qQ/gA^2 \quad (1)$$

with $S_f = Q^2/K^2A^2\, R^{4/3}$

x : distance in the direction of flow
H : total head
S_f : energy slope
q : lateral inflow or outflow
(per unit length offtakes discharge, seepage losses, rain inflow, ...)
Q : discharge in the section
g : acceleration of gravity
A : wetted area
R : hydraulic radius
α : energy coefficient

Depending on the unknown parameter that is sought, it is necessary to know the following parameters and boundary conditions :

Unknown Parameters	Parameters necessary to know		SIC modules used
	Boundary Conditions	Other Ones	
Water profile	. U/S discharge . D/S water elevation	K q	Steady flow computation
K	. U/S discharge . U/S water elevation . D/S water elevation	q	SIC calibration module then SIC steady flow computation

As the equation does not have an analytical solution, in the general case, it is discretized to obtain a numerical solution.

(1) integrated between two sections i and j is :

$$H_j - H_i - kq\, \Delta x_{ij}/2g\ (V_j/A_j + V_i/A_i) + \Delta x_{ij}\ (S_{fi}+S_{fj})/2 = 0$$

iii. SIC calibration module

For a homogeneous reach, defined for instance between two consecutive cross structures, SIC uses more than two calculation sections, say n, then (1) integrated between n sections gives[13] :

$$(2)\ Hn - H1 - \sum_{i=1}^{n-1} kq\ \Delta x_{(i,\,i+1)}/zg\ (V_i/A_i + V_j/A_j) + \sum_{i=1}^{n-1} \Delta x_{(i,\,i+1)}\ (S_{fi} + S_{fj})/2 = 0$$

Through a section (1), Manning Strickler formula gives :

$$K_i = Q_i^2 / S_{fi} A_i^2 R_i^{4/3} = D_i/S_{fi}$$

Assuming that the roughness of the reach is the same in every part of that reach :

$K_i = K$, $i = 1$ to n[14]

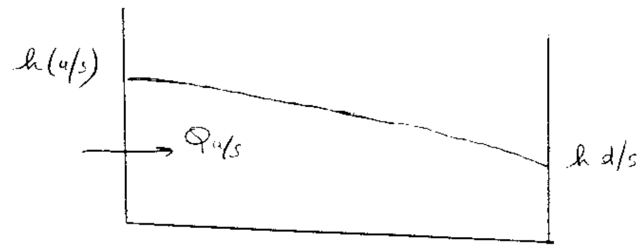
13 SIC calibration module allows to take into account singular head losses in the reach : it is possible to add corresponding terms in the sum of left member of equation (2).

14 SIC calibration module actually allows to write $Ki = \alpha_i K$, $i = 1$ to n, i.e., the unicity of roughness in the reach is not any more a necessary condition to choose the reach.

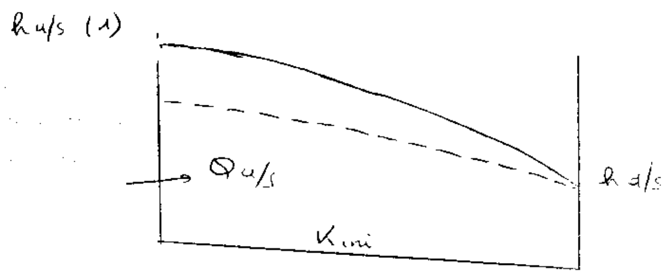
SIC CALIBRATION MODULE
PRINCIPLE

This is a theoretical example showing how SIC calibrates a Strickler's coefficient in a reach where U/S and D/S water elevations and U/S discharge are known.

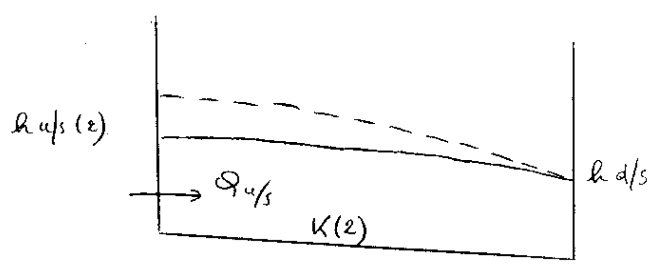
TARGET WATER PROFILE



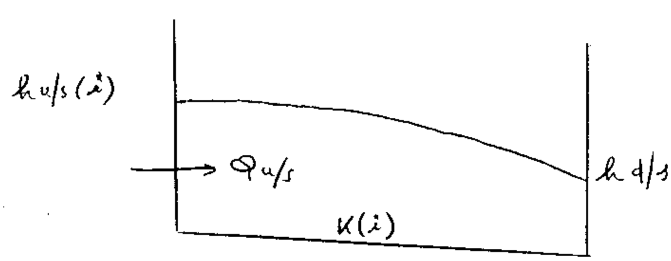
First iteration :
input : Kini , initial value of K
output : hu/s(1) > hu/s(target)
decision for second iteration : test K(2) > Kini



Second iteration :
input : K(2)
output : hu/s(2) < hu/s(target)
decision for third iteration : test K(3) < K(2)



And so on till iteration i (i<=20) :
input : K(i)
output : hu/s(i) = hu/s(target)



K(i) is the calibrated value of K

The last term of the sum (2) becomes :

$$1/K \sum_{i=1}^{n-1} \Delta x_{(i,\, i+1)} \quad (D_i + D_{i+1}) \,/2$$

and (2) becomes :

$$K = \frac{\displaystyle\sum_{i=1}^{n-1} \Delta x_{(i,\, i+1)} \quad (D_i + D_{i+1}) \,/2}{H_1 - H_n - \displaystyle\sum_{i=1}^{n-1} kq \quad \Delta x_{(i,\, i+1)}/zg \; (V_i/A_i + V_j/A_j)} \qquad (3)$$

SIC starts the calibration using an initial value of K stored in a (.FLU) file. One calibration is done with a proper expected value of K between each part of the canal limited by two sections for which calibration water elevations were entered in a (.FLU) file.[15]

Starting with that initial value, several iterations (up to 20) are implemented. Each iteration consists in the calculation of a water profile for which :

- hydraulic inputs are U/S discharge, D/S reference water elevation, q and tested value of K ;

- hydraulic output is U/S water elevation.

If say output U/S water elevation > U/S target reference water elevation, a higher value of K will be tested in next iteration.

The computation stops after 20 iterations or when output and target U/S water elevations match.

Before running SIC calibration module with any set of data, it is absolutely necessary to make sure this data were collected during a Steady Flow Period (SFP) in the reach. This first step requires a very careful analysis of the data and, in the aim to analyze the evolution of K through time which is the core of the present survey, this search can be implemented using a DBASE program called SFP.

15 See Annex 8.2.2.b to learn how to build a (.FLU) file.

1.2 Restricted meaning of K : indicator of roughness in a canal

The Strickler coefficient is defined as an indicator of the resistance offered by the canal to the flow of water, and integrates different effects such as :[16]

- surface roughness : represented by the size and shape of the grains of the material forming the wetted perimeter ;
- vegetation : which is a kind of surface roughness, but also can markedly reduce the capacity of conveyance of the channel ;[17]
- channel irregularity : sand bars, sand waves, ridges and depressions, holes and humps ;
- channel alignment : smooth curvature with large radius or sharp curvatures with severe meandering ;
- obstructions : log jams, bridge piers ;
- siltation and scouring.

It is very difficult to predict the real value of K. The standard interval [20, 40] is frequently met in literature for earthen channels.

Generally, K is calibrated when all the other physical or hydraulic parameters are determined. If these measurements are reliable, then the value of K should not be significantly modified through time, unless a major change affects one of the pre-cited effects.

To calibrate a value for K, two different kinds of inputs are requested :

- geometric data : cross sections in at least two locations ;
- hydraulic data : water elevations, discharges, gate openings.

Whether geometric data and hydraulic data are contemporary or not, the meaning of K is absolutely different. This is discussed in the next paragraph.

---

16 CHOW, 1973. "Open channel hydraulics", McGraw-Hill International editions, pp.101-108.

17 See recent article of BAKRY Mohamed F. et al. "Field measured hydraulic resistance characteristics in vegetation-infested canals". Journal of Irrigation and Drainage Engineering, Vol.118, No.2, March/April 1992, pp.256-274.

1.3 Wider meaning : indicator of physical status of a canal

When it is calibrated, K gets a wider meaning and should have two distinct interpretations :

- if the geometric and the hydraulic data are contemporary, the calibrated value of K actually stands for the roughness status of the canal.

  As example, in the case of the RBMC, 1988's set of hydraulic data and 1988's topography are contemporary : calibrated K should only account for the roughness of the canal. A 1992's set of hydraulic data and 1992's topography, if it existed, would be expected to give a neighbor value for K, under the same conditions of vegetation and unless big changes in size and shapes of the grains or channel alignment would have happened.

- if the topography used in the model is different from the real one when the hydraulic data are measured, the resulting calibrated K will account for the roughness <u>and</u> for the differences between the geometric data used for the calibration and the actual geometry of the canal.

  In the case of the RBMC, the Strickler coefficients are calibrated using 1991's and 1992's sets of data, combined with 1988's topography file. Different values of K between 1988 and 1991-92 may account both for changes in roughness and in topography.

Changes in topography include :

- bed geometry : siltation or scouring;
- bank geometry : erosion, damages due to cattle.

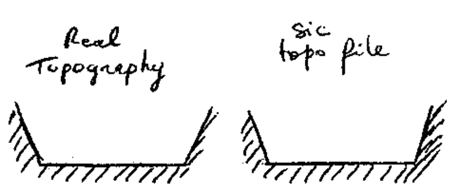
THE TWO MEANINGS OF THE CALIBRATED VALUES OF THE STRICKLER'S COEFFICIENT

Restricted meaning :

Real topography and SIC topography file are identical

(this is likely if they are contemporary)

K stands for roughness only

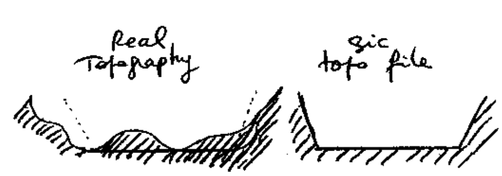


Wider meaning :

Real topography has been modified, but not SIC topography file

(this is likely if the topography study is several years old)

K stands both for roughness and for topography changes



2. FROM FIELD COLLECTED RAW DATA TO CALIBRATED SETS OF STRICKLERS

2.1 Isolating steady flow periods in the data : Program SFP

a. Necessary conditions at each boundary cross section

Steady Flow Periods (SFPs) are sought on a reach delimited by two boundary cross sections. One SFP can be defined for a reach if a SFP can be defined for both boundary cross sections of the reach during a common time interval. It is assumed that if stable conditions of flow can be underlined at the extremities of a reach, conditions of flow are also stable in every point of the reach, particularly at every offtake.

On KO RBMC, the natural subdivision was to take the cross structures as boundary cross sections as hydraulic measurements across the main canal are taken only at the GRs (Gate Regulators, i.e. cross structures). These are singular sections, as the water profile can be discontinuous through the GRs. On the other hand, as the water profile is continuous on the reach, it is possible to get a single calibrated value of K on the reach.

In the general case, any cross sections of the canal, either singular or not, can be used, as far as water elevations and discharges are available. Moreover, Program SFP can consider a rupture in the continuity of the water profile in a reach. If the water profile is discontinuous between the two chosen cross sections, more than one value of K will be calibrated : at least one on every part where the water profile is continuous.

To define a SFP, two conditions are necessary, at each boundary cross section : **water levels[18] and discharges[19]** must be stable. **Because of the inaccuracy on the measurements,** "stable" means that are not **expected to be strictly identical** between one data record and the next ones. **Some tolerance should be admitted.** This tolerance may be, for instance, **equal to the inaccuracy** on the measurements. In the case of **KO RBMC, a complementary survey** was therefore conducted (see part C.1.1).

---

18 In the database used for KO RBMC, U/S water elevations of D/S GR are not directly stored but calculated using three data:
- $D1_{(m)}$: field GAU_UP (in AL_REAL.DBF file) : reading in m of the gauge located U/S the GR ;
- $D2_{(m)}$: TBM (in REGULAT.DBF file) : absolute elevation of a mark painted on the GR ;
- $D3_{(m)}$: GAU_UP (in REGULAT.DBF file) : vertical distance between the TBM and the top of the gauge located U/S the GR;

The water elevation is D2 - D3 - D1.
The only source of inaccuracy is assumed due to D1 reading.

19 On RBMC assuming that the Cross Structures functioning conditions are most of the time Pipe Flow/Submerged Flow conditions, the hydraulic law for one Cross Structure should be :

$Q = a\, h^{1/2}$ where Q is the discharge through the Cross Structure and h is the water level immediately U/S the Cross Structure.

Consequently, the relations between the accuracies ΔQ and Δh on Q and h should be : $\Delta Q/Q = 1/2\, \Delta h/h$.

b. Necessary conditions for the reach

Two additional conditions, defined not at the level of the boundary cross sections, but at the level of the whole reach, have to be satisfied to validate the first isolated set of flow periods into SFPs :

- Some SFPs out of this first set may last only a few minutes. A minimal duration for the SFP should be defined ;

- Not all the raw data are reliable (by errors in gauge readings, wrong data entry). These errors interfere with systematic and unavoidable errors in the computation of the discharges, more particularly due to inaccurate estimations for the discharge coefficients used for the structures. One test, based on the calculation of the instant seepage coefficient in the reach, should help selecting the most reliable SFPs.

i. Minimal duration for SFP

It should be superior to the amount of time necessary for the establishment of the uniform flow in the reaches, after a perturbation was provoked (eg. opening or closing a gate U/S or D/S the reach).

A very simple assessment of this duration can be defined as follows :

D/S water elevation of the reach is maintained constant (normal working condition of any reach of RBMC), starting with a steady flow defined by a couple (Q_1 U/S discharge, V_1 volume of water in the reach). Then if Q_1 is suddenly modified into Q_2, after the propagation of a discharge wave, a new steady flow will settle, defined by the couple (Q_2, V_2).

The mean time for the establishment of the new steady flow is equal to the time necessary to fill the volume $\Delta V = V_2 - V_1$ thanks to the discharge $\Delta Q = Q_2 - Q_1$:

$T = V_2 - V_1 / Q_2 - Q_1 = \Delta V / \Delta Q$ (Kleitz Seddon relation)

We applied this method to a long reach of RBMC (GR3-GR4) using SIC steady flow module.

. $Q_1 = 2\ m^3/s$ $V_1 = 36\ 370\ m^3/s$
. $Q_2 = 5\ m^3/s$ $V_2 = 52\ 870\ m^3/s$
$T = \underline{92\ mn}$

This value is the absolute minimal duration of a SFP we can rely on. Moreover, on RBMC, measurements are collected twice a day, one set one early morning and one in the afternoon.
The minimal duration of 6 hours was used in the calculation, to make sure that a SFP is defined at least between the two sets of one day : SFP defined either only inside a morning or only inside an afternoon, even longer than 90 mn, were not considered reliable enough.

ii. Instant Seepage Test

.. The calculation of the instant seepage coefficient during a SFP in a given reach as :

$$L = -10^6 (Q_{U/S} - (Q_{D/S} + Q_{offtakes}))/\text{reach length} \quad (l/s/km)$$

L > O inflow ; L < O outflow

Q : m^3/s, reach length : m

is an indicator of

(i) the true value of the seepage in the reach ;

(ii) all the inaccuracies accumulated through the different steps of the calculation of the discharge :

- theoretical approximations : discharge coefficient C_d in the formulas linking Q and water levels for sluices and weirs (systematic errors)[20]. C_d is frequently chosen arbitrarily, and moreover, it is fixed to a single value, though depending on hydraulic conditions ;
- practical approximations : inaccuracies on readings of gauges (water levels) and structures working conditions (gate openings) that can be considered as random variables[21] (random and punctual errors) ; topography survey errors having repercussions on the conversion of gauge headings into absolute elevations (systematic errors).

The values and variations of the coefficient L can be huge : see example in table below (KO RBMC, GR2-GR3, 18 Sept. 91 to 13 Jan. 92). In this case, L calculated for steady flow periods, ranges from -165 l/s/km to 1038 l/s/km, while the average value measured for the RBMC in 1988[22] is -43 l/s/km[23].

---

20 See p.22 the formulas linking Q and C_d. On KO RBMC, C_d = 0.5 for the GRs and C_d = 0.4 for the offtakes.

21 See data analysis of water level measurement at the GRs of the RBMC in part C.1.1.b.

22 See SALLY, H. and al. 1988. "Calibration of the Kirindi Oya RBMC mathematical flow simulation model : description of the field measurement campaign and preliminary results". IIMI Working Paper No.10, IIMI, Colombo, Sri Lanka.

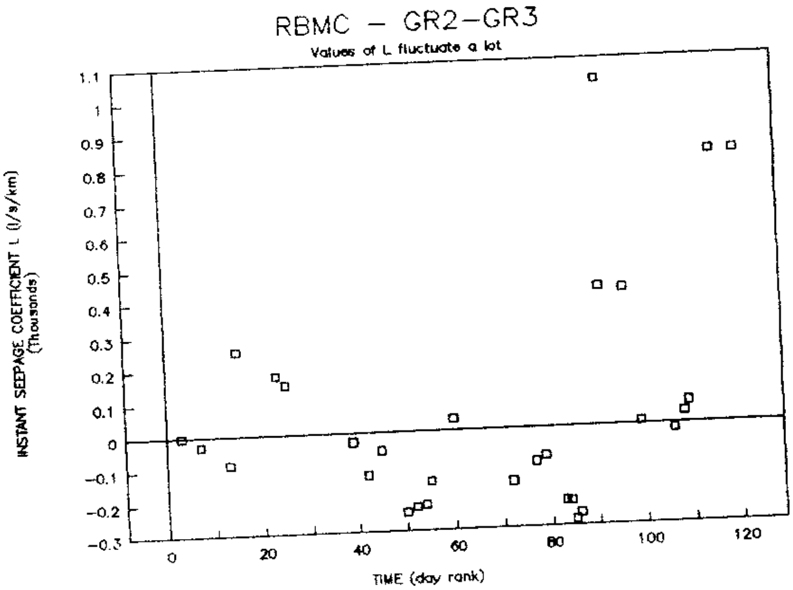
23 This value is the only available trial of measurement. Real seepage coefficients have been really bad known till now in KO RBMC.

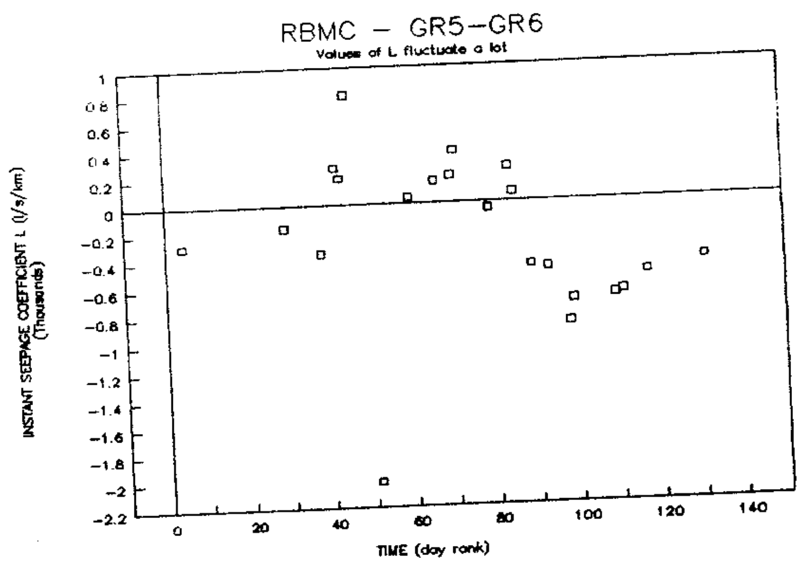
INSTANT SEEPAGE COEFFICIENT L
RBMC - GR2-GR3 AND GR5-GR6

L=-10^6*[Qu/s - (Qd/s+Qofftake)](m3/s)/Reach length(m)
L>0 : inflow ; L<0 : outflow

T : Time (Rank day=1 for date=15/09/91)

GR2-GR3		GR5-GR6	
T	L	T	L
3	1	4	-292
7	-28	29	-162
13	-86	38	-359
15	254	42	272
23	178	43	193
25	149	45	799
39	-27	51	-2017
42	-128	60	45
45	-56	66	160
50	-245	70	195
52	-228	71	380
54	-222	79	-48
55	-153	84	252
60	35	85	67
72	-160	89	-470
77	-103	93	-487
79	-86	98	-891
83	-224	99	-728
84	-225	109	-698
85	-282	111	-675
86	-264	117	-537
91	415	131	-446
92	1035		
96	409		
99	9		
106	-15		
108	36		
109	65		
115	814		
120	814		





Values such as +1038 l/s/km are a physical non-sense and the use of the corresponding SFP to calibrate one value of K without a complementary investigation would also be a non-sense. When huge inflows are underlined, i.e. $Q_{U/S} << Q_{D/S} + Q_L$ this suggests that one or several of the following assumptions is (are) true :

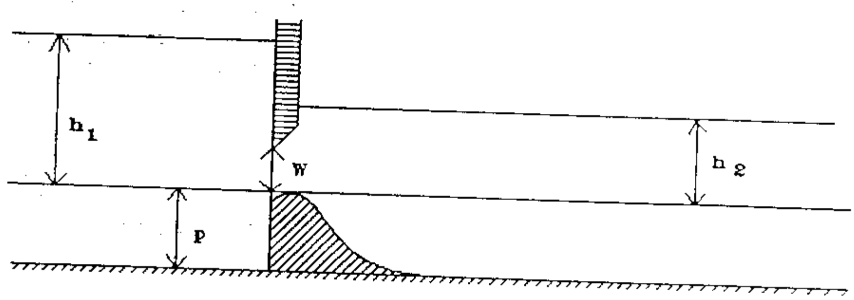
(i) Real U/S value of Q may be underestimated ;
(ii) Real D/S value of Q may be overestimated ;
(iii) Real lateral value of Q may be overestimated.

When huge outflows are underlined, i.e. $Q_{U/S} >> Q_{D/S} + Q_L$, the opposite assumptions may be checked.

Based on the observations made on KO RBMC, a test is integrated in the program to help the user to select the most likely SFPs for further use in SIC calibration module.

.. This test requires several raw information :

1. If the discharges through cross structures and offtakes are calculated using the classical formulas[24] :



Open channel/Free flow $Q = C_{d1}\ l(2g)^{1/2}\ h_1^{3/2}$

Open channel/Submerged flow $Q = C_{d2}\ l(2g)^{1/2}\ (h_1 - h_2)^{1/2}\ h_2$

Pipe flow/Free flow $Q = C_{d3}\ lw(2g)^{1/2}\ h_1^{1/2}$

Pipe flow/Submerged flow $Q = C_{d4}\ lw(2g)^{1/2}\ h_1^{1/2}$

The values of Q depend on measured values : h_1, h_2, w and estimated ones : C_d. Moreover, according to our earlier remarks, the calculated value of Q can be written :

$$Q_{recorded} = Q_{real}\ (1 + \Delta Q_{5\%}) + \Delta Q_T.$$

---

24 If the structure is, say, a mask module, the principle of the test remains but it should be appropriately modified.

With ΔQ_s(%) systematic error gathering :

- bad knowledge of C_d ;

- errors on elevations due to inaccurate measurements during a topography survey ;

and ΔQ_r random error expressing that readings of water levels on gauges do not exactly stand for the true value of the level across the canal which can be considered as a random variable. ΔQ_r also contains punctual gross errors.

To assess inaccuracy on Q, it is thus necessary to know :

- accuracy on h_1, h_2 and w and the resulting accuracy on Q : +/- ΔQ_r can be roughly considered as the limits of a confidence interval if h_1 and h_2 are considered to be random variables.[25] ΔQ_r is the maximum random error. (See C.1.1.)

- accuracy on C_d : C_d is a usually bad known variable - its value varies with Q, the geometry of the structure (weir), the opening of a gate (sluice). Fixing C_d once for all results in a systematic error. For each calculation, either C_d was overestimated or underestimated. Then the fixed value C_d should be supposed varying in an interval of width +/- $\Delta C_d(\%)$[26]. As topography errors cannot be quantified "a priori" in the test, $\Delta Q_{st} = \Delta C_d(\%)$.

  Finally, if one calculation processes a value Q, the real discharge should belong to the interval $[Q_{min}, Q_{max}]$, defined as $[Q_{recorded} - \Delta Q_r) / (1 + \Delta Q_{st})$; $(Q_{recorded} + \Delta Q_r) / (1 - \Delta Q_{st})]$.

2. A likely maximum value of seepage should be determined for inflow and outflow : L_{max}.[27]

[25] For the KO RBMC, accuracy on h_1 = +/- 1.5 cm, h_2 = +/2 cm and resulting accuracy on Q using the pipe flow/submerged flow formula gives accuracy on Q = +/- 0.05 m^3/s. Accuracy on w was not studied.

[26] SIC calibration module allows to calibrate discharge coefficients. The present values used in SIC RBMC model were not calibrated individually. C_d value was fixed to 0.5 for all (average result of POUCHELLE study). The accuracy on C_d was fixed to 20%. ΔC_d = 20%.

[27] For KO RBMC, the value of +/- 50 l/s/km was chosen, based on the results of the measurement campaign of 88.

.. Here is the description of the test used in KO RBMC :

L_{max} = 50 l/s/km. ΔQ_r (cross structures) = 50 l/s. ΔQ_r (offtakes) assumed negligible.

- If Abs(L) < L_{max}, the SFP is validated.

- If Abs(L) > L_{max}, two cases are distinguished :

  - A huge outflow is observed (L < O and L < $-L_{max}$) : TEST 1 is applied. This test assumes that Q_{min} was observed for U/S structure and Q_{max} for D/S structure and lateral offtakes. Seepage coefficient is recalculated with the extreme possible real values of Q :

    $$(Q_{D/S} + Q_{offtakes})_{real} = [(Q_{D/S} + Q_{offtakes})_{calc} + \Delta Q_{rD/S}] / (1-\Delta Q_s)$$

    $$(Q_{U/S})_{real} = (Q_{U/Scalc} - \Delta Q_{rU/S}) / (1+\Delta Q_s)$$

    If the new value L_{test} < $-L_{max}$, the SFP is definitely non valid. Otherwise it should be validated.

  - A huge inflow is observed (L > O and L > L_{max}) : TEST 2 is applied. It is exactly symmetrical to TEST 1. If L_{test} > L_{max}, the SFP is definitely non valid. Otherwise, it should be validated.

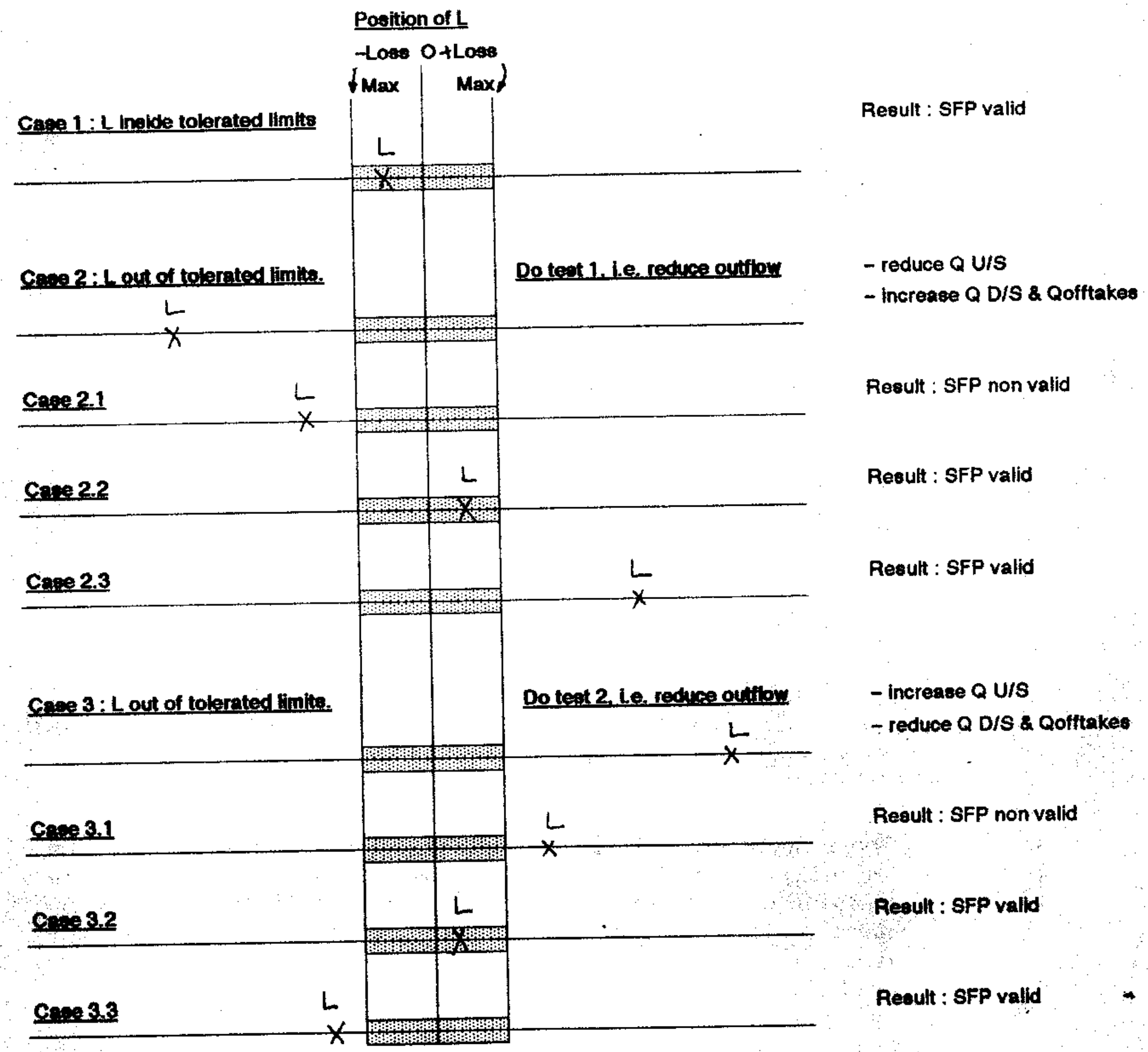
    On KO RBMC, the random error is generally much inferior than the systematic error. eg. if Q = 5 m^3/s, ΔQ_1 = 500 l/s and ΔQ_r = 50 l/s. In these conditions :

    Test 1 approximately <=> $C_{dU/S}$ underestimated and/or $C_{dD/S}$ overestimated
    and
    Test 2 approximately <=> $C_{dU/S}$ overestimated and/or $C_{dD/S}$ underestimated

- **The frequencies of the tests give indirect indication of the validity of the calculation of discharges : if say test 1 is systematically used by the program SFP, there may be an anomaly U/S or D/S of the reach. The reliability of the raw data may be doubtful because one of the two C_d are systematically wrong.**

INSTANT SEEPAGE TEST

LOSS MAX is the maximum tolerated seepage
L is the value of instant seepage



2.2 Extracting and shaping useful hydraulic data: Program SFP

The user may expect two kinds of outputs after running the SFP program :

1. Hydraulic data files directly readable by SIC calibration module.

2. ASCII text file containing information concerning the SFPs : list of records belonging to a SFP, date and duration of a SFP, results of instant seepage tests, inputs selected to calibrate a value of K. All these operations are carried through by the Program SFP, according to the selections of the user.

   The details of these stages are described in Annex B.2.2.

   In a few words, the Program SFP :

   - can shape hydraulic data files with the suffix (.FLU), directly readable by SIC, both to calibrate a single value of K on the selected reach and several values corresponding to as many sub-reaches as the topography of the model described in SIC allows it ;

   - can select, for each cross structure and each offtake, one data record (out of all the records belonging to a given SFP) that will be used in the calibration of K ;

   - can build a text file, with the suffix (.TXT) and containing a set of information concerning the SFPs selected by the user.

2.3 Obtaining sets of Strickler : SIC calibration module

When (.FLU) files are created, it is then possible to use SIC and calibrate the sets of Strickler.

For the absolute beginner, Annex B.2.3 describes step by step all the stages to get these values. In particular, it describes the process to divide a large model of canal in as many sub-reaches as desired, and the cautions that have to be respected to allow a perfect compatibility of the sub-models topography with the (.FLU) files created under DBASE environment.

3. FROM CALIBRATED SETS OF STRICKLER TO INDIRECT INFORMATION ABOUT THE PHYSICAL STATUS OF A CANAL

3.1 Expecting trends and jumps in sets of K

a. Evolution of K through time : qualitative and quantitative approaches

i. Qualitative approach

The survey is conducted at two scales of time :

- short term perspective, i.e. analyzing the sets of calibrated values of K within a cultural season[28].

  Two questions can be raised :

  - Can removals of weeds, periodically achieved by the maintenance teams be detected, following the evolution of K ?

    As these operations are punctual, if a significant effect on K is underlined, it is expected to be a sudden increase (jump) in K.

  - Can a medium term phenomenon such as siltation be detected within one season ?

    If siltation is significant within a single irrigation season, the expected evolution on K is a trend to decrease more or less regularly whether the phenomenon of siltation is itself more or less regular.

- long term perspective, i.e. comparing sets of K calibrated during two different seasons, or two different years.

  One question can be raised :

  - Can siltation or any other significant modification of topography be detected in the long term ?

    Notice that to achieve a long-term analysis, it must first be checked that short-term perturbations (eg. vegetation) do not interfere in the process.

In both approaches, when a trend or a jump was statistically underlined, it is necessary to explain it physically.

---

28 In Sri Lanka for instance, between Sept. 91 and Jan. 92, i.e. Maha season.

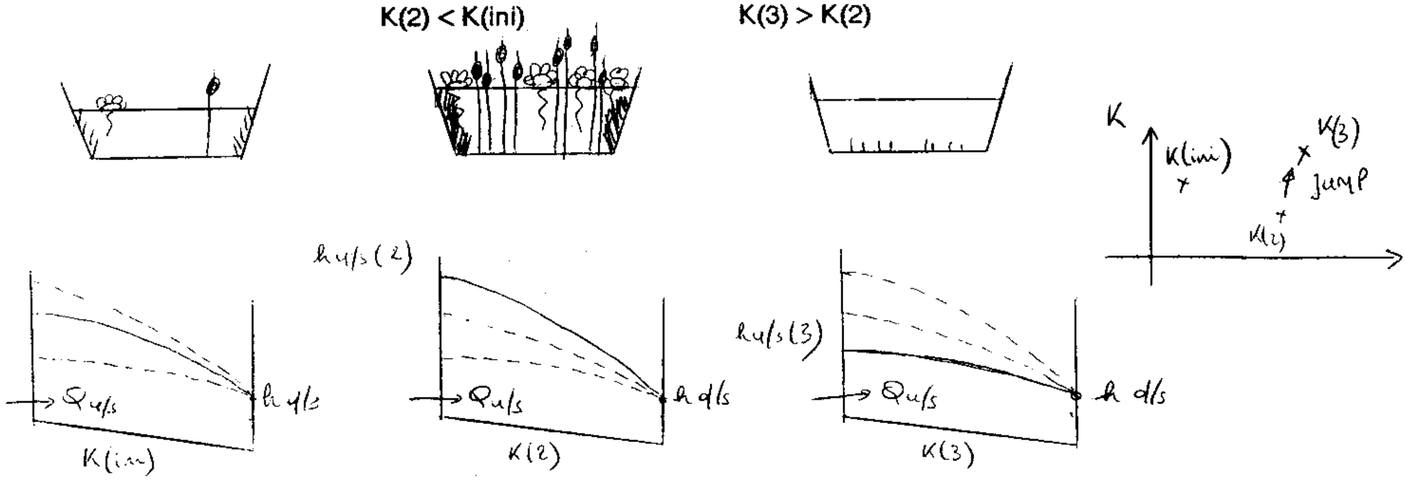
EVOLUTION OF K THROUGH TIME
QUALITATIVE APPROACH

f a significant link exists between the evolutions in time of the physical status of the canal and the value of the Strickler's coefficient, hese theoretical diagrameshow how K is expected to vary in two cases : growth and removal of weeds, siltation.

n all the diagrams, U/S discharge and D/S water elevation are supposed fixed to normal functioning conditions.
The same topography files are used by SIC calibration module through time.
The values of K are CALIBRATED values, they stand for both channel roughness
AND differences between the REAL topography of the channel and the topography file used by SIC.

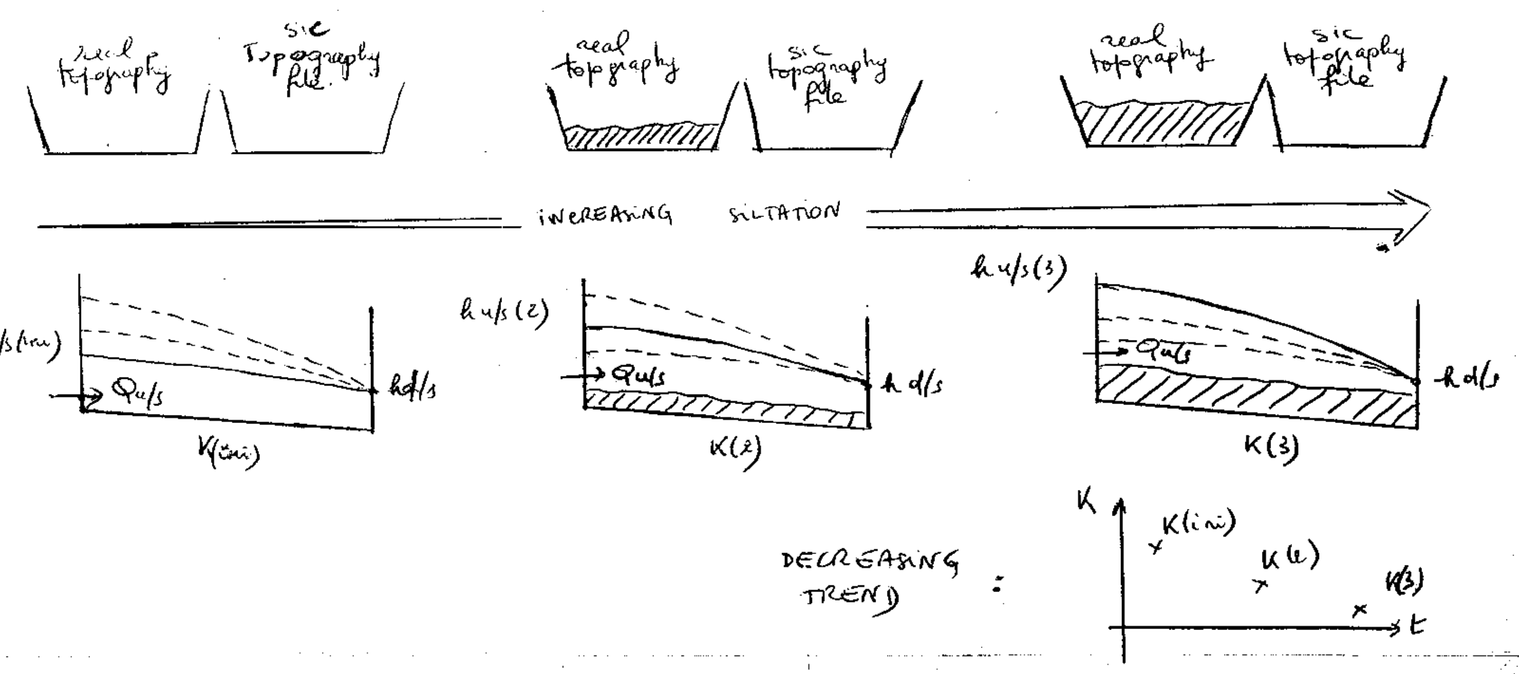
WEEDS :

1. initial situation	2. important weed growth	3. removal of aquatic vegetation
K=K(ini)	hu/s(2) > hu/s(ini) K(2) < K(ini)	hu/s(3) < hu/s(2) K(3) > K(2)



A JUMP is expected in the values of K

SILTATION : a continuous phenomenon of siltation should result in a continous decrease in the calibrated values of K



ii. Quantitative approach

- if a qualitative correlation between time evolution of K and physical evolution in the status of the canal was determined, it will be interesting to try to quantify that relation. This would allow to forecast trends and determine in which amount of time a phenomenon such as siltation can be considered perturbing the hydraulic conditions of flow enough to require a maintenance operation (see theoretical diagram in front page).

- Different types of quantifications should be tested :

  1. Let us assume that a significant trend has been identified within a given period of time, underlining a difference ΔK between the starting (K_s) and finishing (K_f) values of K.

     As an example :

     Given a hydraulic data file containing several inputs :

     h_1 : U/S water elevation ;
     h_2 : D/S water elevation ;
     Q_1 : U/S discharge ;
     Q_{off} : lateral discharge
     L : seepage losses

     and the starting value K_s for K, it is possible to modify the topography until K_f is found. Two ways to modify the topography can be tested :

     - homogeneous modification : eg. increase the bed elevation for all the calculation sections with a given level. This transformation is made on (.TAL) topography file of the studied model. The operation was semi-automated using LOTUS macro-programmation (see details in note 1).

     - heterogeneous modification : this assumes that siltation occurs in privileged locations of the studied reach. These locations can correspond to : (i) sections following a slope breaking, (ii) sections of the canal where a visual survey led to suspect a phenomenon of siltation[29].

29 See more details in Part B.3.2 : simulating siltation/erosion in a canal.

QUANTITATIVE CORRELATION BETWEEN EVOLUTION IN TIME K AND A PHYSICAL PHENOMENON IN THE CHANNEL THEORETICAL DIAGRAM

The values of K are calibrated using the same SIC topography file.

On this diagram, the physical phenomenon is an increase in bed elevation simulating siltation.

It is supposed not to be easily directly observable by the managers of the channels.

K should be an indirect gauge for that phenomenon.

If a quantitative link can be underlined between these two parameters, forecast become possible.

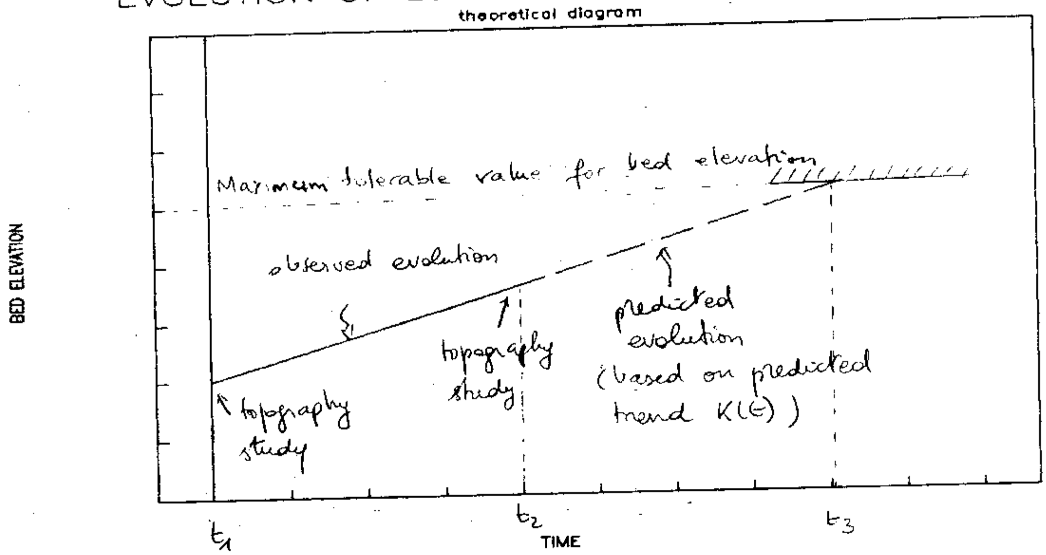
On this diagram, the linkage is fitted between t1 and t2. The managers are supposed to know a maximum tolerable value for the bed elevation beyond which siltation is likely to disturb too much the functioning of th

This corresponds to the value K3, and the linkage between K and bed elevation allows to predict t3, where an intervention should be planned.

The straight-line relations between K and time and between bed elevation iand time are purely theoretical.

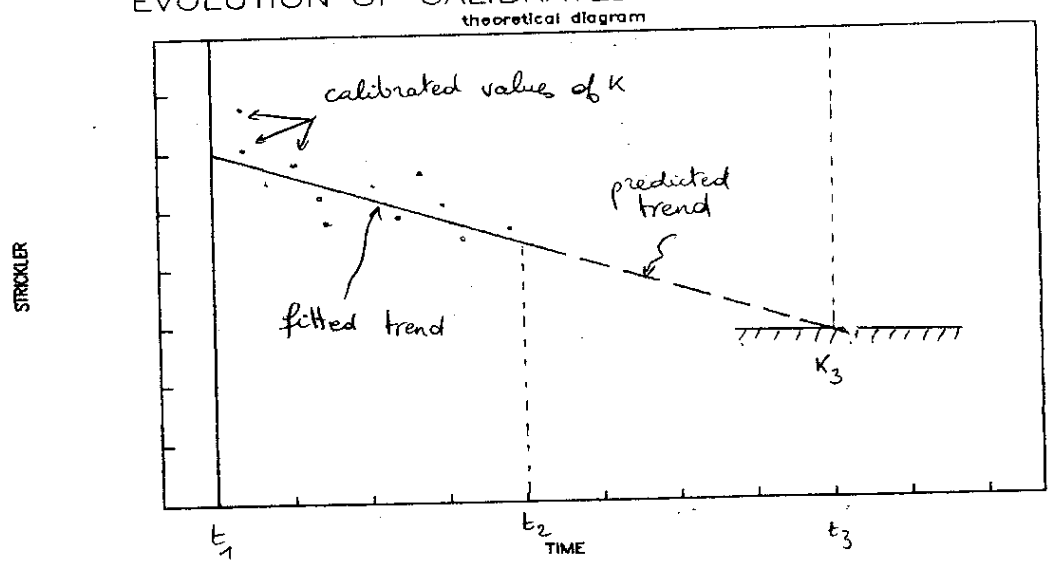
EVOLUTION OF BED ELEVATION THROUGH TIME

theoretical diagram



EVOLUTION OF CALIBRATED K THROUGH TIME

theoretical diagram



The advantage of such a theoretical study is that it does not imply any new topography survey (which involves to wait until the channel is dry if this can happen). The drawback is a lack of precision : both methods can lead to the same result, so how to know where siltation actually occurs ? Moreover, such surveys do not consider modifications of geometry in the banks.

2. With the same starting assumption, another method considers the evolution of the real roughness coefficient through time. It is possible to compare say K_{88} = K (topo 88, hydr data 88) and K_{92} = K (topo 92, hydr data 92) as far as a topography survey is achieved in 92. The values are expected to be near each other.

   This allows to calculate an expected value of restricted roughness coefficient for 91.

   As an example :

   If two values of K are available, say one in 1988, K_{88}, and one in 1992, K_{92}, assuming that the evolution rate of K is constant from one year to another, it can be written :

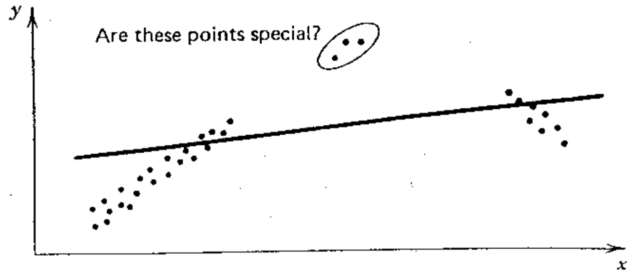
   $$K_{91} = 1/4\ K_{88} + 3/4\ K_{92}$$

   Moreover, if it is possible to simulate the unknown topography of 1991 as follows :

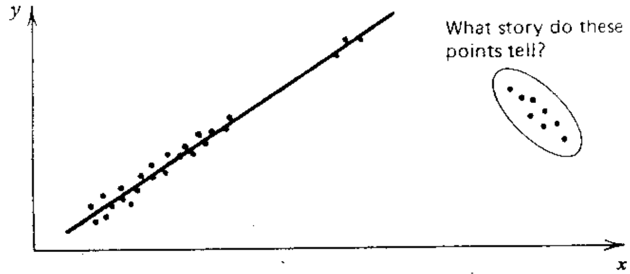
   $$T_{91} = 1/4\ T_{88} + 3/4\ T_{92},$$ [30]

   The new topography file should be tested with several hydraulic data collected during Sept. 91, using SIC calibration module. The calibrated value of K should be compared with the expected value K_{91}. If the results were satisfactory, it would show that a straight-line time correlation exists both for K and T. This would be the most favorable situation to make predictions !

30 This involves to be able to make a linear combination of two topography files. This can be semi-automatized through LOTUS. Yet, notice that it may be a little time-consuming!

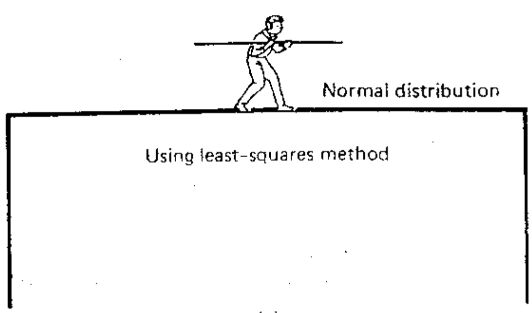


(a) Least-squares fit: average opinion of all points (noisy)

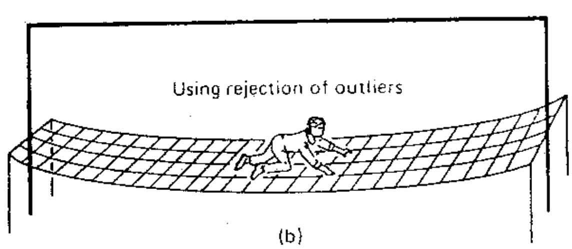


(b) Highly robust fit: clear opinion of majority of points

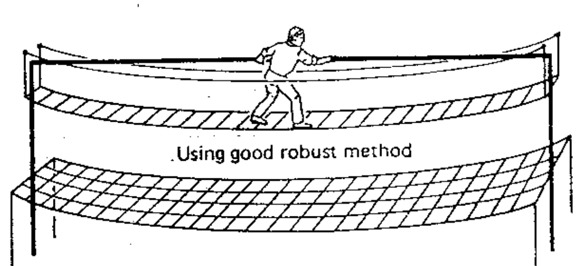
Which fit do we want?



(a)



(b)



(c)

Various ways of analyzing data.

b. **Appropriated data analysis techniques : Robust methods**

In spite of the application of several criteria and tests to define reliable SFPs out of the raw data, it appears that these successive "fences" are not sufficient and some of them provided non-sensed calibrated values of K, probably gross errors due to bad readings at the gauges or errors in data entry[31]. This extreme value of K will appear in graphs K vs time as outliers. It is necessary to use statistical tools that allow to underline trends in the bulk of the data and that reject outliers.

Using the classical linear regression methods based on maximum likelihood techniques, a set of highly sharp assumptions[32] can lead to wrong conclusions in analyzing the sets of calibrated Stricklers, as a single huge unnoticed gross error can spoil a statistical analysis completely.

Robust statistics seem to particularly fit the problems raised by the calibrated sets of K, as Hampel et al.[33] identify the main aims of robust statistics as :

1. To describe the structure best fitting the bulk of the data. It is tentatively assumed a parametric model and then done as well as possible with estimating and testing the parameters of the model, taking explicitly into account that the model may be distorted and that a minority of the data may not belong to the model at all ;

2. To identify deviating data points (outliers) or deviating substructures for further treatment, if desired. The residuals from a robust fitting automatically show outliers and the proper random variability of the "good" data, much clearer than for example residuals from least squares which tend to smear the effect of outliers on many data points, and where outliers blow up the residual mean-squared error, again making their detection more difficult ;

3. To identify and give a warning about highly influential data points;

4. To deal with unsuspected serial correlations, or more generally, with deviations from the assumed correlated structures.

---

31 Such as 220 102.8 on the reach GR2-GR3. Other values are visually "suspect", but it would be risky to eliminate them relying only on this visual criterion.

32 Mainly normality, independence, homosedasticity of the residuals in a model.

33 HAMPEL, F.R., RONCHETTI, E.M., ROUSEEOW, P.J. and STAHEL, W.A., "Robust statistics : The approach based on influence functions, ed. John Wiley and Sons, New York, 1986.

With Robust statistics, it is not necessary to assume that the residuals of a model obey exactly, eg. Gaussian distribution.

Moreover, in a classical multiple regression, outliers are eliminated visually or after observing the distribution of the standardized residuals. This may be risky, particularly with visual discrimination that is highly subjective. Robust methods avoid this risk as they reject outliers "smoothly" : to each observation corresponds a weight, i.e. a value between 1 and 0.5 :

- 1 means that the observation has a strong influence (weight) on the fitting of the model ;

- intermediate values indicate the decreasing influence of an observation, lower and lower values corresponding to more and more likely outliers.[34]

Consequently, a multiple regression Robust report consists in :

- the classical tools of regression : student tests of parameters, analysis of variance and Fisher ratio to test the whole model, use of the R coefficient of correlation to quantify the amount of variance explained by the model ;

- a Robust weight report, on which perfect and likely outliers can be easily located ;

Notice that a graph of residuals is useful in Robust methods as well as for classical methods to possibly improve a model.

Synthetic tables of results should contain the following information :

. Probability level for parameters estimates indicate if a given independent variable is significantly correlated with the dependent studied variable. For instance, in the model $K = a + bT$, $b = 0.69$ and prob. level of b equal to 0.25 means : b is a random variable following a Gaussian distribution, its present estimate is 0.69, and if actually $b = 0$ (no correlation between T and K), the probability to observe the value $b = 0.69$ is 0.25. When prob. level is null or low (< 0.05 for instance) the hypothesis of absence of correlation has to be rejected.

[34] Rejection rules such as "25A" are used : three part redescending Haber's M - estimator, corners at 2.5, 4.5, 9.5 medium deviations at 1.7, 3.0, 6.4 standard deviations. For more details see HAMPEL et al. op.cit.

- Seq R-sqr (sequential squared correlation coefficient) is defined for each independent variable and shows which proper contribution brings the last listed independent variable in the model. For instance, let us consider the model K = a + bT + cQ with seq R-sqr (T) = 0.959 and seq R-sqr (Q) = 0.963. It means that T explains 95.9% of the variability of the sample, and adding Q brings only 0.4 of supplementary explanation. In other words, Q and T convey the same information.

- R squared (squared correlation coefficient) is defined for a model : R = 0.95 means that the model explains 95% of the variability of the sample.

- F ratio and its associated prob. level are the outputs of Fisher test on the whole set of parameter estimates of the model. Prob. level = 0.25 means : the parameters are independent random variables following a Gaussian distribution and if all of them are null, the probability to observe this set of estimates is 0.25. A high R-squared and a null (or low, < 0.05 for instance) prob. level mean that the model is good.

- Low weighted values of K are the outliers underlined by the Robust regression. Weight <0.1/means that the observation is definitely an outlier for the model, weight <25% means that the observation is quite remote from the bulk of the sample.

c. Confront the trends with accuracy on K

Before concluding that a trend or a jump exists in a set of calibrated values of K, it is necessary to remind that inaccuracies on the raw data measurements used to calibrate the values of K lead to an inaccuracy in the values of K.

In other words, the result of one calibration is not so much one value of K, but an interval centered on the value appearing in the (.LST) SIC calibration result file after the calibration.

In the present survey of RBMC, the sources of inaccuracy on K taken into account were :

- inaccuracy on the water elevation measured D/S of the U/S structure of the reach ;
- inaccuracy on the water elevation measured U/S of the D/S structure of the reach ;
- and the resulting inaccuracy on the calculation of discharge U/S of the reach.

The detailed analysis is described in Part C.1.

In the general case, it is necessary to consider :

- whether the reading of a water level at one gauge can be considered as the real water level in the cross section. In RBMC survey, the water level could be considered as a random variable and the reading at the gauge matched with the limit of 95% confidence interval on the real unknown value of the water level ;

- the accuracy on one reading at one gauge.

Moreover, if the SFP that was used to calibrate one value of K was validated after using a test on the instant seepage value, the inaccuracy on U/S discharge used in the calibration should be much greater than the only effect of the random component, and the consequence on K also.

In the general case, it is not easy to find a mathematical relation between the accuracies on inputs and the accuracy of the output : K. Yet, approximations can be assessed. (See Part C.1.3).

After that, it is possible to observe the suspected trends in the set of calibrated values of K.

For instance, let's suppose that, through a period, K "seems" to increase from 20 to 25. If the accuracy on K is 10 units, the comparison has to be done not between the values 20 and 25, but between the intervals [10 ; 30] and [15 ; 35]. If the accuracy is 1 unit, the comparison is between [19 ; 21] and [14 ; 26].

The relevance of the conditions highly depends on the accuracy of each parameter used to calibrate the values of K. It is much more random to conclude that 20 and 25 are different if accuracy on K is 10 units than if it is 1 unit. If inaccuracy on K is high, it is hopeless to expect quantitative links between evolution of K and evolution of the topography.

3.2 Simulating siltation/erosion in the canal

a. Simulation and accuracy on K

- Given an unknown modification of topography along a given period of time, and its consequence on the value of K, it is interesting to find out which level of siltation in the bed of the canal provokes the same modification in the value of K.

  For low variations of K, it is necessary to check that these variations are significant, i.e. that the variation is higher than the accuracy on the value of K calibrated in that location (approximately 10% on RBMC).

  Another way to use simultaneously the surveys about accuracy on K and simulation of siltation is to answer the questions : given an accuracy on K, which minimal value of siltation can be significantly detected ? (See section C.3.32 for an example in RBMC).

  If the accuracy on one calibrated value of K is +/-e%, the result is not K but an interval [K(1-e), K(1+e)]. Consequently, values significantly different from that K are below K(1-2e)% or beyond K(1+2e)%.

. Whatever the transformation, as soon as it is supposed to reflect partially the possible evolution of the channel, this theoretical survey should help analyzing calibrated sets of K based upon observed data :

- Given an accuracy e on calibrated values of K, let us assume that through time, a significant trend was statistically underlined, and say the difference between initial value in the set of K K_{ini} and final value K_{fin} equals $\Delta K = (K_{fin}-K_{ini})/K_{ini}$ (%). If $\Delta K < 2e$, it is not possible to conclude a correlation between evolution of K and that topography transformation because the assumption $K_{ini} = K_{fin}$ should not be rejected ;

  A theoretical simulation of siltation/erosion should allow to get a quantitative idea of the lowest topography modification detectable through variation of calibrated values of K.

  If the inaccuracy of K is low, it is expected to detect low variation in the topography[35].

  If the inaccuracy on K is high, not allowing to detect bed siltation lower than say 30 or 40 cm. then the present methodology should be useful only for a long term survey of the corresponding canal.

- A simulation should allow to check the likelihood of a suspected evolution of a canal.

  Say (i) a significant difference between K_{ini} and K_{fin} through a period of time equals ΔK and (ii) the major reason for this change is suspected to be only bed siltation. If testing (ii) with different values of bed siltation until (i) can be explained leads to a huge and not likely value of bed siltation, (ii) alone may be wrong and other phenomena may interfere in the process.

b. Simple transformations

. A very simple transformation of the topography is to increase with x cm all the bed elevations of the channel cross sections[36].

35 The results for GR2-GR3 and GR3-GR4 show that it is possible on RBMC.

36 This one is very easy to simulate and little time consuming too program, as the same modification is applied in (.TAL) file to all the cross sections recorded in the model. This can be semi-automated through LOTUS macro programmation.

Another transformation consists in simulating both siltation in bed and erosion in the banks : vertical siltation components for plots in the bed and horizontal erosion components for plots in the bank.

It is possible to use more punctual and precise information, eg. if a field visit allowed to locate visually some places where siltation or erosion seem to be particularly important, and then modify only the corresponding cross sections in the model. But this can hardly be automated and it should be more time consuming.

An intermediate way between these two kinds of simulation is to apply a transformation in locations usually sensitive to erosion (D/S concrete structures across the canal) and siltation (eg. after a sudden decrease of the channel bed slope).

c. **Testing a scenario**

The two hydraulic sets of data used to calibrate K_{ini} and K_{fin} are generally different. Yet, the simulation of topography is based on using the same hydraulic conditions. If the likelihood of a scenario is good ("reasonable" values for bed siltation or bank erosion were found through simulation), it can be checked taking the actual topography of several representative cross sections, and compare it with the topography used in the model. This may be a first step in the decision making process for the management of maintenance.

The simulation consists in replacing the observed difference in K by an assumed difference in the topography. K_{ini} is the reference value of K. If K changes through time, it is supposed to be done to changes in topography, not in the real roughness of the canal. Three steps are required in this process :

- Following that assumption, the first step consists in determining the water profile in the reach using K_{ini}, and the final hydraulic data except h_1, the degree of freedom of the system being h_1 ;
- The second step is to determine the topography T_{fin} that gives the observed hydraulic data ($h_1$fin, $h_2$fin, Q_2fin, L_{fin}) with K_{ini}. The degree of freedom of the system is now the topography ;
- The third step consists in checking if it is possible to relate the variation between K_{ini} and K_{fin} (calibrated using different hydraulic data, but same topographic data) with a variation of topography (using the final hydraulic data).

Notice that in theory many different varied topographies can explain the same variation in K. That is why it is necessary to build the modified topography files upon likely assumptions, and find a way to verify them (validation step).

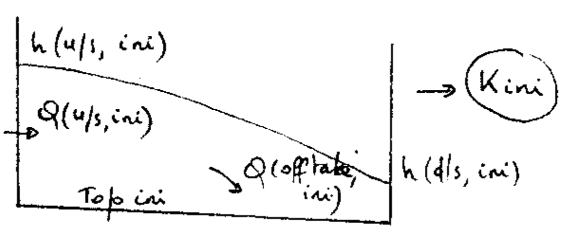
ANALYSIS OF SILTATION PROCESS

Let assume a significant evolution was underlined in K between the start and the end of a study period.
If a siltation phenomenon is suspected, it may be quantified using the final set of data and simulating several modifications in the topography of the reach.
The following table and diagrams show a methodology to achieve this result.

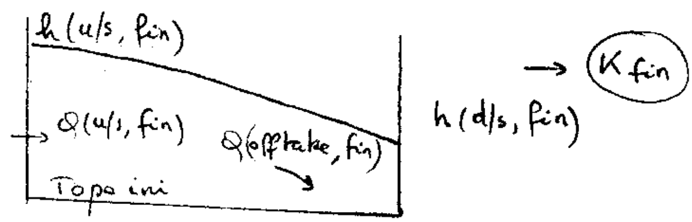
	Observed data		Analysis of siltation process		
	Initial set of data	Final set of data	Step 1	Step 2	Step 3
Topographic Data	Initial topography	Initial topography	Initial topography	Modified topography	Comparison
Hydraulic Data	h(u/s,ini) h(d/s,ini) Q(u/s,ini) Q(offtake,ini)	h(u/s,fin) h(d/s,fin) Q(u/s,fin) Q(offtake,fin)	Kini h(d/s,fin) Q(u/s,fin) Q(offtake,fin)	Kini h(d/s,fin) Q(u/s,fin) Q(offtake,fin)	Initial topo versus Modified topo and Kini versus Kfin
Module used in SIC	Strickler Calibration Module		Steady Flow Modul	Steady Flow Module	
Output of SIC	Kini	Kfin	h(u/s,step 1)	h(u/s,fin)	

Observed data allow to calibrate the Stricklers at the start and at the end of the period.

Initial set of data

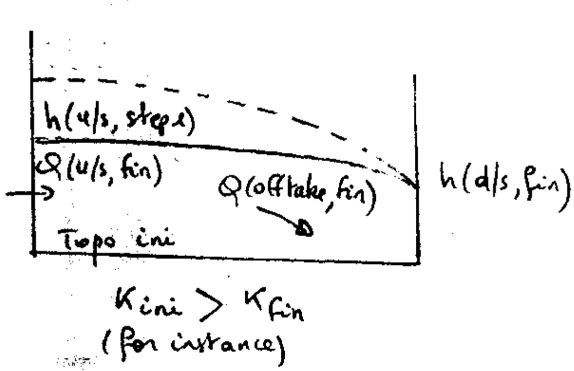


Final set of data

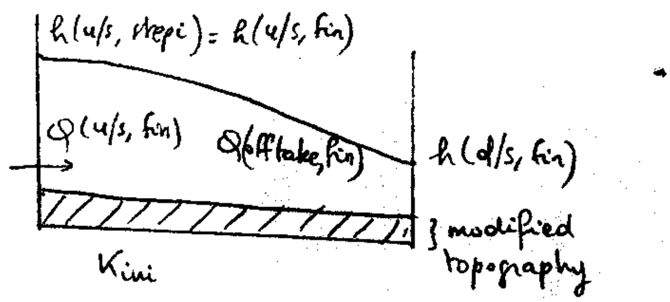


Analyzing the siltation process consists in using Kini (and not any more Kfin) for the final set of data.
But then h(u/s) is modified into h(u/s,step 1). It is possible to calibrate h(u/s) to its previous value by modifying the topography, simulating say siltation in the bed of the channel.
This may be achieved after i steps.

Step 1



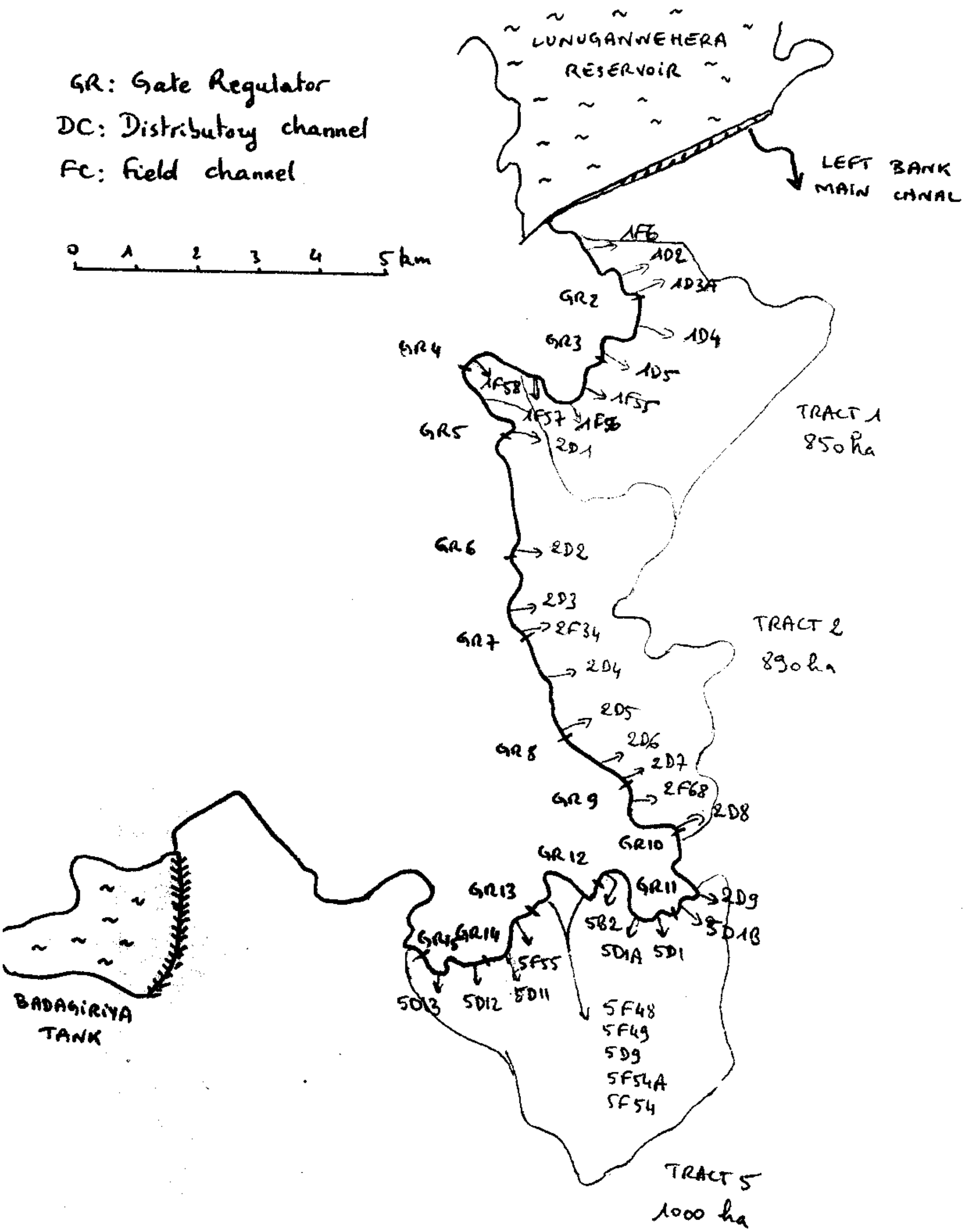
Step i



d. Implementing a simulation

In Annex B.3.2, the technique of modification of a topography file (.TAL) is described. This allows to simulate more or less automatically siltation and erosion phenomena.

KIRINDI OYA RIGHT BANK MAIN CANAL (RBMC)



C. TEST OF THE METHODOLOGY ON KO RBMC

As indicated in Part A, the Kirindi Oya Right Bank Main Canal (KO RBMC) is 32 km long trapezoidal earthen channel. Along its length, 18 gated cross regulators (GRs) help achieving control of water levels in the main canal and discharges in the 33 distributary and field canals (DCs and FCs) that directly take off from it. The RBMC is divided in to 5 tracts (Tract 1, 2, 5, 6 and 7) corresponding to 5 independent irrigated paddy areas. The present study focuses on tracts 1, 2 and 5, including 14 GRs and 33 DCs or FCs.

1. GETTING ACCURACIES ON FIELD MEASUREMENTS AND CALCULATED PARAMETERS

In Part B we have presented a generic methodology which involves the estimation of various accuracies. <u>The purpose of this section is to explicit through the example of RBMC, the practical determination of these accuracies</u>.

A steady flow period is defined as a period where none of the hydraulic parameters describing the flow vary (see Part B for more details). As these parameters result of field measurements, they are known with a certain accuracy. These accuracies have to be quantified to allow the definition of SFP : if accuracy on h_1 is +/- 5 cm, h_{11} = 15 cm and h_{12} = 5 cm cannot be considered different, as both can be equal to 10 cm. These accuracies were estimated during a measurements campaign realized in April and May 1992.

Observations involved checking the absolute elevations of several gauges, because in many cases the validity of the available values could be suspected. The study is done with the set of values collected in April and May 1992 by the Simulation Modelling team.

1.1 Water level measurement accuracies U/S and D/S cross structures

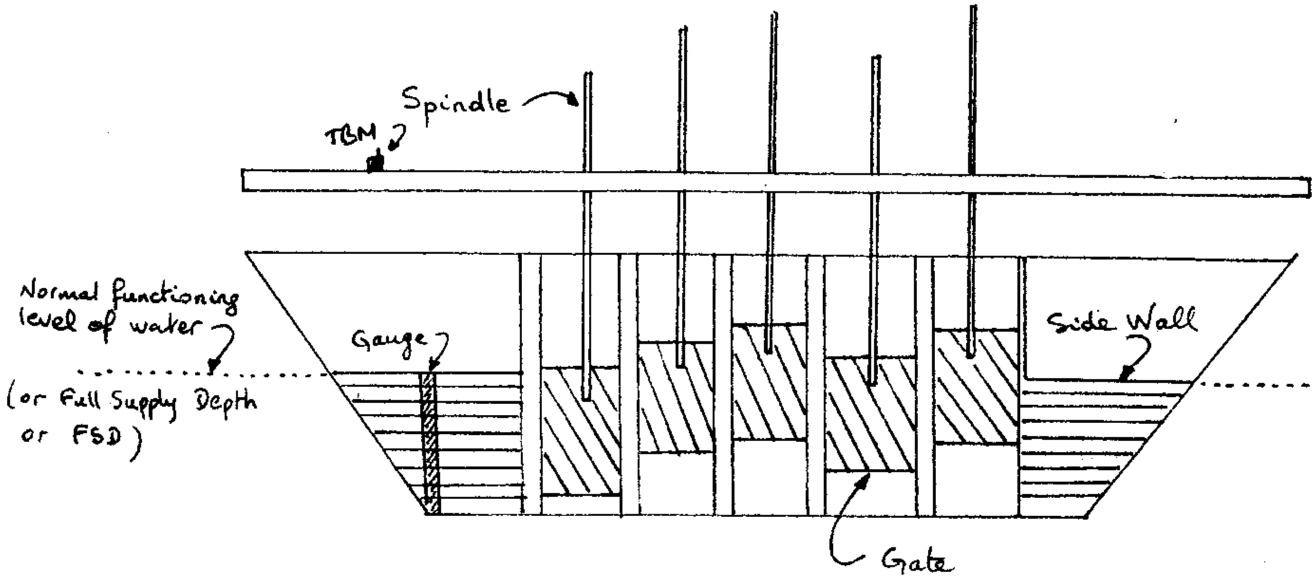
a. Data collecting

On-the-field measurements were collected using a theodolite (dumpy level) on 04/24/92.

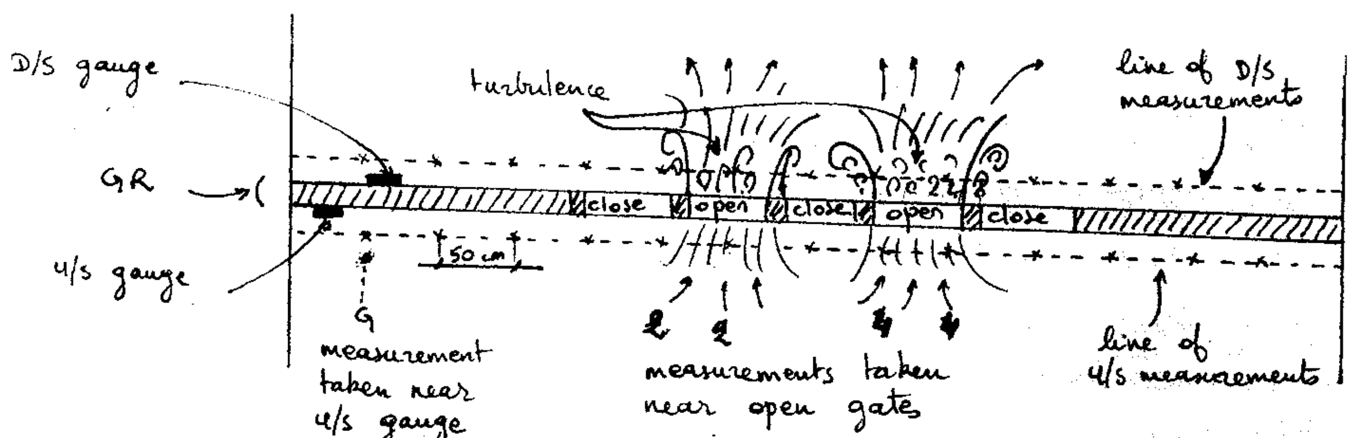
The study involved taking measurements across the canal, around every 50 cm, immediately U/S and immediately D/S each Cross Structure between GR2 and GR14.

Data are collected in the forms named 'WATER LEVEL MEASUREMENTS ACCURACY'. **(See Annex C.1.)**

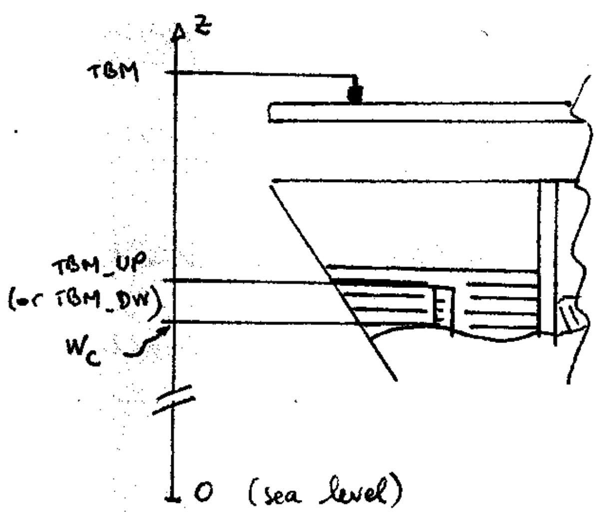
Measurements taken near the gauge are marked with the letter 'G'. **(See diagrams in following pages.)**



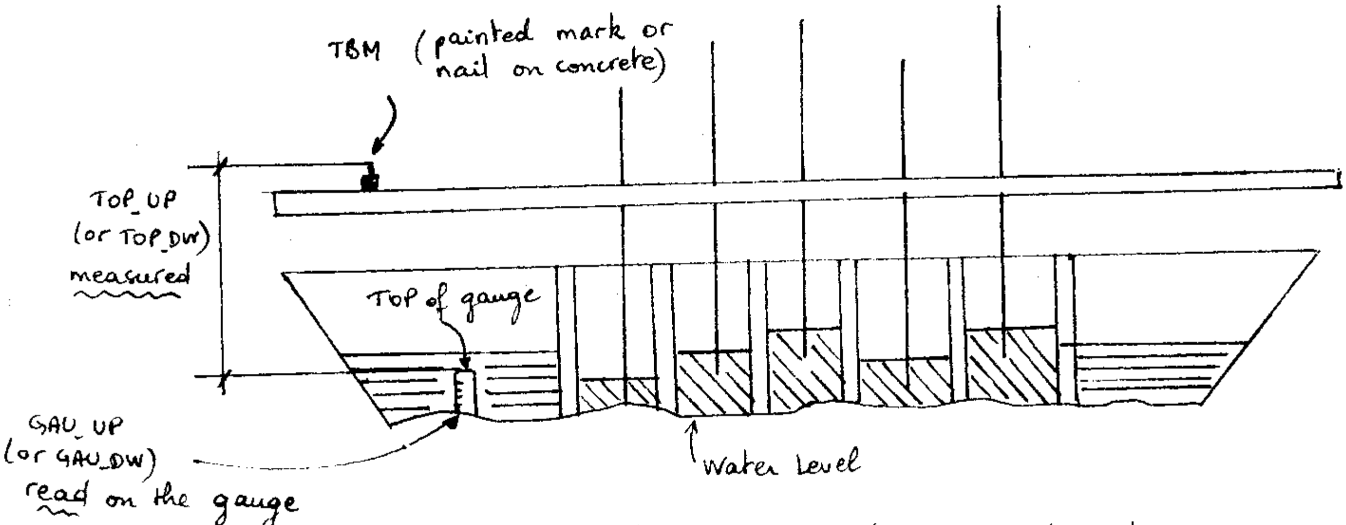
Schematic diagram of a Gate Regulator (GR) on RBMC



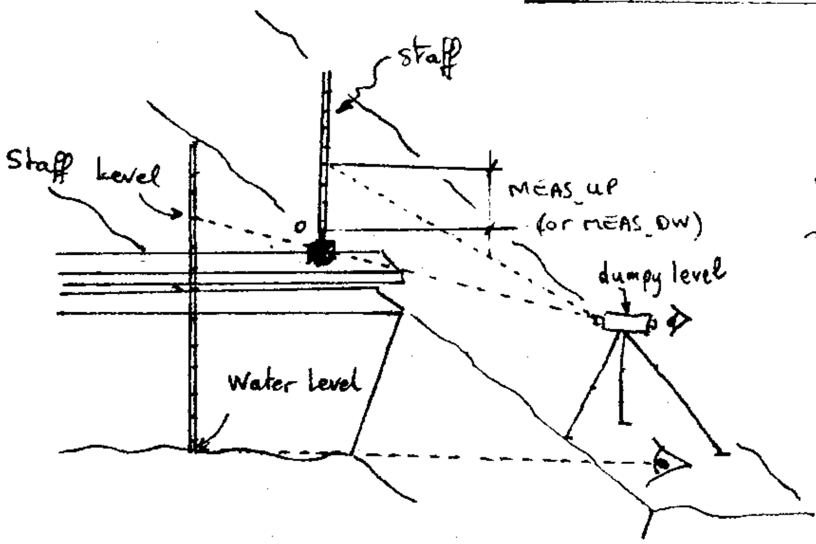
Water level measurements u/s and D/s the GRs



Absolute elevations



Readings and Measurements at gauges

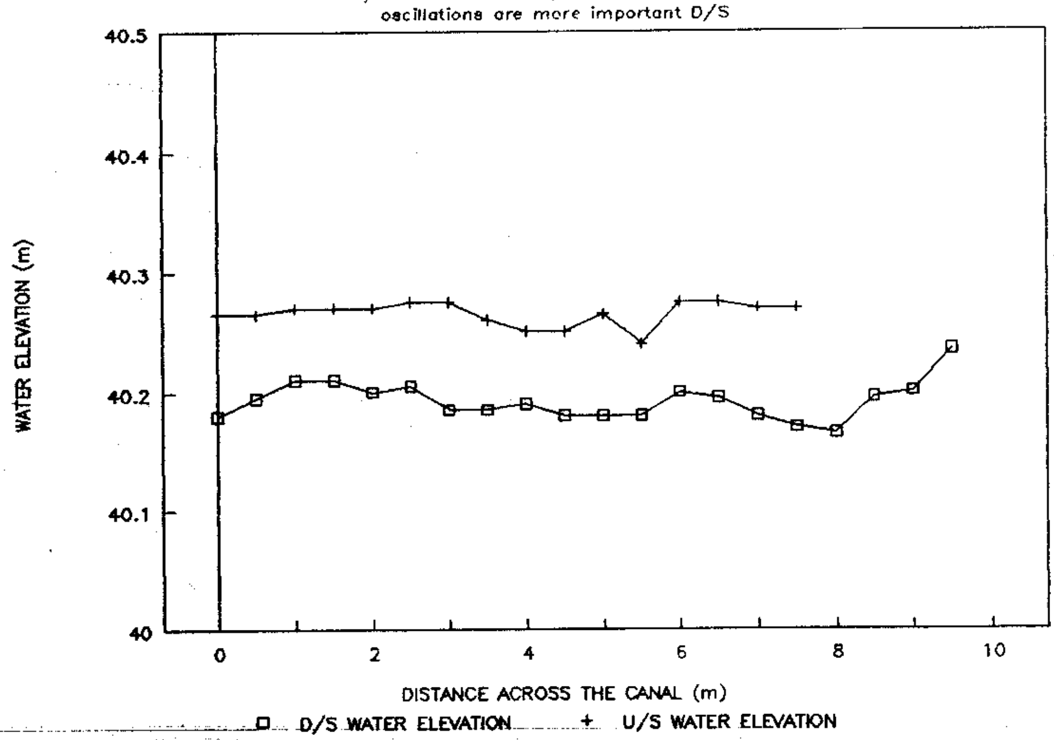


Water elevation = TBM + MEAS_UP (DW) − (Staff level − Water level)

Readings and measurements of water levels

GR 10 – U/S AND D/S WATER ELEVATIONS

oscillations are more important D/S



Measurements taken near an open gate are marked with the number of the gate.

Suspect values are marked with the letter 'S'.

Gauge levels were read and stored in the variables GAU_UP and GAU_DW.

Exterior data were also stored in the forms : Temporary Bench Marks (TBM), ie. absolute references defined during a former topographic campaign of measurements, top of gauges absolute elevations TBM_UP and TBM_DW.

Accuracy on each water elevation calculated using collected data is 2 cm :

- 0.5cm reading MEAS_UP or MEAS_DW ;
- 0.5cm reading Staff Level ;
- 1cm reading Water Level.

Water elevations were calculated using the following formula (TBM is the value of TBM for the corresponding Cross Structure found in IIMI 89's set of data) :

Water elevation (m) = TBM + MEAS_UP(DW) - (Staff Level - Water level)

One particular value derived of this set is Wc :
Wc (m) = 'G' marked values average water elevation
Wc is the water elevation near the gauge calculated directly using TBM value.

b. Data analysis

A data analysis was achieved in order to answer the question :

Q1 : **Can the Wc water elevation calculated at the gauge be considered as the real water elevation across the canal ?**

This question is worth being raised because at cross structures, the flow is presenting turbulence, generally more important D/S the structure than U/S the structure.

W real water elevation was supposed to be a random variable following a Normal distribution with unknown parameters mu and sigma (mean and standard deviation).

Under this assumption, Q1 can be answered implementing a Student test using different parameters :

- sample mean m ;
- sample standard deviation s ;
- degrees of freedom : amount of non-suspect measurements ;
- T statistics : T = (m-Wc)/sqrt(s^2/n) ;
- level of reject of the test : 5% (common value) ;
- T value of reject of the test : T(n,5%) read in 't Critical points' table.

Student test allows testing 'H0 : mu = Wc' against 'H1 : mu # Wc'
Decision rule : if T > T(n,5%) then reject H0 (R) else do not reject H0 (NR).

Probability to take a wrong decision rejecting H0 is 5%.

Results are displayed in the table below. H0 should be rejected in 15 **cases out of 24 : statistically, the gauge water elevation is different from the real value in 60% of the cases.**

WATER LEVEL AT THE GAUGES AND REAL WATER LEVEL ACROSS THE CANAL

Student Test : "H0 : Water Level = Wc" against "Water level # Wc"

Test level : 5% **Degrees of freedom : n Student value : T (n,5%)**

Decision rule : if Wc > T then reject H0 (R) else do not reject H0 (NR)

Probability to take a wrong decision rejecting H0 is 5%

	GR3	GR4	GR5	GR6	GR7	GR8	GR9	GR10	GR11	GR12	GR13	GR14
D/S	R	R	R	NR	NR	R	R	NR	R	R	NR	NR
U/S	NR	R	R	R	R	NR	NR	NR	NR	R	R	R

However, for these values, we can have an idea about whether they are "very wrong" or "wrong but giving a good idea of the true value", using the confidence interval for the mean.

Given a level of risk of mistaking (5%), the T value T(n,5%) and the sample values m and s, it is possible to define an interval within which the real mean mu for W belong with the probability of 95%. The formula used to define the limits of this confidence interval is : Probability that mu belongs to :
[m-T(n,5%)*sqrt(s^2/n), m+T(n,5%)*sqrt(s^2/n)] is 95%.

It appears that in all the cases except two, Wc rejected values belong to the confidence interval (see Table below). In the three former cases (GAU_UP, GR4 and GR7, GAU_DW, GR12), they are very close to that interval (less than 1.5 cm).

Wc AND CONFIDENCE INTERVAL FOR THE MEAN MU

This table locates the calculated value of the water elevation below, within or beyond the limits of the confidence interval for mu. Unit is meter.

	DOWNSTREAM water level measurements					UPSTREAM water level measurements				
	Wc	lower limit	Wc	upper limit	Wc	Wc	lower limit	Wc	upper limit	Wc
GR3		44.29	44.30	44.30			44.41	44.42	44.42	
GR4		43.33	43.34	43.34		43.33	43.35		43.36	
GR5		42.58	42.58	42.59			42.67	42.69	42.69	
GR6		42.05	42.05	42.07			42.25	42.27	42.27	
GR7		41.20	41.22	41.22			41.44		41.46	41.47
GR8		40.80	40.81	40.81			40.98	40.99	40.99	
GR9		40.48	40.48	40.50			40.59	40.60	40.61	
GR10		40.19	40.19	40.20			40.26	40.27	40.27	
GR11		39.62	39.63	39.63			39.76	39.76	39.76	
GR12		38.87		38.88	38.89		39.19	39.19	39.20	
GR13		38.30	38.30	38.31			38.69	38.70	38.70	
GR14		37.82	37.83	37.83			38.17	38.17	38.18	

This remark has no statistical sense but shows that Wc rejected values "give a good idea of what the real value for W is".

The width of the largest confidence interval is 2.41cm for D/S gauge measurements (7) and 2.37cm for U/S gauge measurements.

That means : if a value W of a water level is correctly read on a Cross Structure gauge, the real value of the water elevation belongs in the worst case to the interval [W-1.2, W+1.2] with a probability of 95%. Moreover, the accuracy on the reading of a gauge is equal to 1 to 2 cm.

Let us determine the accuracies on the measurements in the several cases we met :

(a) Wc value and mu should not be considered different : the accuracy on the reading is the only source of mistake.

(b) Wc value and mu should be considered different : we then know that mu belongs to the confidence interval with the probability of 95% (statistical result) and we observed that the calculated value Wc belongs to that interval (empirical result). Assuming that Wc belongs to that interval in any case (no theoretical reason), the maximal gap between mu and Wc should be approximately equal 2.4cm. Adding the systematic mistake on the reading, the total accuracy should be included between 3 and 4cm.

Mistakes on the readings are mainly due to some turbulence immediately D/S and U/S the gauge (see the example of GR10 on the graph). As turbulence are generally more important D/S than U/S, we should adopt the following accuracies :

- U/S water elevation measurements : +/- 1.5cm ;
- D/S water elevation measurements : +/- 2cm.

Consequently, the values used in the SFP program as the maximum gap admitted between the two elevations to be considered not different are :

- between two U/S water elevations : 3 cm ;
- between two D/S water elevations : 4 cm.

1.2 Discharge accuracy at the Cross Structures

a. As evoked earlier in the presentation of the methodology, inaccuracies on h1, h2, w imply a random inaccuracy on Q.

Discharges are not measured, but computed using water elevations measurements, gate openings measurements and hydraulic relations described in Part B.2.1.b..

As the usual flow through the Gate Regulator is Pipe Flow/Submerged Flow, it is possible to write :

$$Q = a\sqrt{h_1}$$

and $dQ/Q = \frac{1}{2}\, dh_1/h_1$

Considering typical values for the flow in RBMC : $Q = 5m^3/s$ and $h1 = 1m$ and taking +/- 1.5 cm for $\Delta h1$, the corresponding value for ΔQ_r is $0.0375m^3/s$.

As this is a raw approximation, in the calculations, we will use the following value for ΔQ_r : $\Delta Q_r = +/-0.050\ m^3/s$.

b. The systematic error on discharge coefficient was not studied and the accuracy was fixed at 20% (by product of a calibration set of current metering in 1988 : C_d varies from 0.4 to 0.6).

1.3 Calibrated Strickler values accuracy

a. Interest

K coefficients are calibrated on one reach by SIC calibration module using three hydraulic inputs, measured or calculated with accuracies that we defined above :

- U/S water elevation h1, measured with an accuracy of +/- 1.5 cm ;

- D/S water elevation h2, measured with an accuracy of +/- 2 cm;

- U/S discharge Q1, calculated with an accuracy of +/- 0.05 m^3/s

Given these accuracies on h1, h2 and Q1, what is the resulting accuracy on the calibrated values of K ?

The systematic error on Q due to C_d was not considered at this stage.

If the systematic error on C_d is constant, then the computed K are false but their trends are good and the following results are meaningful. If it is dependent on the discharge, the trends are not fully explained and this study will explain only partially the variability on K.

The interests of this study are :

1. to determine a mean value of the accuracy on the Strickler coefficients calibrated further in the survey ;

2. to understand the sources of variability on the calibrated K.

b. Protocol

Two reaches of RBMC were selected to test this influence: a long one, 3-4 (length : 3000m) and a short one, 2-3 (length : 1600m).

A set of three values of K was tested: 20, 30 and 40. For each, two kinds of information were looked for :

- The influence of each parameter on the value of K. The parameter could take two values, e.g. for h1 : h1+2cm and h1-2cm. The other parameters were fixed.

- The value of K combining errors on all the parameters. Two situations were tested in order to assess the extreme possible errors on calibrated K :

  (a) the case where real roughness was as overestimated as possible: this happens if
    (i) real h1 is higher than measured h1,

    (ii) real h2 is lower than measured h2 and

    (iii) real Q1 is lower than calculated Q1. Testing the set (h1+2cm, h2-1.5cm, Q1-0.05m3/s), the minimal value of K is expected to be assessed ;

  (b) the case where real roughness was as underestimated as possible : testing the set (h1-2cm, h2+1.5cm, Q1+0.05m^3/s), the maximal value of K should be found.

  Initial values of h1, h2 and Q1 were taken as follows :

- Q1 was fixed to 5m^3/s, which is a mean discharge condition in 2-3 and 3-4 ;

- h2 was fixed to FSD (Full Supply Depth) of the D/S Cross Structure, ie. target condition of water elevation D/S of each reach of RBMC ;

- h1 was processed using SIC steady flow module, RBMC model and the following hydraulic conditions : Q1 at the U/S Cross Structure, h2 at the D/S Cross Structure, tested K as roughness parameter, seepage coefficient equal to -14 l/s/km, "adjustable gate option" at D/S Cross Structure and all other Cross Structures widely open to avoid any influence on the flow in the reach.

Given a value of K, before running SIC calibration module with test sets, it was checked that the set (h1, h2, Q1), input in SIC calibration module, actually outputs the value of K. Sometimes slightly different values were obtained (see results table row 'K cal') due to calculation errors in SIC.

Relative gaps between these reference values and values of K processed with test sets were finally calculated, i.e. ratios

$$\frac{K-Kcal}{Kcal} \ (\%)$$

Accuracy on calibrated K for two reaches of RBMC

K=f(h1,h2,Q1) – Different values for K were calibrated varying h1, h2 and/or Q1 in the limits of the accuracies of each of these 3 parameters.

h1 : U/S water elevation, h2 : D/S water elevation, Q1 : U/S discharge.
h2 was fixed to the FSD (Full Supply Depth) of the D/S GR :
Q1 was fixed to 5 m3/S, which is a typical condition of flow in this part of RBMC ;
h1 was calibrated using h1, Q1 and K values thanks to SIC Steady Flow Module.

3 values for K were tested : 20, 30 and 40.
k cal is the feed-back value of k calculated in SIC calibration module. Due to calculation errors, it is sometimes sligthly different from the expected value.

At the right side of each k column is given the relative gap between the values of k and k cal.

	GR2–GR3						GR3–GR4					
	k=20		k=30		k=40		k=20		k=30		k=40	
h1 (m)	45.60		45.41		45.30		45.04		44.81		44.68	
h2 (m)	45.01		45.01		45.01		43.96		43.96		43.96	
Q1 (m3/s)	5		5		5		5		5		5	
k cal	20.1		30.0		40.4		20.0		30.0		39.9	
			Values of k						values of k			
h1-2cm	20.9	4.0%	31.7	5.5%	43.1	6.7%	20.7	3.2%	30.8	2.7%	37.9	-5.0%
h1+2cm	20.8	3.5%	28.8	-4.2%	38.3	-5.2%	19.4	-3.0%	29.0	-3.5%	38.2	-4.4%
h2-1.5cm	20.0	-0.5%	29.9	-0.5%	40.0	-1.0%	20.0	0.0%	30.0	0.0%	39.8	-0.3%
h2+1.5cm	20.2	0.5%	30.3	1.0%	41.0	1.5%	20.0	0.0%	30.1	0.3%	40.0	0.3%
Q1-.05m3/s	19.9	-1.0%	29.8	-0.7%	40.1	-0.9%	19.8	-1.0%	29.8	-0.8%	39.5	-1.0%
Q1+.05m3/s	20.3	1.0%	30.4	1.2%	40.8	1.0%	20.2	1.0%	30.4	1.2%	40.3	1.0%
h1-2cm Q1+.05m3/s h2+1.5cm	21.2	5.2%	32.2	7.3%	44.0	8.9%	20.9	4.5%	31.6	5.3%	42.2	5.8%
h1+2cm Q1-.05m3/s h2-1.5cm	19.1	-5.0%	28.3	-5.7%	37.4	-7.4%	19.2	-4.0%	28.7	-4.5%	37.8	-5.4%

c. **Results**

See results table for numerical values.

It appears that :

(i) Variability of $h_{u/s} = h1$ is the most influential parameter on the variability on K.

(ii) Effects are cumulative :
eg. $\Delta K/K$ (h1-2cm; h2+1.5cm; Q1+0.05 m^3/s)
$\doteq$ $\Delta K/K$ (h1-2cm) + $\Delta K/K$ (h2+1.5cm) + $\Delta K/K$ (Q1+0.05 m3/s)

(iii) Given a reach the variabilities on K are quite different for the 3 values of K : variability increases with K and (h1-h2).

(iv) Given a value of K, variability on K depends on the reach : higher for GR2-GR3 than for GR3-GR4.

. An interpretation of the formula used to calibrate K (see part B.1.1.d). To simplify the reasoning, let's assume :

- K is calibrated using only 2 sections (that is the case on RBMC with the files 1*.FLU and 3*.FLU) : n = 2 in the formula in page ... ;

- in the term $H_1 - H_n - \sum kq$ (...) head loss due to lateral outflow $\sum kq$ (...) is negligible in front of $H_1 - H_n = \Delta H$;

- variations of $A_i^2 \; R_i^{4/3}$ between U/S and D/S cross sections are negligible

Under this set of assumptions, $K = f(Q^2) / \Delta H$ and $dK/K = -d\Delta H/\Delta H + df(Q^2)/f(Q^2)$.

In other words, the variability of K, dK, depends on five terms = K, ΔH, Q, $d\Delta Hm$ and dQ. dQ is the inaccuracy on the discharge, $d\Delta H$ is the inaccuracy on the head loss.

The inaccuracy on Q is treated when SFPs are validated : a test on the instant seepage values based on both components (random and systematic) affecting accuracy on Q allows to validate some SFPs only but says nothing on the variability of K.

If Q is fixed, $dK/K = -d\Delta H/\Delta H$.

As $H = z + h + V^2/2g \# z + h$, $dH = dz + dh \# dh$ if absolute references z can be considered perfectly known (it would be better to say that dz is not systematically predictable).

Moreover, $\Delta H = H_{u/s} - H_{d/s}$ and then $d\Delta H = dh_{u/s} + dh_{d/s}$, where $dh_{u/s}$ and $dh_{d/s}$ are the inaccuracies on the measurements of $h_{u/s}$ and $h_{d/s}$, i.e. respectively +/- 2 cm. and +/- 1.5 cm. (confidence intervals 95%).

Finally, $d\Delta H$ = +/- 3.5 cm. and $dK = -3.5\ K/\Delta H_{(cm)}$ (confidence interval 0.95^2 = 90%.

The observed values of ΔH on RBMC fluctuate between 5 and 70 cm.

Corresponding inaccuracies on K are listed in the table below:

ΔH (cm)	5	10	15	20	30	40	50	60	70
$dK/K = -d\Delta H/\Delta H$ (%)	70	35	23	18	12	9	7	6	5

In other words, if a calibrated value of K is K = 30, the accuracy of this value is completely different whether it was calculated with hydraulic data such as ΔH = 5 cm or ΔH = 70 cm.

- K = 30 and ΔH = 5 cm means K belongs to [9; 51] (confidence interval 90%) ;

- K = 30 and ΔH = 70 cm means K belongs to [28.5 ; 31.5] (confidence interval 90%).

. The relation $dK/K = -d\Delta H/\Delta H$ can explain the trends observed inside GR2-GR3 and GR3-GR4 as well as the differences between the two reaches. For instance, the results displayed in table below refer to the table on page 58, the row corresponding to h1-2 cm, Q1 + .05 m^3/s, h2 + 1.5 cm.

	GR2-GR3			GR3-GR4		
	K = 20	K = 30	K = 40	K = 20	K = 30	K = 40
ΔH (cm)	59	40	29	105	85	73
$d\Delta H/\Delta H$ (%)	5.9	8.8	12	3.3	4.1	4.8
dK/K calc. (%)	5.2	7.3	8.9	4.5	5.3	5.8

. <u>Practical consequences</u> :

- In channels with high slopes, head losses are expected to be high and calibrated values of K more reliable ;

- On RBMC, if the inaccuracy tolerated on K is fixed to 10%, the values of K corresponding to head losses less than 35 cm have to be treated very carefully, as they are not reliable enough.

BIEF	DEB	FIN	COEF
1	1	12	44.9795
2	1	8	41.7513
3	1	10	61.9037
4	3	9	75.8193
4	1	2	24.9044
5	1	12	47.5046
6	4	19	41.1022
6	1	3	100.0000
7	1	3	34.0610
8	1	7	24.8933
9	1	13	16.4481
10	13	25	22.6920
10	9	12	15.0794
10	4	8	23.2140
10	1	3	17.2862
11	3	24	49.3732
11	1	2	11.4826
12	3	15	38.8250
12	1	2	100.0000
13	1	4	43.1271
14	4	16	35.9596
14	1	3	10.1046
15	1	8	25.3165
16	3	14	39.5668
16	1	2	100.0000
17	1	6	28.0352
18	5	7	28.2434
18	1	4	135.4330
19	1	11	17.2540
20	3	20	25.7460
20	1	2	5.6439
21	1	5	41.4526
22	3	12	41.5146
22	1	2	10.3301
23	1	6	50.5125
24	1	7	21.5667
25	3	7	15.7245
25	1	2	121.8873
26	1	14	31.4288
27	1	5	18.6562
28	1	3	16.1634
29	1	4	100.0000
30	4	12	34.9022
30	1	3	63.1535
31	1	6	12.9832
32	3	13	14.2479
32	1	2	100.0000
33	1	4	100.0000

Table 1. Initial set of 1988's calibrated values of K

This set was calibrated by POUCHELLE D. in 1990.

A value of 100 means that no value of K could be calibrated because the head loss was too low on the reach.

1 1 12 means that K is calibrated on reach 1 between calculation section 1 and 12.
"reach" has the definition of SIC : part of the canal delimited by two offtakes.

Table 2. Calibrated values of K – 1988's set of hydraulic data

Klow=K(1-3.5/head loss) Kup=K(1+3.5/head loss)
3.5cm is the accuracy on head loss, assuming that the accuracy of water level measurements in 1988 was the same as in 1992.

REACH	K	hu/s	hd/s	head loss	90% confidence interval on K	
		(m)	(m)	(cm)	Klow	Kup
DAM-GR2	49.0	45.66	45.45	21	40.8	57.2
GR2-GR3	58.3	45.17	45.01	16	45.5	71.1
GR3-GR4	32.7	44.72	44.03	69	31.0	34.4
GR4-GR5	19.8	43.94	43.39	55	18.5	21.1
GR5-GR6	49.8	42.97	42.78	19	40.6	59.0
GR6-GR7	37.4	42.54	42.43	11	25.5	49.3
GR7-GR8	32.9	41.82	41.71	11	22.4	43.4
GR8-GR9	36.9	41.20	41.12	8	20.8	53.0
GR9-GR10	17.2	40.89	40.68	21	14.3	20.1
GR10-GR11	25.5	40.31	40.08	23	21.6	29.4
GR11-GR12	38.5	39.56	39.42	14	28.9	48.1
GR12-GR13	24.7	38.82	38.61	21	20.6	28.8
GR13-GR14	28.1	38.23	38.19	4	3.5	52.7
GR14-GR15	13.8	37.95	37.91	4	1.7	25.9

2. CALIBRATION OF STRICKLER COEFFICIENTS

2.1 1988's set of data

a. A measurement campaign was carried out over a 10 day period in April/May 1988, by a joint IIMI-CEMAGREF team with the assistance of the Irrigation Department[1], during a steady flow period for the whole RBMC. Water surface elevation and discharge measurements were estimated in different points in the RBMC, and at all lateral offtakes.

A mean value for canal losses on the whole channel was estimated at -46 l/s/km.

Sluice coefficients were calibrated by Pouchelle[2] (one coefficient for each Cross Structure).

A set of Strickler coefficients was calibrated using a topographic file of 1988. One K is available for each reach of RBMC model.

These coefficients were checked, with very slight differences, using SIC calibration module and RBMC topographic file[3]. (See Table 1 in front page.)

As the present study is based on reaches that are defined between two Cross Structures, i.e. not matching the SIC "reaches", a new set of Stricklers was calibrated between the Cross Structures.

b. This set of Stricklers describes approximately the starting physical status of the canal. As both topographic and hydraulic files are contemporary, this set of Stricklers describes only the roughness of the canal. All the evolutions in the topography of the RBMC should be related to this absolute reference.

This assessment assumes that the measures of the 1988's campaign are reliable. Moreover, it is a strong assumption as there was only one campaign of measurements.

We can only be suspicious with the values of K that are outside the physical standard range of values, i.e. for GR2-GR3 (K=67), and GR14-GR15 (K=14).

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1 See SALLY, H. et al. 1988. "Calibration of the Kirindi Oya RBMC mathematical flow simulation model : Description of the field measurement campaign and preliminary results". IIMI Working Paper 10. IIMI, Colombo, Sri Lanka.

2 Pouchelle, D., Avril-Juillet 1991. "Détermination algébrique des coefficients de Strickler - Application à une méthodologie de calage des modèles hydrauliques". ENSHMG-CEMAGREF, France.

3 Hydraulic conditions : head discharge 4.607 m^3/s, losses - 46 l/s/km, no D/S boundary condition, discharges at offtakes = values given in footnotes (15) and (16), all GR widely open. The results are listed in file K88.LST.

All other values are plausible[4]. (See Table 2 in front page, where head loss was indicated to help analyze the results.)

2.2 Maha 1991-1992's set of data

a. Preliminary remarks

- Maha is the main cultural season extending from September to March-April.

- Tracts 6 and 7 have been irrigated only since 1991. As they are located at the tail end of RBMC, and because of the water shortage during these past few years, it was the first irrigation season. The topography model of those has not been computed yet.

- Tracts 1, 2 and 5 are irrigated following a planning elaborated between Irrigation Department and farmers representatives before the beginning of the season. During the last Maha :

  - Tract 1 area received water from 14 Sept. 1991 to 20 Jan. 1992 ;
  - Tract 2 area from 01 Dec. 1991 to 10 April 1992 ;
  - Tract 5 area from 08 Jan. 1992 to 09 May 1992.

  Consequently, three separate sets of raw data are available, the length of each being approximately 4 months. Data for RBMC Tract 1 cross structures are not collected after 20 January 1992, even if water crossed GR2, GR3 and GR4 until 09 May 1992. It would have been more interesting to analyze data on the whole period, but this was not possible because of staff constraints.

- Water levels are collected at Gate Regulators (GRs) and lateral offtakes (DCs and FCs) daily following two principles :

  - two basic records every day : one early morning (around 8 a.m.), one in the afternoon (around 4 p.m.) ;

  - one additional record at a given structure whenever an operation (i.e. a manoeuver of a gate at a GR or a sluice at an offtake) is achieved.

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4 Note that whereas in Table 1, i.e. K calibrated on each reach of SIC RBMC model, various values have no physical sense (eg. K 7 1 3 = 1000, K 15 1 3 = 10, K 23 1 2 = 10, etc..), this does not happen for Table 2 results, i.e. considering reaches defined between two GRs. As the problematic reaches are generally very short (2 to 3 calculation sections only), this suggests that it is worth calibrating K on longer reaches, in order to obtain more reliable results.

- Maintenance operations achieved on RBMC are collected monthly by one of the Irrigation Engineers of the ID in a document called "Progress Report". Main operations are removal of weeds on the banks above the normal functioning water level, removal of aquatic vegetation (bamboos, sedges), repairs in some structures. The field visits achieved after 10 May 1992, when the canal was dry, showed very little trace of aquatic vegetation : most of the parts of the banks located below the normal water level are naked. This lack of aquatic vegetation in the wetted perimeter is common, all year long, according to the engineer in charge of the maintenance. In the analysis of the calibrated sets of Stricklers, it was considered that on RBMC, vegetation does not influence the value of the Strickler coefficient.

- The following paragraph displays the conclusions of the study on RBMC. For each reach, a table and a graph show the raw calibrated values of K through the period. Unit for time (T) is called "day rank", which is the amount of days between the initial date of the survey (14 Sept. 91 for Tract 1, 01 Dec. 91 for Tract 2, 08 Jan. 92 for Tract 5) and the starting date of the SFP.

  Only when more than 15 values of K were calibrated, a statistical analysis was achieved. On the corresponding reaches, the outputs are :

  - a graph K(T) with the best fitting curve and the corresponding graph of residuals ;

  - a graph K(Q) or K($H_{U/S}$) and its residuals ;

  - one graph plotting the residuals of K(Q) or K($H_{U/S}$) vs T ;

  - synthetic tables for all the statistical models tested to analyze the data ;

  - a table to study the influence of the head loss on K and calculate the accuracy on K.

  All these documents are located in Annex C.2.

b. Main results

1. 13 out of 14 reaches of Tracts 1, 2 and 5 can be processed with Program SFP. The number of SFPs varies between 6 (GR9-GR10) and 29 (GR2-GR3, GR11-GR12). Data analysis is achieved when the size of the sample overtakes 15 values, i.e. only 7 reaches.

2. For the other reaches :

- GR4-GR5 cannot be processed by SFP Program because data were not collected simultaneously at the two GRs ;

- GR10-GR11 shows few SFPs because data were collected simultaneously during a few weeks only ;

- GR14-GR15 shows few validated SFPs because discharges are very low at the tail end and then SFPs easier rejected after the test on instant seepage coefficient ;

- GR9-GR10 shows few validated SFPs ;

- GR7-GR8 and GR8-GR9 cannot be calibrated by SIC because of a topography error at GR8 ;

- GR12-GR13 showed few SFPs because of an error in the computation of the discharges at GR12. After correction, it showed 29 SFPs, but the results are not in the core of that study.

3. Plotting K vs time shows in most of the reaches a very high variability of K. Many values do not belong to the interval [20, 40] which is the standard interval expected for the roughness coefficient of earthen channels. Visual outliers can be suspected on all the graphs.

4. A straight line correlation between K and T, $K = a + bT$, never fits well the bulk of the data, except for DAM-GR2 ($R = 0.958$).

5. A quadratic model $K = a + bT + cT^2$ fits :

   - well or very well the data of GR5-GR6 ($R = 0.94$), GR13-GR14 ($R = 0.80$), GR6-GR7 ($R = 0.64$).

   - acceptably GR2-GR3 ($R = 0.48$) and GR3-GR4 ($R = 0.42$).

   A cubic model $K = a + bT + cT^2 + dT^3$ fits very well the data of GR11-GR12 ($R = 0.93$).

6. Yet, the fitted curves are really different from one reach to another and their magnitude is sometimes really very surprising. As examples :

   - on GR2-GR3, the parabola starts from $K = 38$, reaches $K = 75$ two months later and decreased back to $K = 68$ another two months later.

   - on GR5-GR6, the parabola oscillates between $K = 40$ and $K = 50$ during the first 3 months, but then takes off up to 85 during the last 40 days.

7. Variations in topography can certainly not explain alone such variations in K[5]. In other words, the calibrated values of K contain information not only about channel roughness and topography but also about other variables. Fitting K directly on T has mostly no physical sense on RBMC.

8. Actually, and it is very surprising "a priori", hydraulic data explain most of the variability in values of K :

   a straight line model $K = a + bQ_{U/S}$ fits very well the bulk of the data for DAM-GR2 ($R = 0.88$), GR2-GR3 ($R = 0.87$), GR6-GR7 ($R = 0.92$), GR11-GR12 ($R = 0.82$), GR13-GR14 ($R = 0.96$), and a straight-line model $K = a + bH_{U/S}$ fits very well these for GR5-GR6 ($R = 0.87$).

9. The quality of these models is compared with the quality of models such as $K = a + f(T) + g(Q)$ (or $g(H_{U/S})$) where T and Q or $H_{U/S}$ are considered independent : adding T to Q (or $H_{U/S}$) is useless or explains a marginal part of the variance except for GR3-GR4. That suggests that K and T are mostly little correlated.

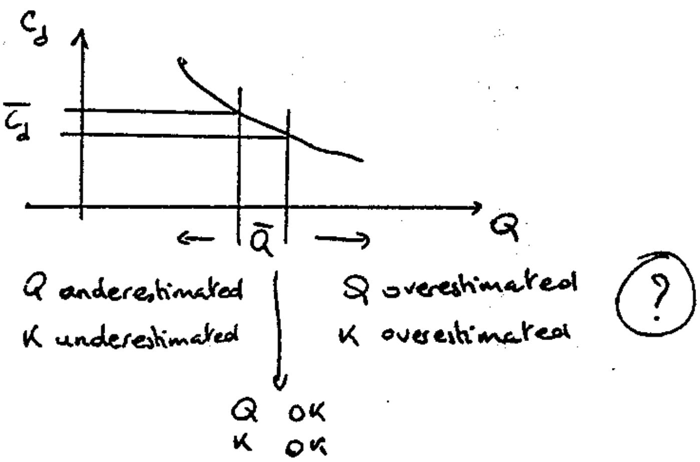
10. Plotting and regressing the residuals $K - a - bQ$ (or $bH_{U/S}$) vs time through simple regression models $K - a - bQ$ (or $bH_{U/S}$) $= d + eT$ confirm that assumption for DAM-GR2 ($R = 0.00$), GR11-GR12 (cluster of low discharges : $R = 0.02$, cluster of high discharges : $R = 0.20$ and "$c = 0$" should not be rejected), GR13-GR14 (cluster of low discharges : $R = 0.03$, cluster of high discharges : $R = 0.03$). For GR2-GR3 and GR3-GR4, a statistically link is underlined, but the trend is not significant regarding the inaccuracy on the calibration of K. That last remark is also valid for GR6-GR7.

11. In all the cases, Q seems to synthesize most of the hydraulic information on the reach : $Q = a + b\,(H_{U/S} - H_{D/S})$ show a strong correlation between Q and $H_{U/S} - H_{D/S}$: GR2-GR3 ($R = 0.84$), GR3-GR4 ($R = 0.97$), GR5-GR6 ($R = 0.94$), GR6-GR7 ($R = 0.83$), GR11-GR12 ($R = 0.79$), GR13-GR14 ($R = 0.80$).

---

5 Given hydraulic data, the simulation of a 10 cm homogeneous siltation in the bed of GR2-GR3 provokes a change in K varying between 4 and 10 units. On the fitted curve, K increases with 37 units, then decreases with 17 units in only 4 months. See detailed results in next paragraph.

12. This is not surprising, given the hydraulic functioning conditions of a reach : $h_{D/S}$ has to be maintained to the FSD level and consequently, giving a value to Q results as a value for $h_{U/S}$. What is only partially explainable by hydraulic considerations is the strong straight-line relation between K and Q. K should not depend on hydraulic conditions. It is important to find out if this behavior is RBMC specific or SIC calibration module specific. The general dependance is an increase of K with Q. One interpretation is that high discharges are overestimated with a constant C_d coefficient. If such $C_d = \overline{C}_d - \alpha(Q - \overline{Q})$, Q and K should be under or overestimated in the following way.



The best means to lighten that problem should be to use SIC calibration module on another irrigation canal.

13. If the values of K corresponding to $(H_{U/S} - H_{D/S}) < 0.30$ m are eliminated (the inaccuracy in these values is > 11%), this :

- strongly reduces the size of some samples : 29 to 2 (GR2-GR3), 29 to 13 (GR11-GR12), 26 to 16 (GR3-GR4), 22 to 12 (GR5-GR6), 26 to 0 (GR13-GR14).

- can explain the surprising magnitude of some curves K = f(T) : parabola GR2-GR3, end of parabola GR5-GR6 (with high values of K), end of curve GR11-GR12, beginning of set of data GR3-GR4 (with visual outliers).

14. <u>As a conclusion</u>: for Maha 1991-11992's set of data, no correlation was underlined between K and T. K can be considered constant through time. Its calibrated values nevertheless depend on the discharge (or U/S water elevation) and the synthetic table below shows the correspondence K = Q or K = $H_{U/S}$ for each reach. Accuracies refer to the corresponding values of head loss (see Annex C.2 for head loss values and table on page 43 for accuracies).

REACH	Validity	K range	Accuracy on K
DAM-GR2	Q < 3 m3/s	25-30	
	Q > 4 m3/s	35-40	
GR2-GR3	any Q	# 65	+/- 25%
GR3-GR4	any Q	45-50	+/- 10%
GR5-GR6	hu/s < 42.95m	55-60	+/- 18%
	hd/s > 43.15 m	35-40	+/- 9%
GR6-GR7	Q # 3 m3/s	30-35	+/- 8%
	Q # 4 m3/s	40-45	+/- 5%
GR11-GR12	Q < 3 m3/s	30-35	+/- 8%
	Q > 4 m3/s	35-40	+/- 15%
GR13-GR14	Q < 1 m3/s	10-20	+/- 30%
	Q > 3 m3/s	35-45	+/- 15%

REACH	K range
GR9-GR10	30-60
GR10-GR11	# 20
GR12-GR13	50-60
GR14-GR15	5-45

CALIBRATED VALUES OF K - KO RBMC MAHA 1991-1992

15. The long term analysis based on the comparison between the value calibrated with 1988's hydraulic data and Maha 1991's/1992's set of data show intersection between the two confidence intervals on K in all the cases except GR3-GR4 for which K is lower in 88 than in 91.

In other word, globally, no significant changes in K can be underlined between 88 and 91.

c. Complementary results

i. Real and modified discharges

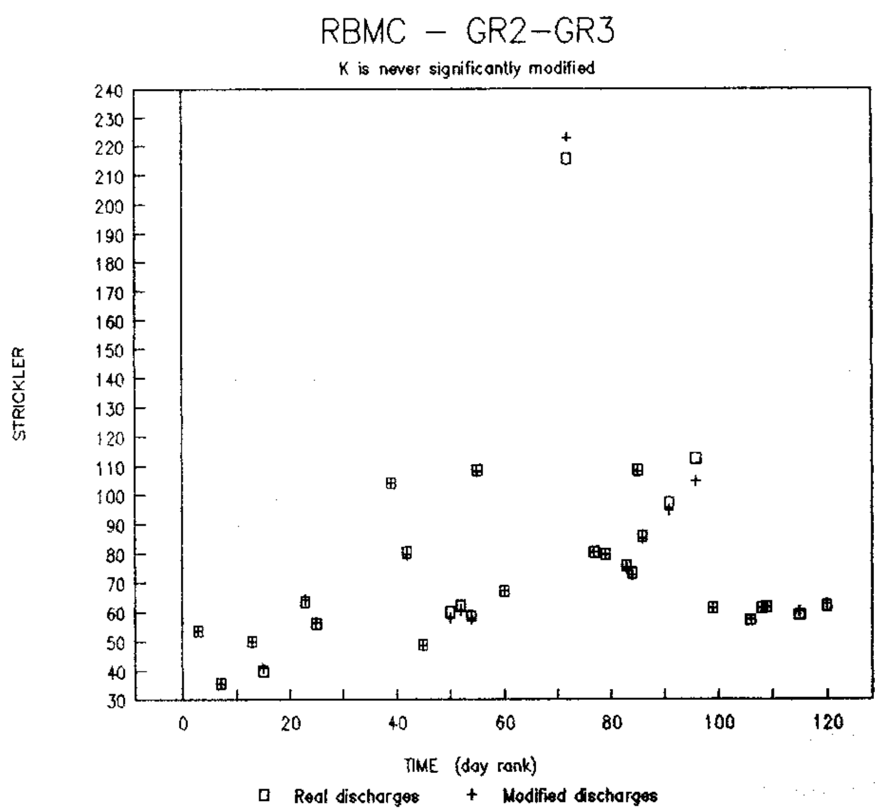
When a SFP was validated after the use of a test on the instant seepage value, two particular (.FLU) files are created (see annex B.2.2.c for more details) :

- 1*.FLU files with non modified discharges ;
- 3*.FLU files with U/S and offtake discharges modified following the value of the instant seepage coefficient, in order to get a more likely seepage coefficient.

KO RBMC - GR2-GR3
STRICKLERS CALIBRATED WITH
REAL AND MODIFIED DISCHARGES

unit for T : day rank, day rank=1 for date=09/14/91
Kreal : values calibrated using initial instant seepage and discharges
Kmod : values calibrated using modified instant seepage and discharges
L : instant seepage coefficient (l/s/km ; L>0 : inflow ; L<0 : outflow)

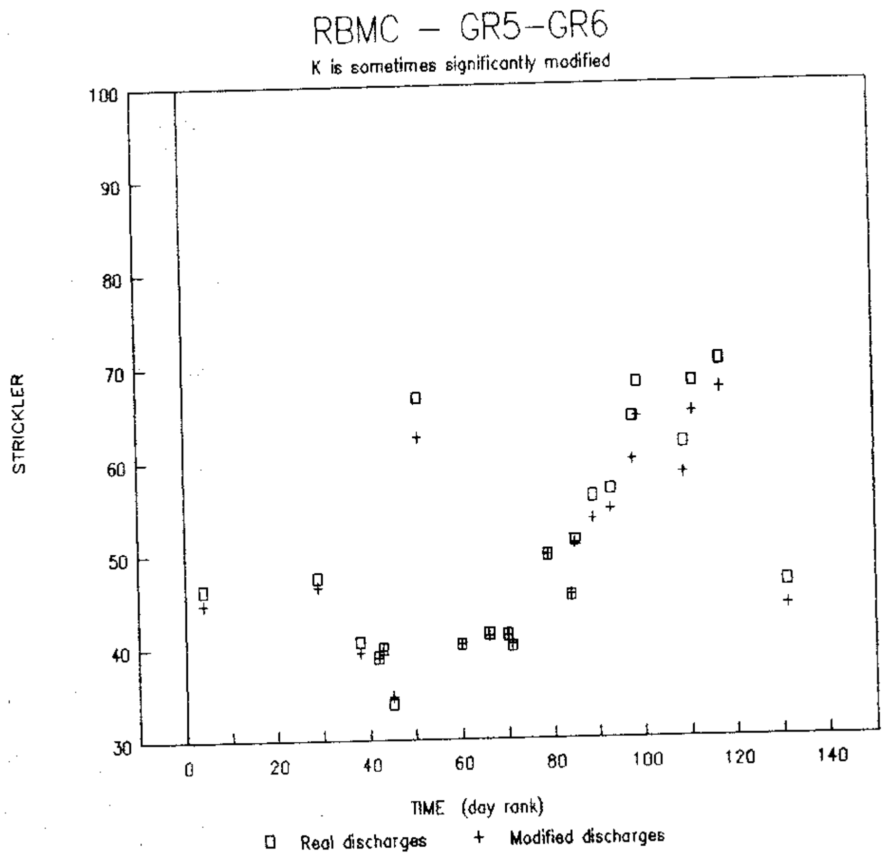
T	Kreal	L	Kmod
3	53.6	1	53.6
7	35.6	-28	35.6
13	50.0	-86	49.8
15	40.0	254	40.8
23	63.6	178	64.2
25	56.0	149	56.4
39	103.9	-27	103.9
42	80.2	-128	79.5
45	48.8	-56	48.6
50	59.9	-245	57.8
52	62.3	-228	60.6
54	58.7	-222	57.7
55	108.4	-153	108.1
60	67.0	35	67
72	215.2	-160	223
77	80.5	-103	80.2
79	79.8	-86	79.6
83	75.7	-224	75
84	73.2	-225	72.5
85	108.4	-282	107.8
86	86.0	-264	85.1
91	97.3	415	94.7
96	112.5	409	104.7
99	61.5	9	61.5
106	57.3	-15	57.3
108	61.4	36	61.4
109	61.8	65	61.8
115	59.0	814	60.3
120	62.0	814	62.9



KO RBMC – GR5–GR6
STRICKLERS CALIBRATED WITH
REAL AND MODIFIED DISCHARGES

t for T : day rank, day rank=1 for date=12/01/91, =140 for date=10/04/92
eal : values calibrated using initial instant seepage and discharges
nod : values calibrated using modified instant seepage and discharges
instant seepage coefficient (l/s/km ; L>0 : inflow ; L<0 : outflow)

T	Kreal	L	Kmod
4	46.2	-292	44.6
29	47.4	-162	46.4
38	40.5	-359	39.4
42	38.9	272	38.9
43	39.8	193	39.6
45	33.8	799	34.7
51	66.6	-2017	62.4
60	40.2	45	40.2
66	41.3	160	41.1
70	41.2	195	41.1
71	40.0	380	40.2
79	49.7	-48	49.7
84	45.3	252	45.4
85	51.2	67	50.9
89	55.9	-470	53.5
93	56.7	-487	54.5
98	64.4	-891	59.8
99	68.0	-728	64.4
109	61.6	-688	58.3
111	68.0	-675	64.8
117	70.3	-537	67.3
131	46.6	-446	44.1



A comparison between the two resulting sets of calibrated Stricklers was done for two reaches : GR2-GR3 and GR5-GR6.

On GR2-GR3, the differences are very slight : using 1*.FLU or 3*.FLU files gives almost the same outputs.

On GR5-GR6, the differences are more significant for the 10 final calibrated values : up to 4 units. The corresponding SFP show high outflows.

In the general case, it should be worth working on 3*.FLU files to increase the absolute precision on K. For studying trends the effect should be less.

ii. Simulation of siltation in the bed on two reaches

The simulation consists in increasing the elevation of the bed with the same value for all the calculated sections.

The aim of that simulation is to find the minimal deposit that can be detected, this depending on the inaccuracy on the calibrated values of K.

The examples of GR2-GR3 and GR3-GR4 were studied.

For GR2 :

- Hydraulic conditions reference value of K equal to 30 corresponds to (non-modified topography),
  $Q_1 = 5m^3/s$, h_2 = FSD = 45.01m, L = O,
  h_1 = 45.60, 45.41 or 45.30 m.
  For calibrated values of K around 30, the accuracy on calibrated values of K is around +/- 7%, i.e. if a calibration gives a value of 30, the result is actually not K=30 but K within the interval
  I_R = [30 x 0.86, 30 x 1.14] = [25.8; 34.2].

- If the initial topography is modified in the following way : all elevations of the channel bed are increased with 5 cm (in (.TAL) file), the same hydraulic conditions give a calibrated value of K equal to K=33.0, i.e. K within the interval
  I_M [33 x 0.86, 33 x 1.14] = [28.4; 37.6].
  As the intersection between I_R and I_M is not empty, the increase of 5 cm of the bed cannot be significantly underlined.

- With an increase of 10 cm, the differences are significant. For this reach, the minimal detectable increase of the bed is between 5 and 10 cm.

For GR3-GR4, this minimal increase is less than 5 cm (see table below).

As no significant evolution in K was detected, we stuck to that theoretical example on RBMC.

SIMULATION OF SILTATION

Table of results for RBMC, GR2-GR3 and GR3-GR4

Topography modification	Calibrated values of K			Kmod-Kini / Kini (%)	Accuracy on K, e (%)	Significance of the difference between Kmod and Kini
	K value	Initial topo Kini	Modified topo Kmod			
GR2-GR3 bed+5cm	20	20.1	21.6	7.0	10.0	}
	30	30.0	33.0	10.0	13.0	}non significant
	40	40.4	45.0	11.0	16.0	}
GR2-GR3 bed+10cm	20	20.1	23.6	17.4	10.0	}
	30	30.0	36.6	20.8	13.0	} significant
	40	40.4	50.7	25.5	16.0	}
GR3-GR4 bed+5cm	20	20.0	22.2	11.0	9.0	}
	30	30.0	33.6	12.0	10.0	} significant
	40	39.9	45.2	13.3	11.0	}

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ANNEXES TO PART B

ANNEX B.2.1 HOW PROGRAM SFP PROCESSES RAW DATA RECORDS

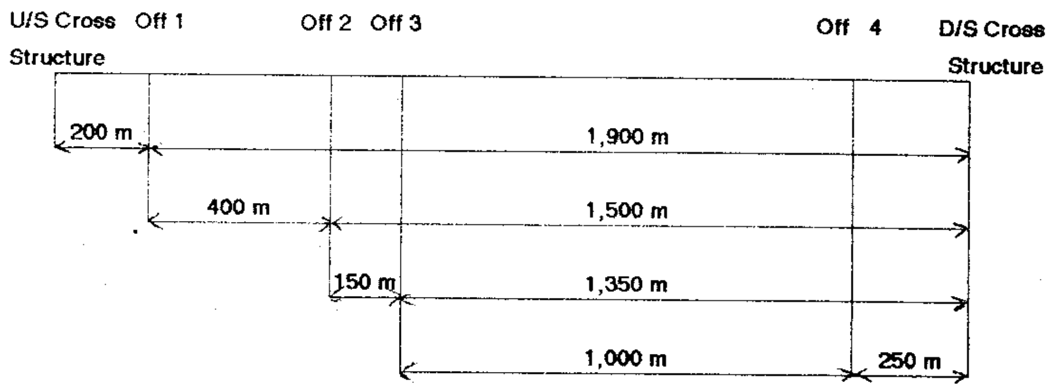
ANNEX B.2.2 WHICH DATA ARE USEFUL TO CALIBRATE STRICKLER COEFFICIENTS

ANNEX B.2.3 OBTAINING SETS OF STRICKLER : SIC CALIBRATION MODULE

ANNEX B.3.2 MODIFICATION OF SIC (.TAL) FILES

ACTIVE AND NON–ACTIVE OFFTAKES

Let us take the following topology for a reach :



Let us suppose that the minimal distance to get meaningful results in **SIC calibration** module is **MIN DIS** = 300 m.

Then the active and non–active offtakes on that reach are :

Off 1	non–active	too close to **U/S** cross structure **(250 m)**
Off 2	active	
Off 3	non–active	too close to Off 2 (150 m)
Off 4	non–active	too close to **D/S** cross structure **(250 m)**

ANNEX B.2.1

HOW PROGRAM SFP PROCESSES RAW DATA RECORDS

Given a starting data record, the next records belong to a SFP as long as the variations of water elevations and discharges calculated between the starting record and the presently tested record belong to the intervals based on the accuracies of the measurements.

The user then indicates the starting date and the finishing date between which the search of SFPs will be processed.

A reach is defined between two Cross Structures. In program SFP :

- Index 1 indicates the D/S cross structure of the reach ;
- Index 2 indicates the U/S cross structure.

First, the user has to select any Cross Structure of the canal as the U/S structure, then the cross structure located immediately D/S as the D/S structure[1].

Between the two defined Cross Structures, the program analyses all the intermediate offtakes that can be either Distributor Channels (DC) or Field Channels (FC). In order to allow good computation of the data in SIC program, a distinction has to be made between the offtakes :

- a given offtake is "active" if the distance between it and (a) the previous offtake, (b) U/S Cross structure and (c) D/S Cross Structure is higher than a minimal distance. The value of 300m was used, i.e. at least 3 calculation sections in SIC. A calibration elevation can be associated to an "active" offtake.
- otherwise the offtake is "non active", no calibration elevation can be associated with such an offtake.

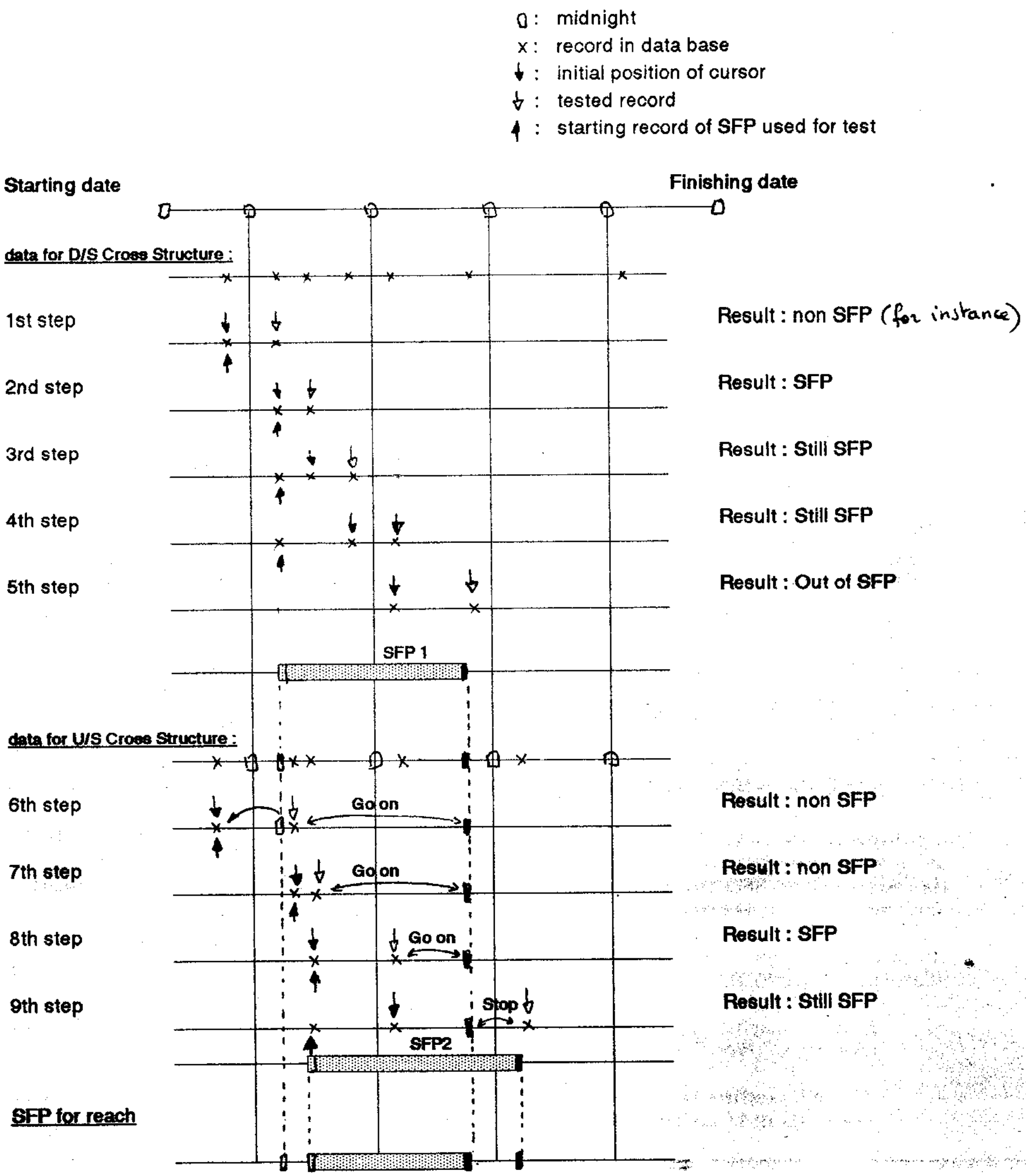
Locating on the earlier record of given starting date or on the closer record after that date within D/S Cross Structure 1 set of data, the cursor tests each record until a SFP is found (if any) within the limits of the time interval defined for the search.

In case a SFP was found for Structure 1 (SFP1), Program SFP looks for a SFP for Structure 2 partially or fully covering SFP 1:

- if SFP1 begins in the afternoon of day D, the cursor locates on the first record of day D in Structure 2 set of data ;
- if SFP1 begins in the morning, the cursor locates on the last record of day D-1 in Structure 2.

1 If another cross structure is selected as D/S cross structure, the search of SFP will be achieved, but program SFP does not analyze the stability of water elevations and discharges at the intermediate cross structures.

SEARCHING SFP



If no record can be found following that rule, the cursor seeks the closer record after day D.

SFP2 is looked for within that beginning record and either (a) the first record overtaking the end of SFP1 or (b) the last record within the time interval defined for the search.

If a SFP2 was found but finishes before SFP1 begins, this SFP2 is ignored and a new search begins for SFP2.

When a SFP was found for each structure, a SFP can be defined for the reach. Its limits in time are the intersections of SFP1 and SFP2.

ANNEX B.2.2

WHICH DATA ARE USEFUL TO CALIBRATE STRICKLER'S COEFFICIENTS

a. SIC calibration module can be used in two different ways :

i. Calculate a Strickler coefficient for the whole reach (portion of the whole main canal delimited by two Cross Structures), i.e. consider the reach as a homogeneous part of the whole main canal. Necessary inputs are :

- Discharge in the main canal U/S of the reach ;
- Water elevation references downstream of U/S Cross Structure and upstream of D/S Cross Structure ;
- Lateral discharges at the intermediate offtakes ;
- Approximation of seepage losses.

ii. Calculate a Strickler coefficient for each of the sub-reaches that can be defined.
Necessary inputs are :

- The same as for case a ;
- Water elevations references in the main canal at each "active" offtake.

Only the offtakes defined as "active" define sub-reaches.

b. **Which outputs data are processed by ?**

i. **Data for boundary cross sections**

Given a SFP for the reach, a single record for each structure of the reach will provide SIC calibration module with hydraulic information, while the SFP spreads over at least two records.

Assuming that the most representative data for the SFP is the latest one belonging to that SFP, the data records that will be used for the boundary cross sections by SIC calibration module are the closest to the end of the SFP.

In the (.FLU) hydraulic data file, two lines are created for the U/S cross section : one (starting with Q) will code the discharge, one (starting with C) will code the calibration elevation.

Only one line will code the calibration elevation of D/S cross section[1].

ii. Data for intermediate offtakes

SFPs are defined processing boundary cross sections data. It is assumed that the conditions of flow are steady all along the canal between these two Cross Structures, and particularly at all the offtakes.

Given a SFP for the reach, for each offtake the record that will provide data to SIC is the first one before the end of that SFP. It can either belong to the SFP itself or be anterior to its start. In the latter case, a message indicates that the record does not belong to the SFP, but is anterior. Appraisal should be done by the user whether that record is near enough of the beginning of the SFP and reliable enough to be processed by SIC or not.

If the user wants to calibrate a single value of K for the whole reach, a single line starting with Q, will code the discharge at the offtake.

If the users wants to calibrate a value of K on each sub-reach, an additional line, starting with C, will code the water elevation at the offtake.

A single line (starting with Q) containing the discharge is created for each "non-active" offtake.

iii. Approximation of seepage losses

The user can choose between two options :

- use a fixed value for the coefficient in any case ;
- calculate an instant seepage coefficient for each SFP, as defined in Section B.32 above :

INSTANT SEEPAGE =(U/S DISCHARGE-D/S DISCHARGE-OFFTAKES DISCHARGES)/REACH LENGTH

One line (starting with L) is created in the file (.FLU) for each sub-reach.

1 It is necessary to provide SFP program with some information concerning the geometry, described in the model used by SIC.

iv. **Initial value for Strickler coefficient**

One line (starting with K) is created for each sub-reach, using procedure REACHINFO to code correctly the information.[2]

c. <u>How to shape this data for SIC : (.FLU) files</u> ?

Data input files directly readable by SIC are (.FLU) files.

The first step for the user is to create an appropriate model for the reach that he studies. Then it is possible to generate correctly (.FLU) files for this model.

SFP program creates automatically two (.FLU) files corresponding to each of the two different ways described in Section B.2.2.a of this annex.

i. **Naming (.FLU) files**

The names of the files are built in the following way:

- A first character indicates the type of the file:

  . '1' means that only one K will be calculated for the whole reach. The file contains calibration elevations only for the Cross Structures;

  . '2' means that one K will be calculated within each sub-reach of the reach. The file contains calibration elevations for Cross Structures and "active" offtakes.

  . '3' has the same meaning as '1' but uses a more likely value for the seepage and consequently for the discharges. It is created only when the SFP was validated after a test on the instant seepage was necessary. Seepage and discharges (lines L and Q) are modified. Seepage takes the value defined as the maximum likely value and Q are modified in the following way :

2 As the calibrated K does not only stand for the roughness of the canal, the set of K determined for each reach can be widely out the classical range [20, 40]. However, giving an initial value not too far from the final calibrated ones is important. If this condition is not respected, the 20 possible calibration iterations of SIC may not be sufficient to get a stable value. To avoid this problem, before running the SFP program on the whole period of time, run it for two or three short periods, calibrate the corresponding K and assume that these values give a good idea of the whole set. Deduct an initial value for K.

```
# File D:\JM1\23\124.FLU
# Steady flow period from 09/30/91 16.45 to 10/02/91 16.00
# Day rank of beginning of SFP :  15
K  1  1  7   40.0000
K  2  1 11   40.0000
K  3  1  3   40.0000
L  1  1  7 254.227
L  2  1 11 254.227
L  3  1  3 254.227
Q1GR2            1.103
Q1D4            -0.462
Q1D5            -0.337
C  1  0
C  1  1   45.12
C  3  3   45.10
```

```
# File D:\JM1\23\324.FLU
# Steady flow period from 09/30/91 16.45 to 10/02/91 16.00
# Day rank of beginning of SFP :  15
# Modified values of discharges to improve likelyhood of L
K  1  1  7   40.0000
K  2  1 11   40.0000
K  3  1  3   40.0000
L  1  1  7  50.000
L  2  1 11  50.000
L  3  1  3  50.000
Q1GR2            1.266
Q1D4            -0.512
Q1D5            -0.373
C  1  0
C  1  1   45.12
C  3  3   45.10
```

```
#File D:\JM1\23\TEMP\224.FLU
#Steady flow period from 09/30/91 16.45 to 10/02/91 16.00
K  1  1  7   40.0000
K  2  1 11   40.0000
K  3  1  3   40.0000
L  1  1  7 254.227
L  2  1 11 254.227
L  3  1  3 254.227
Q1GR2            1.103
Q1D4            -0.462
Q1D5            -0.337
C  1  0
C  1  1   45.12
C  2  1   45.08
C  3  3   45.10
```

With the same hydraulic data, Program SFP builds three different (.FLU) files : 1*.FLU, 2*.FLU and 3*.FLU.

1*.FLU allows to calibrate a single Strickler on the whole reach, with the original values of water levels and discharges. Consequently, there are only two calibration lines "C" (C 1 0 is not a calibration line).

2*.FLU allows to calibrate Stricklers on sub-reaches, using the notion of "active" and "non active offtakes" (see precedent annex). On that reach cited in example, there is one "active" offtake, so one supplementary line "C".

3*.FLU is created only if a test on instant seepage values was used to validate the SFP. It works as for 1*.FLU, but with modified values for the discharges.

DIFFERENT TYPES OF (.FLU) FILES

Let's say that indexes 1 and 3 concern variables in file '1' and '3'.

First,

$$L_3 = L_{max} \text{ if } L_1 > L_{max}$$
$$= L_{max} \text{ if } L_1 < L_{max}$$

Moreover, as :

$$Q_{U/S} - (Q_{D/S} + Q_{offtakes}) = L.10^{-6}.\text{Reach Length}$$
$$Q : m^3/s, \quad L : l/s/km, \quad \text{Reach length} : m,$$

it can be written :

$$[Q_{U/S3} - (Q_{D/S3} + Q_{off3})] - [Q_{U/S1} - (Q_{D/S1} + Q_{off1})] = (L_3 - L_1).10^{-6}. \text{ Reach length}$$

It is assumed that the difference $(L_3 - L_1)$ is equally distributed on $Q_{U/S}$ on the one hand, $Q_{D/S} + Q_{off}$ on the other hand :

$$Q_{U/S3} - Q_{U/S1} = (Q_{D/S3} + Q_{off3}) - (Q_{D/S1} + Q_{off1}) = 0.5\ (L_3 - L_1).10^{-6}. \text{ Reach length}$$

The discharge inputs for file '3' are consequently :

$$Q_{U/S3} = Q_{U/S1} + 0.5\ (L_3 - L_1).10^{-6}. \text{ Reach length,}$$

and for each offtake Q_i ($Q_{off} = \Sigma\ Q_i$, $i = 1,m$)

$$Q_{i3} = Q_{i1} + \frac{Q_{i1}}{Q_{D/S1} + Q_{off1}}\ 0.5\ (L_3 - L_1).10^{-6}. \text{ Reach Length}$$

- A second list of characters is the code of the reach (1 to 4 characters).
- A third list of characters indicates the rank of the considered SFP out of all the SFPs determined within the total time interval. It matches with the number indicated on the first line of the (.TXT) file.
- The suffix '.FLU' is automatically added.

Example : '124.FLU' allows to calculate only one K (1) for the reach GR2-GR3 ('2' is the code of the reach defined by the user for this reach) and the corresponding SFP was the fourth one ('4') found during the search. See listings of files of KO RBMC 124.FLU, 224.FLU AND 324.FLU below.

ii. Content of (.FLU) files

- Three information lines indicate :

  - the rank of the SFP ;
  - the starting and finishing dates and times of the SFP ;
  - the rank T of the starting date, with the convention that T = 1 for date = starting date of the reach.

- Then are displayed the lines starting with K (initial value of K), L (seepage losses in l/s/km, negative value for an outflow), Q and finally C.

  More generally, FORTRAN formats to code L, K. Q and C lines of data are :

  - for discharges : "Q" + name of structure (5 characters) + value (8 characters, unit : m^3/s) ;
  - for calibration : "C" + reach number (3 characters) + calculation section (3 characters) + value (8 characters, unit : m) ;
  - for seepage losses : defined on each sub-reach. "L" + nb. of 1st section (3 characters) + nb. of last section (3 characters) + value (14 characters, unit : l/s/km) ;
  - for initial Strickler value : same structure as for L, the line beginning with a K.

  To code this information correctly, observe a (.FLU) file created by SIC after using the menu **STEADY FLOW MODULE/DATA EDITOR/CREATION OF A HYDRAULIC FILE.** Such a line should be observed :

```
L   1   1   12     -50
```

  That is, "the seepage losses (L), for the sub-reach 1, between the calculation sections 1 and 12 are -50 l/s/km".

  When program SFP wants to build all the seepage code lines, it requires the amount of sub-reaches and, for each, the number of calculation sections. This has to be coded by the user in a single line, in the procedure REACHINFO.

  If say a reach RRRRR contains 3 sub-reaches with respectively 7, 11 and 3 calculations sections, the user will code two lines in procedure REACHINFO as :

```
CASE  INSTRUCTURE  =  'XXXXXX'
MINFO =  '   7    11    3 '
```

Where Program SFP builds the L lines of a (.FLU) file with a value of L = -50 l/s/km, it will write :

L	1	1	7	-50
L	2	1	11	-50
L	3	1	3	-50

c. <u>How to check these data : (.TXT) files</u> ?

The results are displayed on screen and can also be directed to a file (.TXT).

Two basic options can be chosen: STANDARD results and PERSONALIZED results.

STANDARD results option displays only data that will be used by SIC calibration module (see previous Section B.2.2.b) and information on seepage tests.

PERSONALIZED results options displays STANDARD results and add more information about the SFPs.

In this menu, several options are proposed as regards the content of the results :

1. Displaying results for Structure 1, Structure 2 and the reach whenever a SFP or not was found. This option allows to check each step of the processing of data and gives the maximal information ;

2. Displaying results only when a SFP for the reach was found. All results relative to Non SFP periods are not displayed ;

3. Displaying all the records of a SFP when a SFP was found for a Cross Structure. If e.g. 5 records define a SFP for one Cross Structure, all of them will be displayed ;

4. Displaying only starting and finishing records of a SFP when a SFP was found for a Cross Structure. This gives an idea of the extent in time of the SFP for the Cross Structure ;

5. Displaying a SFP for the reach whatever its duration ;

6. Displaying a SFP when its duration is higher than a defined minimal duration. Default value is 6 hrs. (see Section B.31).

ANNEX B.2.3

OBTAINING SETS OF STRICKLER : SIC CALIBRATION MODULE

a. How to simplify manipulations of files ?

When (.FLU) files are created, the user quits DBASE environment and skips to SIC environment. To calibrate Strickler, it is necessary to use pre-defined models of canal. As the model will be used only in steady flow periods, only 3 files are useful out of all the created through SIC topography module :

- (.TAL) ASCII file and (.MIN) binary file containing the description of the topography ;
- (.EDI) file necessary to use the menu TOPOGRAPHY MODULE/DATA EDITOR.

Topography files and (.FLU) have to be in the same directory.

We found it more convenient to divide the complete model of the main canal in as many sub-models as there are reaches concerned by the survey[1]. Each sub-model is stored in its own sub-directory. This allows to save time running SIC (calibration iterations are limited to the interesting part of the model) and facilitates the management of inputs and outputs files. The user indicates in which directory results files will be written.

b. How to create a SIC topography sub-model of a larger model ?

If the whole model for RBMC is used to calibrate a Strickler on a single reach, say GR2-GR3, a large amount of time computation can be saved if the user works not on the whole model, but on the excerpt of that model containing only the interesting part, i.e. on our example the sub-model delimited by GR2 as U/S extremity and GR3 as D/S extremity.

All the necessary modifications can be done to the (.TAL) file of the whole model.

---

1 For example, on KO RBMC one sub-model for reach GR2-GR3, one for reach GR3-GR4, and so on.

```
***********************************************************
*  Annex to Part ..2..3 : Description of a (.TAL) file    *
* Description of the geometry for GR2-GR3 submodel of RBMC *
***********************************************************


!GR2-GR3
***********     REACH : REACH 1   FROM  1GR2 TO  1D4                        ***********
# TRACT 1 1GR2  1D4        0     REACH 1   FROM 1GR2  TO  1D4
N*D/S 1GR2
L  2415  0.    7.45 10.58 18.75 20.67
         44.15 44.19 44.7  46.72 47.77
N S
   2500-12.1  -5.3   0.    5.35  9.5
         47.64 44.49 44.37 44.54 45.85
N S
   2600-13.6  -6.1   0.    6.3  11.05
         48.14 44.81 44.12 44.75 47.17
N S
   2700-15.12 -6.6   0.    5.19  9.65
         48.65 44.73 44.35 44.69 47.13
N S
   2800-14.54 -4.84  0.    4.99 10.41
         48.93 44.64 44.21 44.73 46.74
N S
   2900-12.1  -4.7   0.    5.17  9.17
         46.9  44.52 44.13 44.37 45.86
N*END  REACH 4
L  2977  0.    9.17 11.54 20.53
         44.13 44.35 44.55 46.76
***********     REACH : REACH 2   FROM  1D4   TO  1D5                       ***********
# TRACT 1 1D4   1D5        0     REACH 2   FROM  1D4   TO  1D5
N*BEG. REACH 5
L  2977  0.    9.17 11.54 20.53
         44.13 44.35 44.55 46.76
N S
   3000-10.25 -5.2   0.    5.9  10.1
         46.72 44.36 44.17 44.41 46.34
N S
   3100-10.66 -5.3   0.    4.93  9.15
         46.6  44.22 44.   44.28 46.26
N S
   3200 -9.6  -3.87  0.    4.25  9.35
         46.13 43.74 43.56 43.99 45.57
N S
   3300 -9.9  -4.5   0.    5.15  8.7
         46.54 43.81 43.49 43.85 45.55
N S
   3400-10.6  -4.78  0.    5.8   9.5
         46.5  43.78 43.33 43.91 45.8
N S
   3500 -7.15 -4.3   0.    4.65  7.
         45.7  44.16 43.77 44.17 45.63
N S
   3600 -8.4  -5.3   0.    4.6   8.02
         45.73 44.18 43.83 44.24 45.77
N S
   3800-11.3  -5.45  0.    5.1   9.75
         46.78 44.21 43.84 44.04 46.3
N S
   3900-10.3  -4.73  0.    5.48  9.45
         46.25 44.   43.7  43.94 45.88
N*END  REACH 5
L  3967  0.    6.47 10.79 19.13
         43.68 43.85 44.1  46.1
***********     REACH : REACH 3   FROM  1D5   TO  1GR3                      ***********
# TRACT 1 1D5   1GR3       0     REACH 3   FROM  1D5   TO  1GR3
N*CR2N
L  3967  0.    6.47 10.79 19.13
         43.68 43.85 44.1  46.1
N S
   4000 -9.87 -5.48  0.    4.7   9.
         46.04 44.1  43.7  43.85 45.6
N*U/S 1GR3
L  4012  0.    7.6  11.27 18.84
         43.56 43.58 44.2  46.03
```

i. Description of a (.TAL) file[2]

A (.TAL) file is a ASCii file containing ordered lines.

- 1st line : "!" + title of the model (70 characters max.) followed by one or several lines of comment starting with "*".

- Then for each reach of the model :

  - 1st line: "*" + information : name of the reach

  - 2nd line: "#" col 1 + "blank" col 2 + description of reach :
    - 8 characters : branch name (col 3 to 10)
    - 6 characters : U/S node name (col 11 to 16)
    - 6 characters : D/S node name (col 17 to 22)
    - 5 characters : computational step (col 23 to 27, default : 0 in col 27)
    - 5 characters : sinuosity of medium used (col 28 to 32, default = blank)
    - 46 characters : reach title (col 33 to 72)

- Then for each cross section from the 1st node, 3 lines :

  - 1st line :
    - 1 character : N
    - 1 character : blank if the section is not to be displayed, "*" otherwise
    - 15 characters : name of section

  - 2nd line : abscissa or width.
    - 1 character : blank if abscissa - elevation section, 'L' if width-elevation. In the case of parametered sections (circle, culvert, trapezoidal, ...) refer SIC Programmer's Guide.
    - 6 characters : distance from U/S boundary in m (col 2 to 7)

    - for each abscissa or width : 6 characters

  - 3rd line : elevation, from col 8
    - for each elevation : 6 characters

Tip: do not leave any blank line at the end of (.TAL) file.

---

2 For more details, see SIC, Version 1.0. Programmer's Guide.

ii. Erasing non-interesting part of the whole model

- Edit (.TAL) ASCii file under any file editor.

- Modify the title of the model. Locate on following line.

- Select then erase the lines until you find the description of the cross-section corresponding to the downstream of the cross structure that will be the U/S extremity of the sub-model.

- Delete all the lines following the description of the cross section corresponding to upstream of the cross structure that will be the D/S extremity of the sub-model.

- Add any comment starting a corresponding line with "*".

iii. Modifying branches and nodes names

It is necessary to build a perfect compatibility for the names of branches, reaches, nodes (cross structures and offtakes) of the canal between the database files and the model topology, the link joining DBASE program and SIC Strickler calibration module being the (.FLU) ASCii files created by SFP program and used by SIC.

The modifications have to be made in the lines starting with "#". Such lines need to be created at the top of the first reach which starts with D/S cross section of U/S cross structure.

iv. Building a SIC model from (.TAL) file

Run SIC and choose the option "TOPOGRAPHY MODULE/TOPOGRAPHY COMPUTATION", then select the (.TAL) file. If any problem arises, check that the (.TAL file matches exactly its architecture. (See annex - Description of (.TAL) file.) Some error messages are available in (.LST) file to help locate errors.

Then several files are generated. Some of them can be erased to save memory : (.GEO) (.SIR) (used for unsteady flow computation), (.LST) file.

The created (.MIN) file is fully usable by SIC steady flow module. To use SIC TOPOGRAPHY MODULE/DATA EDITOR, it is necessary to build the little ASCii (.EDI) file containing information to draw the model on the screen, under the data file editor :

1st line	:	7
2nd line	:	2
following line containing :	:	one for each node (cross structure or offtake)
6 characters	:	node name (col 1 to 6)
5 characters	:	horizontal abscissa (col 7 to 11, value : 1 to 3000)
5 characters	:	vertical abscissa (col 12 to 16, value : 1 to 2000)

c. **How to process (.FLU) files ?**

To calculate the sets of Stricklers, the user runs SIC choosing the data directory corresponding to the sub-model he is studying. Then three steps are necessary to get the results :

- Convert (.FLU) text files into (.DON) binary files, using STEADY FLOW MODULE/DATA EDITOR/VERIFICATION OF HYDRAULIC DATA FILE ;
- Compute the (.DON) files using STEADY FLOW MODULE/STEADY FLOW COMPUTATION ;
- Visualize the results stored in the (.LST) generated text file using STEADY FLOW MODULE/TYPE using the text editor incorporated in SIC.

(.SRF) binary result file is useless and should be erased to save memory.

d. **How to collect the results ?**

Once a (.LST) file was edited, collect the result on a sheet of paper. Once the whole set is collected, it can be entered in a pre-defined LOTUS worksheet computed by SFP, containing a column with the ranks of the defined SFPs. Some graphs can then be drawn. To build this worksheet, Program SFP uses a file called LOTUS.DBF.

ANNEX B-3-2

MODIFICATION OF SIC (.TAL) FILES

To simulate siltation in bed, erosion in bank, or any other geometric modification in a given model of canal used by SIC, the most direct way consists in modifying (.TAL) file of the model either using any file editor, or, if a semi-automatic transformation is asked, a spreadsheet such as LOTUS 123. (.TAL) file contains the topographical data to be checked and processed by TALWEG.

i. Direct modification of topography

- to modify the elevations of the bed channel : locate which abscissas or widths define the bed (generally 3 abscissas : one in the center of the bed, two on the sides or 2 widths, one usually with 0 for bed center, one for the width of the bed) and modify the corresponding elevations in the line below.

- to simulate erosion in the banks : locate which abscissas or width correspond to the banks. Increase the positive values, decrease the negative ones, without modifying the elevations.

ii. Using a spreadsheet to build these modifications

The different steps are described for LOTUS 123 version 2.0. Provide a listing of (.TAL) file and load MODITOPO.WK1 file.

1st step : Converting ASCii (.TAL) file into a (.WK1) worksheet with column widths matching with the data format of cross section description.

This step is automated in macro\c. Run {Alt+C} after loading MODITOPO.WK1.

2nd step : manual corrections

Step 1 brought artefacts that must be corrected manually : "!", "#" and "N" lines may have been inopportunately modified, as they contain figures. Check this and build them up correctly again if necessary.

- negative abscissas containing two figures both for integer part and decimal part such as -11.11 are replaced by "******". Round these abscissas to only one decimal using the menu /rff1 (range/format/fixed/1) for the corresponding cells.

- modify the title of the model in the first line, indicating the nature of the topography modifications.

LOTUS macro-instructions used to modify semi-automatically elevations in a (.TAL) topography file

```
\c      {GOTO}A1~
        /WCS2~
        {RIGHT}
        /WCS5~
        {right}
        /wcce{right 9}~6~
        {RIGHT 14}
        /WCS2~
        {RIGHT}
        /WCS5~
        {right}
        /wcce{right 9}~6~
        {GOTO}A1~
        /FIT{?}~
        {GOTO}A1~
        /DPFC~FEL>V>>>>V>>>>>V>>>>>V>>>>>V>>>>>V>>>>>V>>>>>V>>>>>V>>>>>V>>>
        IA1.A200~
        OQ2.Q2~
        G
        /REA1.O200~
        {GOTO}Q2~
        /MQ2.AE201~A1~
        {HOME}
        /rff2~d3.p200~
        /xq


\s      /pf{?}~
        RA1.{?}~
        OML0~MR100~MT0~MB0~P100~
        OUQGQ
        /xq

\m      {down}{left}
        {edit}+0.05~{right}
        {edit}+0.05~{right}
        {edit}+0.05~
        {left}{down 2}
        /xq


\l      {down}{edit}+0.05~
        {right}{edit}+0.05~
        {down 2}{right}
        /xq

\k      {left 2}
        /xq

\d      /feo{?}~y
        /xq
```

<u>3rd step</u> : modifying the topography

Move to the text of the macros and observe the macros \m and \l. :

running \m increases bed elevations with 5 cm abscissa-elevations for cross sections. Before running it, locate on the abscissa 0 of the first section, then press {Alt-m}.\l does the same for width-elevations cross sections. Locate on the first width before running \l.

It is very easy to build such macros containing the standard modifications of each cross section.

<u>4th step</u> : saving the new (.TAL) file as an ASCii file

- locate the rank of the last written row and last written column and remember them. (Not any blank line must exist at the end of (TAL) file) ;
- Choose a name for the output file with the suffix (.TAL) and check that this name does not exist yet. Otherwise erase the existing file running \d macro ;
- Run \s macro to save the file : the created (.TAL) file is directly readable by SIC.

ANNEXES TO PART C

ANNEX C.1 WATER LEVEL MEASUREMENTS ACCURACY - NUMERICAL RESULTS FOR GR3 TO GR14

ANNEX C.2 CALIBRATED SETS OF STRICKLERS - NUMERICAL AND GRAPHICAL RESULTS FOR KO RBMC DAM-GR2 TO GR14-GR15

ANNEX C.1

WATER LEVEL MEASUREMENTS

ACCURACY - NUMERICAL RESULTS

FOR GR3 TO GR14

WATER LEVEL MEASUREMENTS ACCURACY GR3

24/4/92

ABSOLUTE REFERENCES (m)		
TBM	Top of gauges	
	TBM_DW	TBM_UP
46.845	45.010	45.120

FIELD MEASUREMENTS (m)			
Local references		Gauge levels	
MEAS_DW	MEAS_UP	GAU_DW	GAU_UP
0.47	0.295	0.76	0.8

D/S	Staff level	Water level	Water elevation	
1	3.385	0.37	44.300	
2	3.645	0.63	44.300	G
3	3.650	0.64	44.305	G
4	3.655	0.64	44.300	1
5	3.655	0.65	44.310	1
6	3.655	0.62	44.280	1
7	3.650	0.61	44.275	
8	3.650	0.60	44.265	
9	3.655	0.61	44.270	
10	3.640	0.61	44.285	
11	3.640	0.62	44.295	
12	3.640	0.62	44.295	
13	3.645	0.62	44.290	
14	3.645	0.62	44.290	4
15	3.640	0.61	44.285	4
16	3.655	0.66	44.320	4
17	3.660	0.65	44.305	
18	3.665	0.66	44.310	
19	3.660	0.66	44.315	
20	3.650	0.64	44.305	

STATISTICS :		
Average level	mean_DS	44.295
Std deviation	std_DS	0.015
Maximum measured level		44.32
Minimum measured level		44.265
Maximum gap		0.055

CONFIDENCE INTERVAL (LEVEL 5%) :		
Degrees of freedom	n_DS	20
Student,level 5%	T_DS	1.72
Lower limit		44.289
Upper limit		44.301
Confidence interval width		0.0112

TEST FOR CALCULATED GAU_DW VALUE :	
GAU_DW calculation : cells	2,3
Value for GAU_DW	44.303
T statistics	2.30
Result of test :	reject GAU_DW value
(GAU_DW measurement :	44.25)

U/S	Staff level	Water level	Water elevation	
1	3.255	0.53	44.415	
2	3.510	0.79	44.420	G
3	3.577	0.85	44.413	G
4	3.570	0.85	44.420	1
5	3.565	0.84	44.415	1
6	3.560	0.83	44.410	
7	3.570	0.85	44.420	
8	3.590	0.87	44.420	
9	3.575	0.86	44.425	
10	3.585	0.87	44.425	
11	3.575	0.86	44.425	4
12	3.580	0.84	44.400	4
13	3.585	0.80	44.355	4
14	3.590	0.86	44.410	
15	3.580	0.86	44.420	
16	3.565	0.84	44.415	
17	3.415	0.68	44.405	
18	3.090	0.36	44.410	
19				
20				

STATISTICS :		
Average level	mean_US	44.412
Std deviation	std_US	0.015
Maximum measured level		44.425
Minimum measured level		44.355
Maximum gap		0.07

CONFIDENCE INTERVAL (LEVEL 5%) :		
Degrees of freedom	n_US	18
Student,level 5%	T_US	1.73
Lower limit		44.406
Upper limit		44.419
Confidence interval width		0.0126

TEST FOR CALCULATED GAU_UP VALUE :	
GAU_UP calculation : cells	2,3
Value for GAU_UP	44.417
T statistics	1.13
Result of test :	accept GAU_UP value
(GAU_UP measurement :	44.32)

WATER LEVEL MEASUREMENTS ACCURACY GR4

24/4/92

ABSOLUTE REFERENCES (m)		
TBM	Top of gauges	
	TBM_DW	TBM_UP
45.939	44.070	44.200

FIELD MEASUREMENTS (m)			
Local references		Gauge levels	
MEAS_DW	MEAS_UP	GAU_DW	GAU_UP
0.822	0.595	0.83	0.97

D/S	Staff level	Water level	Water elevation
1	3.560	0.14	43.336
2	3.835	0.42	43.346
3	3.955	0.57	43.371
4	3.993	0.60	43.368
5	3.985	0.54	43.316
6	3.990	0.56	43.331
7	3.995	0.57	43.331
8	3.986	0.56	43.33
9	3.980	0.54	43.321
10	3.973	0.54	43.328
11	3.980	0.54	43.316
12	3.982	0.54	43.319
13	3.980	0.54	43.321
14	3.978	0.54	43.323
15	3.972	0.55	43.339
16	3.960	0.53	43.331
17			
18			
19			
20			

STATISTICS :		
Average level	mean_DS	43.333
Std deviation	std_DS	0.016
Maximum measured level		43.371
Minimum measured level		43.316
Maximum gap		0.055

CONFIDENCE INTERVAL (LEVEL 5%) :		
Degrees of freedom	n_DS	16
Student,level 5%	T_DS	1.75
Lower limit		43.326
Upper limit		43.340
Confidence interval width		0.0140

TEST FOR CALCULATED GAU_DW VALUE	
GAU_DW calculation : cells	2
Value for GAU_DW	43.340
T statistics	1.77
Result of test :	reject GAU_DW value
(GAU_DW measurement :	43.24

U/S	Staff level	Water level	Water elevation
1	3.528	0.32	43.326
2	3.860	0.66	43.329
3	3.850	0.69	43.374
4	3.859	0.69	43.365
5	3.862	0.69	43.362
6	3.855	0.69	43.369
7	3.860	0.70	43.374
8	3.848	0.69	43.376
9	3.845	0.69	43.379
10	3.841	0.67	43.363
11	3.850	0.68	43.364
12	3.840	0.67	43.364
13	3.843	0.66	43.351
14	3.830	0.64	43.344
15	3.830	0.66	43.364
16	3.840	0.64	43.334
17	3.845	0.64	43.329
18			
19			
20			

STATISTICS :		
Average level	mean_US	43.357
Std deviation	std_US	0.017
Maximum measured level		43.379
Minimum measured level		43.326
Maximum gap		0.053

CONFIDENCE INTERVAL (LEVEL 5%) :		
Degrees of freedom	n_US	17
Student,level 5%	T_US	1.74
Lower limit		43.350
Upper limit		43.364
Confidence interval width		0.0146

TEST FOR CALCULATED GAU_UP VALUE :	
GAU_UP calculation : cells	2
Value for GAU_UP	43.330
T statistics	6.40
Result of test :	reject GAU_UP value
(GAU_UP measurement :	43.23

WATER LEVEL MEASUREMENTS ACCURACY GR5

24/4/92

ABSOLUTE REFERENCES (m)		
TBM	Top of gauges	
	TBM_DW	TBM_UP
45.110	43.360	43.510

FIELD MEASUREMENTS (m)			
Local references		Gauge levels	
MEAS_DW	MEAS_UP	GAU_DW	GAU_UP
0.79	0.63	0.81	0.85

D/S	Staff level	Water level	Water elevation	
1	3.695	0.40	42.575	
2	3.885	0.60	42.585	
3	3.880	0.59	42.580	G
4	3.890	0.60	42.580	G
5	3.885	0.60	42.585	
6	3.890	0.60	42.580	
7	3.890	0.60	42.580	
8	3.900	0.64	42.610	2
9	3.895	0.63	42.605	2
10	3.882	0.56	42.548	
11	3.895	0.62	42.595	3
12	3.890	0.65	42.630	3
13	3.888	0.60	42.582	
14	3.895	0.60	42.575	
15	3.895	0.61	42.585	
16	3.890	0.60	42.580	
17	3.890	0.61	42.590	
18	3.890	0.61	42.590	
19	3.890	0.61	42.590	
20				

STATISTICS :		
Average level	mean_DS	42.587
Std deviation	std_DS	0.016
Maximum measured level		42.630
Minimum measured level		42.548
Maximum gap		0.082

CONFIDENCE INTERVAL (LEVEL 5%) :		
Degrees of freedom	n_DS	19
Student,level 5%	T_DS	1.73
Lower limit		42.580
Upper limit		42.593
Confidence interval width		0.0127

TEST FOR CALCULATED GAU_DW VALUE :	
GAU_DW calculation : cells	3,4
Value for GAU_DW	42.580
T statistics	1.79
Result of test :	reject GAU_DW value
(GAU_DW measurement :	42.55)

U/S	Staff level	Water level	Water elevation	
1	3.550	0.51	42.700	
2	3.782	0.72	42.678	
3	3.815	0.75	42.675	
4	3.833	0.78	42.687	G
5	3.830	0.78	42.690	G
6	3.823	0.78	42.697	
7	3.835	0.79	42.695	2
8	3.840	0.77	42.670	2
9	3.840	0.77	42.665	2
10	3.845	0.78	42.680	
11	3.860	0.77	42.650	3
12	3.860	0.80	42.700	3
13	3.840	0.75	42.650	
14	3.845	0.79	42.685	
15	3.860	0.80	42.680	
16	3.860	0.80	42.680	
17	3.720	0.67	42.690	
18				
19				
20				

STATISTICS :		
Average level	mean_US	42.680
Std deviation	std_US	0.016
Maximum measured level		42.7
Minimum measured level		42.65
Maximum gap		0.05

CONFIDENCE INTERVAL (LEVEL 5%) :		
Degrees of freedom	n_US	17
Student,level 5%	T_US	1.74
Lower limit		42.673
Upper limit		42.686
Confidence interval width		0.0132

TEST FOR CALCULATED GAU_UP VALUE :	
GAU_UP calculation : cells	3,4
Value for GAU_UP	42.689
T statistics	2.37
Result of test :	reject GAU_UP value
(GAU_UP measurement :	42.66)

WATER LEVEL MEASUREMENTS ACCURACY GR6

24/4/92

ABSOLUTE REFERENCES (m)		
TBM	Top of gauges	
	TBM_DW	TBM_UP
44.591	42.780	42.930

FIELD MEASUREMENTS (m)			
Local references		Gauge levels	
MEAS_DW	MEAS_UP	GAU_DW	GAU_UP
0.625	0.718	0.76	0.8

D/S	Staff level	Water level	Water elevation	
1	3.695	0.53	42.051	
2	3.805	0.64	42.051	G
3	3.810	0.68	42.086	1
4	3.805	0.65	42.061	1
5	3.805	0.61	42.021	1
6	3.800	0.61	42.026	
7	3.800	0.60	42.016	
8	3.800	0.62	42.036	
9	3.800	0.62	42.036	
10	3.805	0.67	42.081	3
11	3.805	0.70	42.111	3
12	3.805	0.65	42.061	3
13	3.800	0.65	42.066	
14	3.800	0.65	42.066	
15	3.800	0.65	42.066	
16	3.800	0.65	42.066	
17	3.800	0.65	42.066	
18	3.800	0.65	42.066	
19	3.800	0.65	42.066	
20	3.800	0.65	42.066	

STATISTICS :		
Average level	mean_DS	42.058
Std deviation	std_DS	0.022
Maximum measured level		42.111
Minimum measured level		42.016
Maximum gap		0.095

CONFIDENCE INTERVAL (LEVEL 5%) :		
Degrees of freedom	n_DS	20
Student,level 5%	T_DS	1.72
Lower limit		42.050
Upper limit		42.067
Confidence interval width		0.0171

TEST FOR CALCULATED GAU_DW VALUE :	
GAU_DW calculation : cells	2
Value for GAU_DW	42.051
T statistics	1.46
Result of test :	accept GAU_DW value
(GAU_DW measurement :	42.02)

U/S	Staff level	Water level	Water elevation	
1	3.810	0.47	41.966	S
2	3.800	0.69	42.196	1
3	3.835	0.80	42.271	1
4	3.860	0.80	42.246	1
5	3.870	0.80	42.236	
6	3.880	0.85	42.276	
7	3.880	0.85	42.276	
8	3.880	0.84	42.266	3
9	3.880	0.84	42.266	3
10	3.880	0.85	42.276	
11	3.870	0.83	42.266	G
12	3.870	0.84	42.276	G
13	3.870	0.84	42.276	G
14				
15				
16				
17				
18				
19				
20				

STATISTICS :		
Average level	mean_US	42.261
Std deviation	std_US	0.023
Maximum measured level		42.276
Minimum measured level		42.196
Maximum gap		0.08

CONFIDENCE INTERVAL (LEVEL 5%) :		
Degrees of freedom	n_US	12
Student,level 5%	T_US	1.78
Lower limit		42.249
Upper limit		42.272
Confidence interval width		0.0237

TEST FOR CALCULATED GAU_UP VALUE :	
GAU_UP calculation : cells	11,12,13
Value for GAU_UP	42.273
T statistics	1.82
Result of test :	reject GAU_UP value
(GAU_UP measurement :	42.13)

WATER LEVEL MEASUREMENTS ACCURACY GR7

24/4/92

ABSOLUTE REFERENCES (m)		
TBM	Top of gauges	
	TBM_DW	TBM_UP
44.081	42.280	42.400

FIELD MEASUREMENTS (m)			
Local references		Gauge levels	
MEAS_DW	MEAS_UP	GAU_DW	GAU_UP
0.112	0.148	1	0.99

D/S	Staff level	Water level	Water elevation	
1	3.260	0.29	41.223	
2	3.365	0.39	41.218	G
3	3.370	0.39	41.213	
4	3.375	0.40	41.218	
5	3.375	0.40	41.218	
6	3.370	0.43	41.253	2
7	3.365	0.37	41.198	2
8	3.368	0.39	41.215	2
9	3.380	0.37	41.183	3
10	3.375	0.45	41.268	3
11	3.375	0.42	41.238	3
12	3.380	0.36	41.178	
13	3.375	0.37	41.183	
14	3.365	0.36	41.178	
15	3.365	0.35	41.178	
16	3.360	0.34	41.168	5
17	3.365	0.43	41.263	5
18	3.360	0.37	41.198	5
19				
20				

STATISTICS :		
Average level	mean_DS	41.211
Std deviation	std_DS	0.030
Maximum measured level		41.268
Minimum measured level		41.168
Maximum gap		0.1

CONFIDENCE INTERVAL (LEVEL 5%) :		
Degrees of freedom	n_DS	18
Student,level 5%	T_DS	1.73
Lower limit		41.199
Upper limit		41.223
Confidence interval width		0.0241

TEST FOR CALCULATED GAU_DW VALUE :	
GAU_DW calculation : cells	2
Value for GAU_DW	41.218
T statistics	1.06
Result of test :	accept GAU_DW value
(GAU_DW measurement :	41.28)

U/S	Staff level	Water level	Water elevation	
1	3.065	0.31	41.474	
2	3.320	0.57	41.479	G
3	3.370	0.60	41.459	G
4	3.390	0.60	41.439	
5	3.400	0.63	41.459	2
6	3.390	0.60	41.439	2
7	3.390	0.60	41.439	2
8	3.405	0.62	41.444	3
9	3.410	0.61	41.429	3
10	3.395	0.63	41.464	
11	3.400	0.63	41.459	
12	3.360	0.60	41.469	
13	3.385	0.59	41.434	5
14	3.375	0.57	41.424	5
15	3.320	0.53	41.439	
16				
17				
18				
19				
20				

STATISTICS :		
Average level	mean_US	41.450
Std deviation	std_US	0.017
Maximum measured level		41.479
Minimum measured level		41.424
Maximum gap		0.055

CONFIDENCE INTERVAL (LEVEL 5%) :		
Degrees of freedom	n_US	15
Student,level 5%	T_US	1.75
Lower limit		41.443
Upper limit		41.457
Confidence interval width		0.0150

TEST FOR CALCULATED GAU_UP VALUE :	
GAU_UP calculation : cells	2,3
Value for GAU_UP	41.469
T statistics	4.45
Result of test :	reject GAU_UP value
(GAU_UP measurement :	41.41)

WATER LEVEL MEASUREMENTS ACCURACY GR8

24/4/92

ABSOLUTE REFERENCES (m)		
TBM	Top of gauges	
	TBM_DW	TBM_UP
43.143	41.660	41.770

FIELD MEASUREMENTS (m)			
Local references		Gauge levels	
MEAS_DW	MEAS_UP	GAU_DW	GAU_UP
1.015	0.99	0.8	0.85

D/S	Staff level	Water level	Water elevation	
1	3.645	0.30	40.813	G
2	3.905	0.56	40.813	G
3	3.960	0.60	40.798	
4	3.965	0.62	40.813	
5	3.980	0.64	40.818	
6	3.975	0.63	40.813	
7	4.005	0.67	40.823	2
8	4.000	0.68	40.838	2
9	3.990	0.63	40.798	2
10	3.995	0.63	40.793	
11	4.005	0.63	40.783	
12	4.000	0.63	40.788	
13	4.000	0.63	40.788	
14	3.990	0.63	40.798	
15	3.990	0.62	40.788	
16	3.985	0.63	40.803	
17	3.980	0.62	40.798	5
18	3.985	0.65	40.823	5
19	3.970	0.64	40.828	5
20	3.880	0.52	40.798	

STATISTICS :		
Average level	mean_DS	40.806
Std deviation	std_DS	0.015
Maximum measured level		40.838
Minimum measured level		40.783
Maximum gap		0.055

CONFIDENCE INTERVAL (LEVEL 5%) :		
Degrees of freedom	n_DS	20
Student,level 5%	T_DS	1.72
Lower limit		40.800
Upper limit		40.811
Confidence interval width		0.0114

TEST FOR CALCULATED GAU_DW VALUE :	
GAU_DW calculation : cells	1,2
Value for GAU_DW	40.813
T statistics	2.18
Result of test :	reject GAU_DW value
(GAU_DW measurement :	40.86)

U/S	Staff level	Water level	Water elevation	
1	3.405	0.26	40.988	
2	3.760	0.62	40.993	G
3	3.920	0.78	40.993	G
4	3.940	0.80	40.993	G
5	3.935	0.80	40.998	
6	3.930	0.79	40.993	2
7	3.960	0.79	40.963	2
8	3.965	0.78	40.948	
9	3.960	0.83	41.003	
10	3.935	0.80	40.998	
11	3.960	0.82	40.993	
12	3.945	0.82	41.008	
13	3.940	0.80	40.993	5
14	3.930	0.76	40.963	5
15	3.930	0.75	40.953	5
16	3.675	0.54	40.998	
17	3.430	0.29	40.993	
18				
19				
20				

STATISTICS :		
Average level	mean_US	40.987
Std deviation	std_US	0.017
Maximum measured level		41.008
Minimum measured level		40.948
Maximum gap		0.06

CONFIDENCE INTERVAL (LEVEL 5%) :		
Degrees of freedom	n_US	17
Student,level 5%	T_US	1.75
Lower limit		40.979
Upper limit		40.994
Confidence interval width		0.0148

TEST FOR CALCULATED GAU_UP VALUE :	
GAU_UP calculation : cells	2,3,4
Value for GAU_UP	40.993
T statistics	1.53
Result of test :	accept GAU_UP value
(GAU_UP measurement :	40.92)

WATER LEVEL MEASUREMENTS ACCURACY GR9

24/4/92

ABSOLUTE REFERENCES (m)		
TBM	Top of gauges	
	TBM_DW	TBM_UP
42.750	41.190	41.340

FIELD MEASUREMENTS (m)			
Local references		Gauge levels	
MEAS_DW	MEAS_UP	GAU_DW	GAU_UP
0.075	0.06	0.77	0.8

D/S	Staff level	Water level	Water elevation	
1	2.685	0.26	40.400	
2	2.875	0.53	40.480	G
3	2.975	0.67	40.520	1
4	2.970	0.65	40.505	1
5	2.980	0.63	40.475	1
6	2.985	0.65	40.490	
7	2.980	0.65	40.495	
8	2.975	0.65	40.500	
9	2.980	0.65	40.495	
10	2.980	0.65	40.495	
11	2.980	0.65	40.495	
12	2.980	0.65	40.495	
13	2.975	0.65	40.500	
14	2.980	0.65	40.495	
15	2.990	0.66	40.495	
16	2.990	0.66	40.495	
17	2.990	0.66	40.495	
18	3.000	0.67	40.495	5
19	3.005	0.72	40.540	5
20	3.000	0.68	40.505	5

STATISTICS :		
Average level	mean_DS	40.493
Std deviation	std_DS	0.025
Maximum measured level		40.540
Minimum measured level		40.400
Maximum gap		0.14

CONFIDENCE INTERVAL (LEVEL 5%) :		
Degrees of freedom	n_DS	20
Student,level 5%	T_DS	1.72
Lower limit		40.484
Upper limit		40.503
Confidence interval width		0.0192

TEST FOR CALCULATED GAU_DW VALUE :	
GAU_DW calculation : cells	2
Value for GAU_DW	40.480
T statistics	2.37
Result of test :	reject GAU_DW value
(GAU_DW measurement :	40.42)

U/S	Staff level	Water level	Water elevation	
1	2.560	0.32	40.590	G
2	2.890	0.67	40.610	G
3	3.050	0.82	40.600	1
4	3.025	0.79	40.595	1
5	3.020	0.74	40.550	1
6	3.055	0.81	40.585	
7	3.050	0.81	40.590	
8	3.045	0.82	40.605	
9	3.045	0.82	40.605	
10	3.060	0.84	40.610	
11	3.060	0.84	40.610	
12	3.065	0.85	40.615	
13	3.060	0.84	40.610	
14	3.030	0.80	40.600	5
15	3.035	0.78	40.575	5
16	2.800	0.58	40.610	
17	2.405	0.29	40.715	S
18				
19				
20				

STATISTICS :		
Average level	mean_US	40.598
Std deviation	std_US	0.016
Maximum measured level		40.615
Minimum measured level		40.550
Maximum gap		0.065

CONFIDENCE INTERVAL (LEVEL 5%) :		
Degrees of freedom	n_US	16
Student,level 5%	T_US	1.75
Lower limit		40.590
Upper limit		40.605
Confidence interval width		0.0143

TEST FOR CALCULATED GAU_UP VALUE :	
GAU_UP calculation : cells	1,2
Value for GAU_UP	40.600
T statistics	0.61
Result of test :	accept GAU_UP value
(GAU_UP measurement :	40.54)

WATER LEVEL MEASUREMENTS ACCURACY GR10

24/4/92

ABSOLUTE REFERENCES (m)		
TBM	Top of gauges	
	TBM_DW	TBM_UP
42.275	39.970	40.870

FIELD MEASUREMENTS (m)			
Local references		Gauge levels	
MEAS_DW	MEAS_UP	GAU_DW	GAU_UP
0.14	0.135	0.61	0.65

D/S	Staff level	Water level	Water elevation	
1	2.765	0.53	40.180	G
2	2.980	0.76	40.195	G
3	3.035	0.83	40.210	
4	3.040	0.84	40.210	
5	3.045	0.83	40.200	
6	3.045	0.84	40.205	
7	3.060	0.83	40.185	
8	3.060	0.83	40.185	3
9	3.065	0.84	40.190	3
10	3.065	0.84	40.180	3
11	3.075	0.87	40.180	4
12	3.075	0.85	40.180	
13	3.080	0.83	40.200	
14	3.070	0.82	40.195	
15	3.065	0.81	40.180	
16	3.065	0.83	40.170	
17	3.060	0.83	40.165	
18	3.050	0.81	40.195	
19	3.045	0.81	40.200	
20	2.990	0.75	40.235	

STATISTICS :		
Average level	mean_DS	40.192
Std deviation	std_DS	0.016
Maximum measured level		40.235
Minimum measured level		40.165
Maximum gap		0.07

CONFIDENCE INTERVAL (LEVEL 5%) :		
Degrees of freedom	n_DS	20
Student,level 5%	T_DS	1.72
Lower limit		40.186
Upper limit		40.198
Confidence interval width		0.0121

TEST FOR CALCULATED GAU_DW VALUE :	
GAU_DW calculation : cells	1,2
Value for GAU_DW	40.188
T statistics	1.28
Result of test :	accept GAU_DW value
(GAU_DW measurement :	39.36)

U/S	Staff level	Water level	Water elevation	
1	2.685	0.54	40.265	G
2	3.085	0.94	40.265	G
3	3.120	0.98	40.270	
4	3.120	0.98	40.270	
5	3.130	0.99	40.270	
6	3.135	1.00	40.275	
7	3.125	0.99	40.275	
8	3.100	0.95	40.260	3
9	3.100	0.94	40.250	3
10	3.100	0.94	40.250	3
11	3.115	0.97	40.265	4
12	3.090	0.92	40.240	
13	3.115	0.98	40.275	
14	3.105	0.97	40.275	
15	2.940	0.80	40.270	
16	2.590	0.45	40.270	
17				
18				
19				
20				

STATISTICS :		
Average level	mean_US	40.265
Std deviation	std_US	0.010
Maximum measured level		40.275
Minimum measured level		40.24
Maximum gap		0.035

CONFIDENCE INTERVAL (LEVEL 5%) :		
Degrees of freedom	n_US	16
Student,level 5%	T_US	1.75
Lower limit		40.261
Upper limit		40.270
Confidence interval width		0.0088

TEST FOR CALCULATED GAU_UP VALUE :	
GAU_UP calculation : cells	1,2
Value for GAU_UP	40.265
T statistics	0.12
Result of test :	accept GAU_UP value
(GAU_UP measurement :	40.22)

WATER LEVEL MEASUREMENTS ACCURACY GR11

24/4/92

ABSOLUTE REFERENCES (m)		
TBM	Top of gauges	
	TBM_DW	TBM_UP
41.603	39.950	40.190

FIELD MEASUREMENTS (m)			
Local references		Gauge levels	
MEAS_DW	MEAS_UP	GAU_DW	GAU_UP
0.37	0.48	0.4	0.5

D/S	Staff level	Water level	Water elevation	
1	3.095	0.75	39.628	G
2	3.260	0.92	39.633	G
3	3.260	0.92	39.633	G
4	3.265	0.92	39.628	G
5	3.270	0.93	39.633	G
6	3.265	0.92	39.628	
7	3.265	0.92	39.628	
8	3.270	0.93	39.633	
9	3.255	0.91	39.628	2
10	3.265	0.92	39.628	2
11	3.260	0.92	39.633	2
12	3.255	0.91	39.628	3
13	3.265	0.90	39.608	3
14	3.250	0.89	39.613	
15	3.255	0.89	39.608	4
16	3.240	0.89	39.623	4
17	3.260	0.91	39.623	
18	3.185	0.84	39.628	
19	2.715	0.38	39.638	
20				

STATISTICS :		
Average level	mean_DS	39.626
Std deviation	std_DS	0.008
Maximum measured level		39.638
Minimum measured level		39.608
Maximum gap		0.03

CONFIDENCE INTERVAL (LEVEL 5%) :		
Degrees of freedom	n_DS	19
Student,level 5%	T_DS	1.73
Lower limit		39.623
Upper limit		39.630
Confidence interval width		0.0064

TEST FOR CALCULATED GAU_DW VALUE :	
GAU_DW calculation : cells	1 TO 5
Value for GAU_DW	39.631
T statistics	2.46
Result of test :	reject GAU_DW value
(GAU_DW measurement :	39.55)

U/S	Staff level	Water level	Water elevation	
1	2.925	0.60	39.758	
2	3.140	0.82	39.763	
3	3.305	0.99	39.768	
4	3.430	1.11	39.763	G
5	3.435	1.12	39.768	
6	3.445	1.12	39.758	
7	3.44	1.12	39.763	2
8	3.435	1.11	39.758	2
9	3.430	1.10	39.753	3
10	3.440	1.12	39.763	3
11	3.410	1.08	39.753	4
12	3.430	1.09	39.743	4
13	3.430	1.09	39.743	
14	3.195	0.88	39.768	
15	2.945	0.63	39.768	
16				
17				
18				
19				
20				

STATISTICS :		
Average level	mean_US	39.759
Std deviation	std_US	0.008
Maximum measured level		39.768
Minimum measured level		39.743
Maximum gap		0.025

CONFIDENCE INTERVAL (LEVEL 5%) :		
Degrees of freedom	n_US	15
Student,level 5%	T_US	1.75
Lower limit		39.756
Upper limit		39.763
Confidence interval width		0.0073

TEST FOR CALCULATED GAU_UP VALUE :	
GAU_UP calculation : cells	4
Value for GAU_UP	39.763
T statistics	1.76
Result of test :	reject GAU_UP value
(GAU_UP measurement :	39.69)

WATER LEVEL MEASUREMENTS ACCURACY GR12

24/4/92

ABSOLUTE REFERENCES (m)		
TBM	Top of gauges	
	TBM_DW	TBM_UP
41.155	39.310	39.620

FIELD MEASUREMENTS (m)			
Local references		Gauge levels	
MEAS_DW	MEAS_UP	GAU_DW	GAU_UP
0.705	0.705	0.46	0.35

D/S	Staff level	Water level	Water elevation	
1	3.415	0.44	38.885	G
2	3.700	0.73	38.890	G
3	3.760	0.78	38.880	
4	3.765	0.78	38.875	
5	3.765	0.78	38.875	
6	3.760	0.79	38.890	
7	3.765	0.79	38.885	
8	3.765	0.78	38.875	
9	3.765	0.77	38.865	
10	3.765	0.80	38.895	
11	3.765	0.79	38.885	
12	3.770	0.79	38.880	4
13	3.770	0.78	38.870	4
14	3.780	0.76	38.840	4
15	3.590	0.59	38.860	4
16	3.260	0.27	38.870	4
17				
18				
19				
20				

STATISTICS :		
Average level	mean_DS	38.876
Std deviation	std_DS	0.013
Maximum measured level		38.895
Minimum measured level		38.84
Maximum gap		0.055

CONFIDENCE INTERVAL (LEVEL 5%) :		
Degrees of freedom	n_DS	16
Student,level 5%	T_DS	1.75
Lower limit		38.870
Upper limit		38.882
Confidence interval width		0.0115

TEST FOR CALCULATED GAU_DW VALUE :	
GAU_DW calculation : cells	1,2
Value for GAU_DW	38.888
T statistics	3.42
Result of test :	reject GAU_DW value
(GAU_DW measurement :	38.85)

U/S	Staff level	Water level	Water elevation	
1	3.245	0.57	39.185	
2	3.535	0.86	39.185	G
3	3.845	1.17	39.185	G
4	3.755	1.07	39.175	
5	3.950	1.28	39.190	
6	3.945	1.28	39.195	
7	3.945	1.28	39.195	
8	3.945	1.28	39.195	
9	3.930	1.26	39.190	
10	3.945	1.28	39.195	
11	3.925	1.26	39.195	4
12	3.930	1.28	39.210	4
13	3.735	1.06	39.185	
14	3.335	0.67	39.195	
15				
16				
17				
18				
19				
20				

STATISTICS :		
Average level	mean_US	39.191
Std deviation	std_US	0.008
Maximum measured level		39.21
Minimum measured level		39.175
Maximum gap		0.035

CONFIDENCE INTERVAL (LEVEL 5%) :		
Degrees of freedom	n_US	14
Student,level 5%	T_US	1.76
Lower limit		39.187
Upper limit		39.195
Confidence interval width		0.0074

TEST FOR CALCULATED GAU_UP VALUE :	
GAU_UP calculation : cells	2,3
Value for GAU_UP	39.185
T statistics	2.90
Result of test :	reject GAU_UP value
(GAU_UP measurement :	39.27)

WATER LEVEL MEASUREMENTS ACCURACY GR13

24/4/92

ABSOLUTE REFERENCES (m)		
TBM	Top of gauges	
	TBM_DW	TBM_UP
40.137	38.600	38.820

FIELD MEASUREMENTS (m)			
Local references		Gauge levels	
MEAS_DW	MEAS_UP	GAU_DW	GAU_UP
0.51	0.535	0.12	0.15

D/S	Staff level	Water level	Water elevation	
1	2.695	0.35	38.302	G
2	2.920	0.58	38.307	G
3	3.155	0.80	38.292	G
4	3.320	0.96	38.287	1
5	3.330	0.98	38.297	1
6	3.335	0.98	38.292	1
7	3.325	0.98	38.302	
8	3.320	0.99	38.317	2
9	3.325	0.98	38.302	2
10	3.325	0.98	38.302	2
11	3.320	0.99	38.317	3
12	3.315	0.97	38.302	3
13	3.300	0.96	38.307	3
14	3.025	0.69	38.312	
15	2.775	0.46	38.332	
16				
17				
18				
19				
20				

STATISTICS :		
Average level	mean_DS	38.305
Std deviation	std_DS	0.011
Maximum measured level		38.332
Minimum measured level		38.287
Maximum gap		0.045

CONFIDENCE INTERVAL (LEVEL 5%) :		
Degrees of freedom	n_DS	15
Student,level 5%	T_DS	1.75
Lower limit		38.300
Upper limit		38.310
Confidence interval width		0.0100

TEST FOR CALCULATED GAU_DW VALUE :	
GAU_DW calculation : cells	1,2,3
Value for GAU_DW	38.300
T statistics	1.51
Result of test :	accept GAU_DW value
(GAU_DW measurement :	38.38)

U/S	Staff level	Water level	Water elevation	
1	2.665	0.68	38.687	
2	3.015	1.04	38.697	
3	3.315	1.34	38.697	G
4	3.425	1.45	38.697	1
5	3.425	1.45	38.697	
6	3.420	1.44	38.692	
7	3.415	1.43	38.687	2
8	3.415	1.43	38.687	2
9	3.410	1.43	38.692	3
10	3.410	1.43	38.692	3
11	3.420	1.44	38.692	3
12	3.060	1.08	38.692	
13	2.700	0.73	38.702	
14	2.365	0.39	38.697	
15				
16				
17				
18				
19				
20				

STATISTICS :		
Average level	mean_US	38.693
Std deviation	std_US	0.004
Maximum measured level		38.702
Minimum measured level		38.687
Maximum gap		0.015

CONFIDENCE INTERVAL (LEVEL 5%) :		
Degrees of freedom	n_US	14
Student,level 5%	T_US	1.76
Lower limit		38.691
Upper limit		38.695
Confidence interval width		0.0041

TEST FOR CALCULATED GAU_UP VALUE :	
GAU_UP calculation : cells	3
Value for GAU_UP	38.697
T statistics	3.03
Result of test :	reject GAU_UP value
(GAU_UP measurement :	38.67)

WATER LEVEL MEASUREMENTS ACCURACY GR14

24/4/92

ABSOLUTE REFERENCES (m)		
TBM	Top of gauges	
	TBM_DW	TBM_UP
39.705	38.160	38.510

FIELD MEASUREMENTS (m)			
Local references		Gauge levels	
MEAS_DW	MEAS_UP	GAU_DW	GAU_UP
0.21	0.5	0.35	0.35

D/S	Staff level	Water level	Water elevation	
1	2.650	0.34	37.605	S
2	2.885	0.80	37.830	G
3	2.995	0.90	37.820	
4	2.990	0.90	37.825	
5	2.985	0.90	37.830	
6	2.995	0.91	37.830	
7	2.990	0.90	37.825	
8	2.980	0.88	37.815	
9	2.980	0.88	37.815	
10	2.970	0.88	37.825	
11	2.970	0.89	37.835	
12	2.865	0.79	37.840	
13	2.620	0.54	37.835	
14				
15				
16				
17				
18				
19				
20				

STATISTICS :		
Average level	mean_DS	37.827
Std deviation	std_DS	0.007
Maximum measured level		37.84
Minimum measured level		37.815
Maximum gap		0.025

CONFIDENCE INTERVAL (LEVEL 5%) :		
Degrees of freedom	n_DS	13
Student,level 5%	T_DS	1.77
Lower limit		37.823
Upper limit		37.831
Confidence interval width		0.0074

TEST FOR CALCULATED GAU_DW VALUE :	
GAU_DW calculation : cells	2
Value for GAU_DW	37.830
T statistics	1.40
Result of test :	accept GAU_DW value
(GAU_DW measurement :	37.8)

U/S	Staff level	Water level	Water elevation	
1	2.910	0.87	38.165	G
2	3.275	1.25	38.180	G
3	3.370	1.34	38.175	
4	3.360	1.34	38.185	
5	3.355	1.33	38.180	
6	3.350	1.33	38.185	
7	3.345	1.31	38.170	
8	3.340	1.31	38.175	
9	3.320	1.29	38.175	
10	2.935	0.90	38.170	
11	2.650	0.63	38.185	
12				
13				
14				
15				
16				
17				
18				
19				
20				

STATISTICS :		
Average level	mean_US	38.177
Std deviation	std_US	0.006
Maximum measured level		38.185
Minimum measured level		38.165
Maximum gap		0.02

CONFIDENCE INTERVAL (LEVEL 5%) :		
Degrees of freedom	n_US	11
Student,level 5%	T_US	1.8
Lower limit		38.173
Upper limit		38.180
Confidence interval width		0.0070

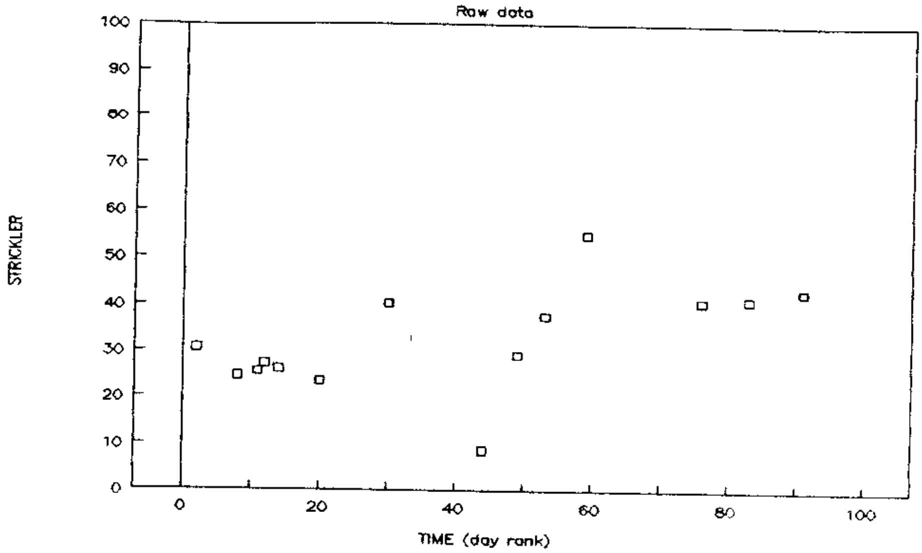
TEST FOR CALCULATED GAU_UP VALUE :	
GAU_UP calculation : cells	1,2
Value for GAU_UP	38.173
T statistics	2.21
Result of test :	reject GAU_UP value
(GAU_UP measurement :	38.16)

ANNEX C.2

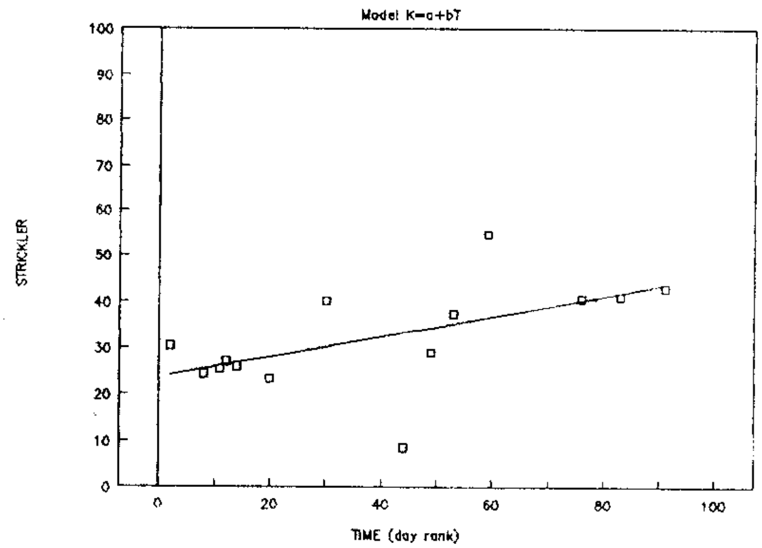
CALIBRATED SETS OF STRICKLERS – NUMERICAL AND GRAPHICAL RESULTS FOR KO RBMC DAM–GR2 TO GR14–GR15

T	K
2	30.5
8	24.4
11	25.4
12	27.1
14	26.0
20	23.3
30	40.1
44	8.6
49	29.1
53	37.4
59	54.7
76	40.6
83	41.0
91	42.7

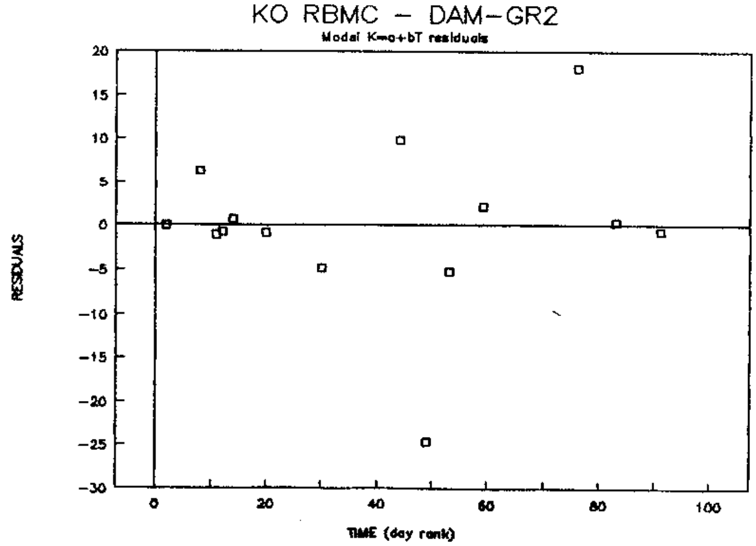
KO RBMC - DAM-GR2

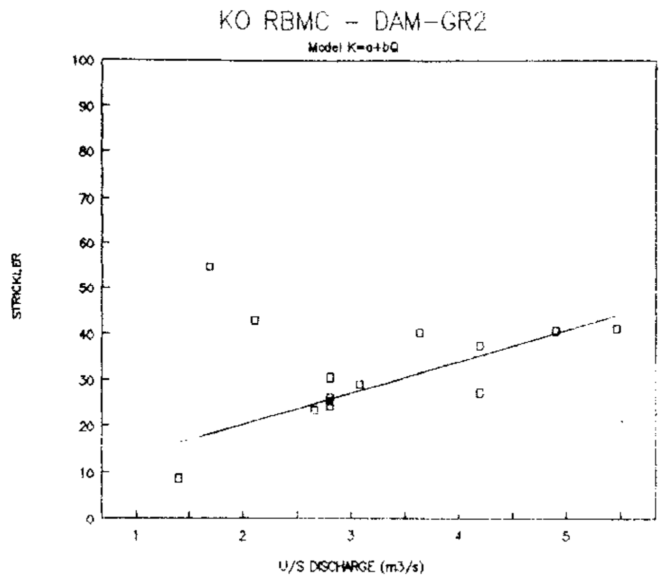


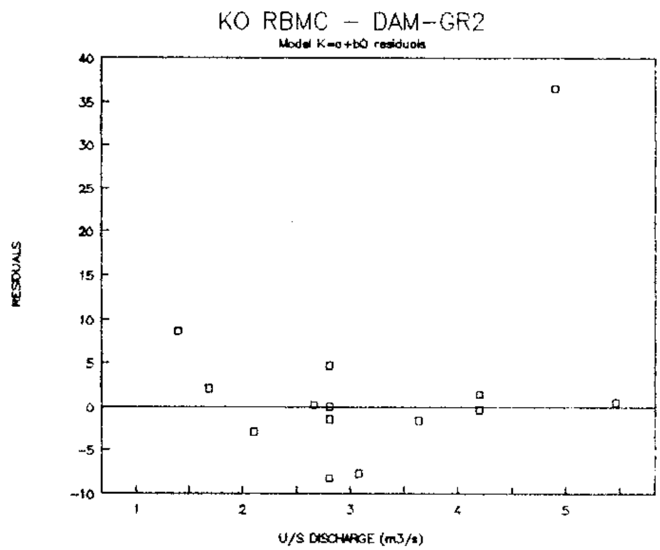
KO RBMC - DAM-GR2

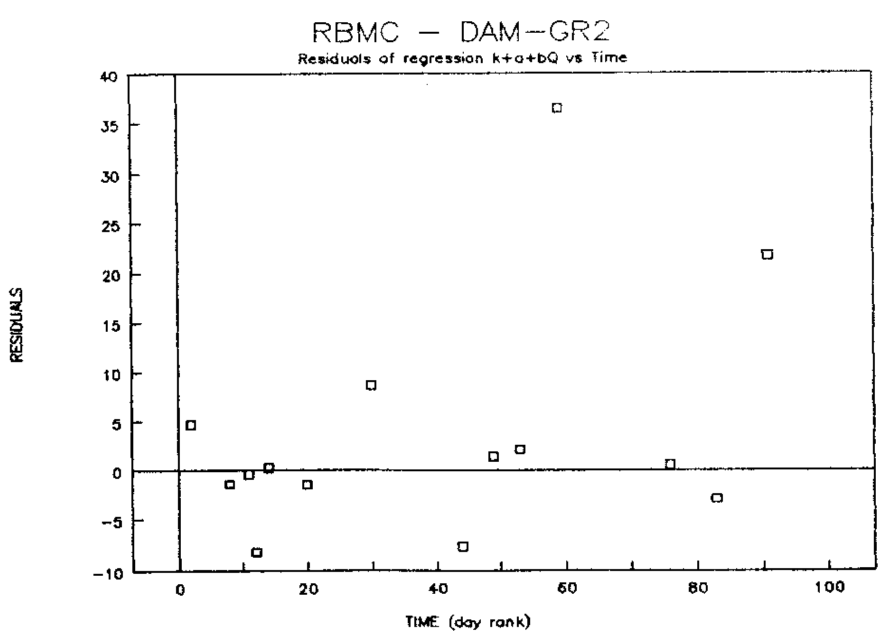


KO RBMC - DAM-GR2




KO RBMC - DAM-GR2
Model K=a+bQ
STRICKLER
U/S DISCHARGE (m3/s)


KO RBMC - DAM-GR2
Model K=a+bQ residuals
RESIDUALS
U/S DISCHARGE (m3/s)


RBMC - DAM-GR2
Residuals of regression k+a+bQ vs Time
RESIDUALS
TIME (day rank)

RBMC - DAM-GR2

influence of the head loss on the value of K

T is time in day rank (T=1 for date=09/15/91)

Q is U/S discharge in m3/s

Hu/s and Hd/s are water elevations in m. Hu/s is water elevation at AF6

Head loss in cm

SFP	T	Qu/s	Hu/s	Hd/s	K	Hu/s-Hd/s head loss
1	2	2.800	45.77	45.68	30.5	8.90
2	8	2.800	45.84	45.74	24.4	9.90
3	11	2.800	45.83	45.74	25.4	8.90
4	12	4.200	45.94	45.77	27.1	16.90
5	14	2.800	45.84	45.75	26.0	8.90
6	20	2.660	45.83	45.73	23.3	9.90
7	30	3.640	45.76	45.67	40.1	8.90
8	44	1.400	45.78	45.03	8.6	74.90
9	49	3.080	45.81	45.70	29.1	10.90
10	53	4.200	45.79	45.64	37.4	14.90
11	59	1.680	45.26	44.90	54.7	35.90
12	76	4.900	45.81	45.65	40.6	15.90
13	83	5.460	45.85	45.66	41.0	18.90
14	91	2.100	45.32	44.88	42.7	43.90

RBMC - DAM-GR2

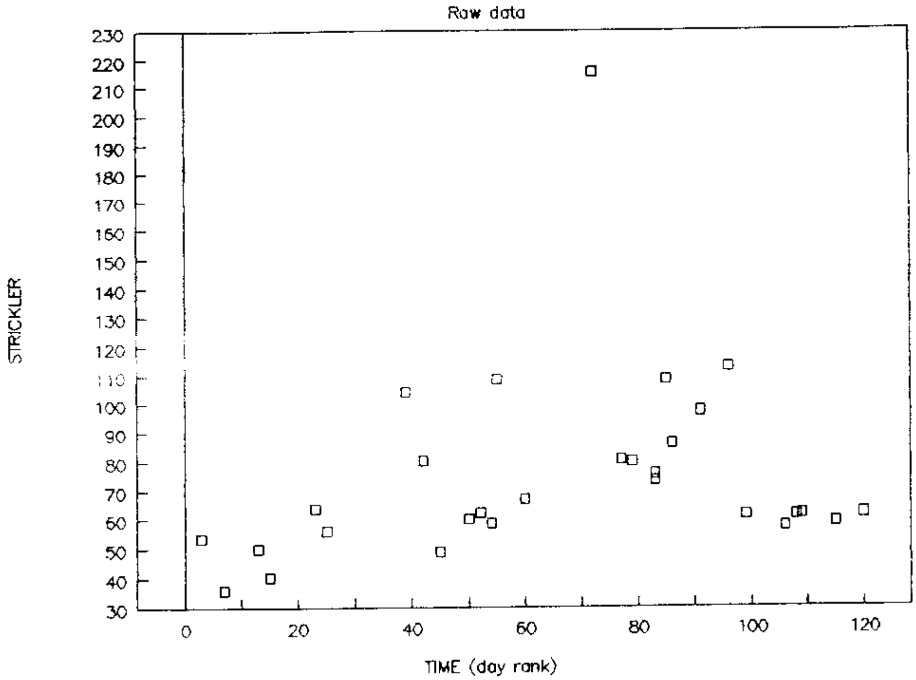
model : K=a+bT				14 observations			
parameters estimates				model quality		low weigthed estimates of K	
variable	estimate	prob.level	seq R-sqr			< 0.1 %	< 25 %
a	23.767	0		R squared	0.958	23.3	30.5
T	0.217	0	0.958	F-ratio	229.7	40.1	40.1
				Prob.level	0	8.6	
						54.7	
comment : K increases from 24 to 43, difficult to explain physically							

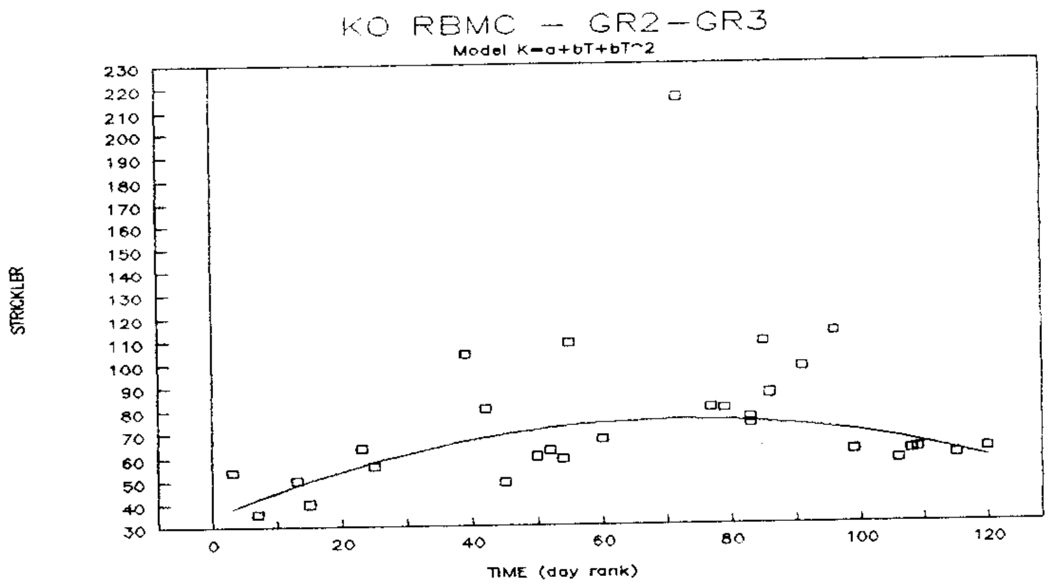
model : K=a+bQ				14 observations			
parameters estimates				model quality		low weigthed estimates of K	
variable	estimate	prob.level	seq R-sqr			< 0.1 %	< 25 %
a	6.722	0.044		R squared	0.878	54.7	27.1
Q	6.805	0	0.878	F-ratio	71.94	42.7	40.1
				Prob.level	0		8.6
comment : very good correlation							

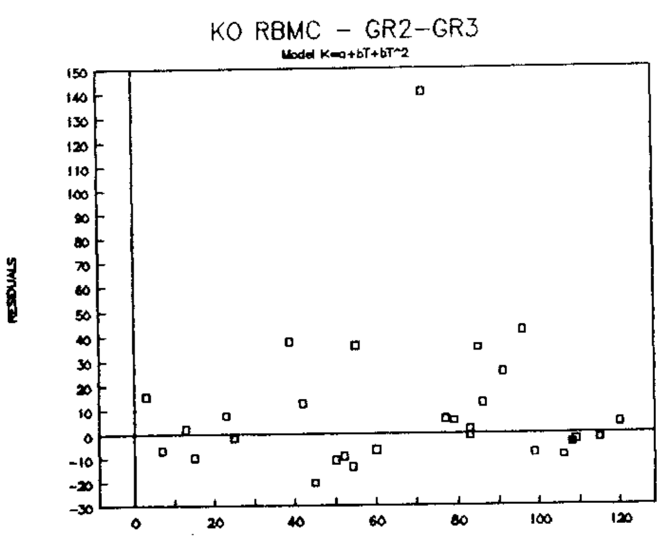
model : K=a+bT+cQ				14 observations			
parameters estimates				model quality		low weigthed estimates of K	
variable	estimate	prob.level	seq R-sqr			< 0.1 %	< 25 %
a	22.333	0		R squared	0.963	23.3	30.5
T	0.209	0	0.959	F-ratio	105.41	40.1	29.1
Q	0.483	0.351	0.963	Prob.level	0	8.6	
						54.7	
comment : Q and T carry the same information, "c=0" should not be rejected							

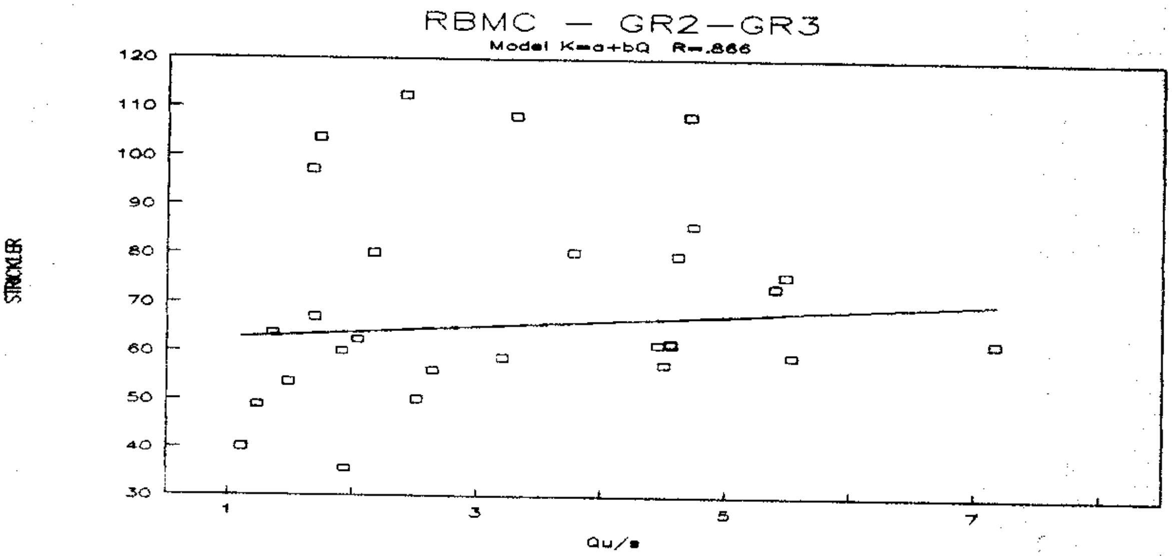
KO RBMC - GR2-GR3

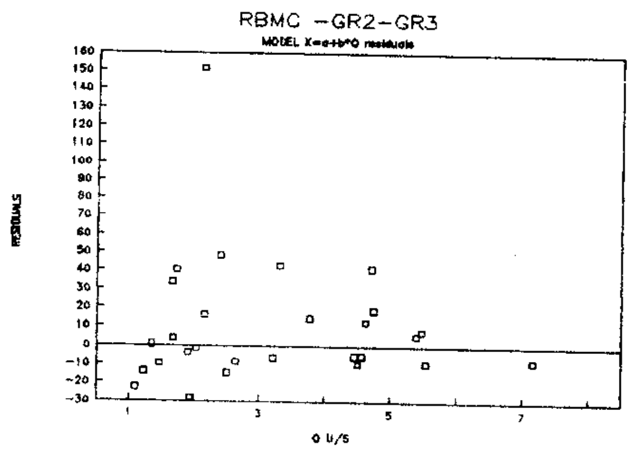
T	K
3	53.6
7	35.6
13	50.0
15	40.0
23	63.6
25	56.0
39	103.9
42	80.2
45	48.8
50	59.9
52	62.3
54	58.7
55	108.4
60	67.0
72	215.2
77	80.5
79	79.8
83	75.7
83	73.2
85	108.4
86	86.0
91	97.3
96	112.5
99	61.5
106	57.3
108	61.4
109	61.8
115	59.0
120	62.0

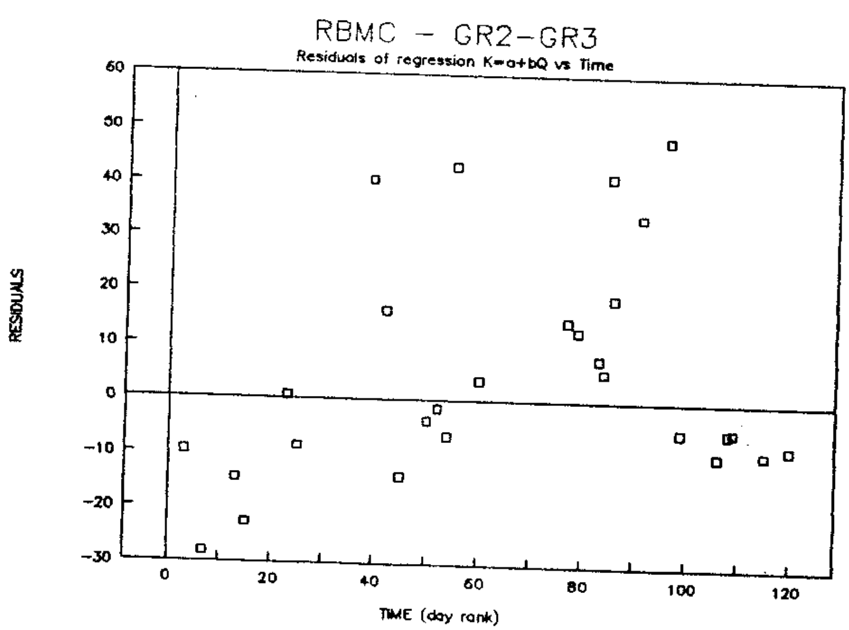







RBMC — GR2-GR3
Model K=a+bQ R=.866
STRICKLER
Qu/s
120
110
100
90
80
70
60
50
40
30
1
3
5
7


RBMC -GR2-GR3
MODEL K=a+b*Q residuals
RESIDUALS
Q U/S


RBMC — GR2-GR3
Residuals of regression K=a+bQ vs Time
RESIDUALS
TIME (day rank)
60
50
40
30
20
10
0
-10
-20
-30
0
20
40
60
80
100
120

RBMC - GR2-GR3
influence of the head loss on the value of K

T is time in day rank (T=1 for date=09/15/91)
Q is U/S discharge in m3/s
Hu/s and Hd/s are water elevations in m
Head loss in cm

SFP	T	Qu/s	Hu/s	Hd/s	K	Hu/s-Hd/s head loss
1	3	1.478	45.074	45.045	53.6	2.90
2	7	1.935	45.194	45.135	35.6	5.90
3	13	2.516	45.194	45.145	50.0	4.90
4	15	1.103	45.124	45.095	40.0	2.90
5	23	1.354	45.124	45.095	63.6	2.90
6	25	2.642	45.114	45.045	56.0	6.90
7	39	1.725	44.994	44.975	103.9	1.90
8	42	2.169	45.054	45.025	80.2	2.90
9	45	1.233	44.854	44.725	48.8	12.90
10	50	1.913	45.004	44.955	59.9	4.90
11	52	2.038	45.054	45.015	62.3	3.90
12	54	3.205	45.104	45.015	58.7	8.90
13	55	3.310	45.084	45.055	108.4	2.90
14	60	1.688	44.844	44.495	67.0	34.90
15	72	2.127	45.024	45.015	215.2	0.90
16	77	3.779	45.094	45.025	80.5	6.90
17	79	4.616	45.104	44.995	79.8	10.90
18	83	5.479	45.144	44.995	75.7	14.90
19	84	5.398	45.144	44.985	73.2	15.90
20	85	4.705	45.104	45.055	108.4	4.90
21	86	4.734	45.124	45.045	86.0	7.90
22	91	1.661	44.774	44.315	97.3	45.90
23	96	2.408	44.774	44.455	112.5	31.90
24	99	4.566	45.184	45.055	61.5	12.90
25	106	4.502	45.184	45.035	57.3	14.90
26	108	4.453	45.164	45.025	61.4	13.90
27	109	4.557	45.174	45.035	61.8	13.90
28	115	5.536	45.244	45.015	59.0	22.90
29	120	7.162	45.304	45.005	62.0	29.90

RBMC – GR2–GR3

model : K=a+bT				29	observations		
parameters estimates				model quality		low weigthed estimates of K	
variable	estimate	prob.level	seq R-sqr			< 0.1 %	< 25 %
a	53.851	0		R squared	0.161	215.2	103.9
T	0.157	0.0346	0.161	F-ratio	4.97		108.4
				Prob.level	0.035		108.4
							97.3 112.5
comment : not satisfying model as R is very low							

model : K=a+bT+cT^2				29	observations		
parameters estimates				model quality		low weigthed estimates of K	
variable	estimate	prob.level	seq R-sqr			< 0.1 %	< 25 %
a	35.059	0		R squared	0.479	215.2	103.9
T	1.102	0	0.156	F-ratio	11.51		108.4
T^2	-0.00759	0	0.479	Prob.level	0		108.4
							97.3 112.5
comment : not very satisfying as hardly half of the total variance is explained							

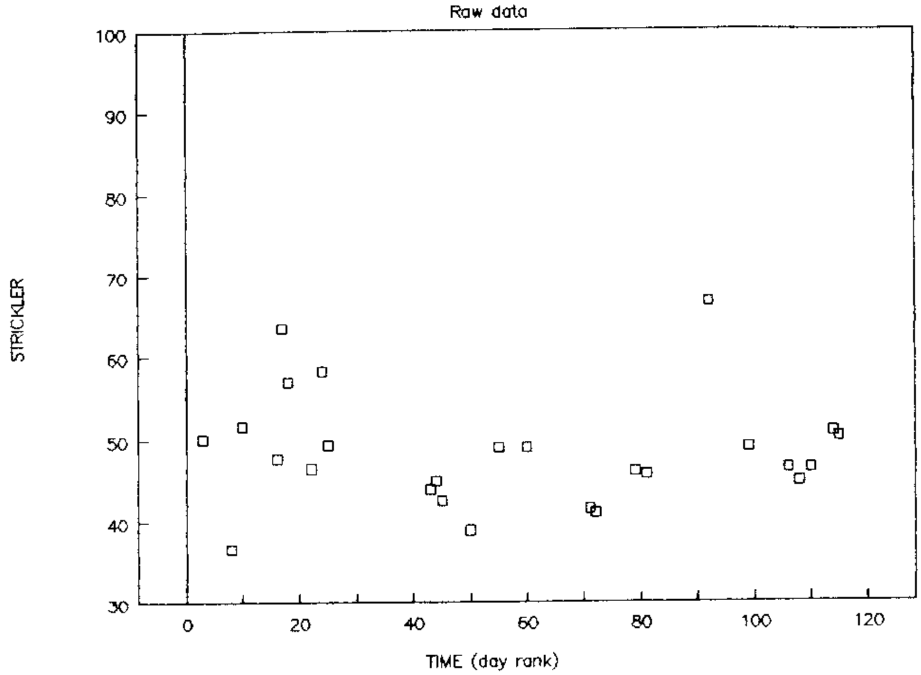
model : K=a+bQ				29	observations		
parameters estimates				model quality		low weigthed estimates of K	
variable	estimate	prob.level	seq R-sqr			< 0.1 %	< 25 %
a	61.386	0		R squared	0.866	35.6	103.9
Q	1.213	0	0.866	F-ratio	174.44	215.2	108.4
				Prob.level	0		108.4
							97.3 112.5
comment : Q alone explains K much better than T alone							

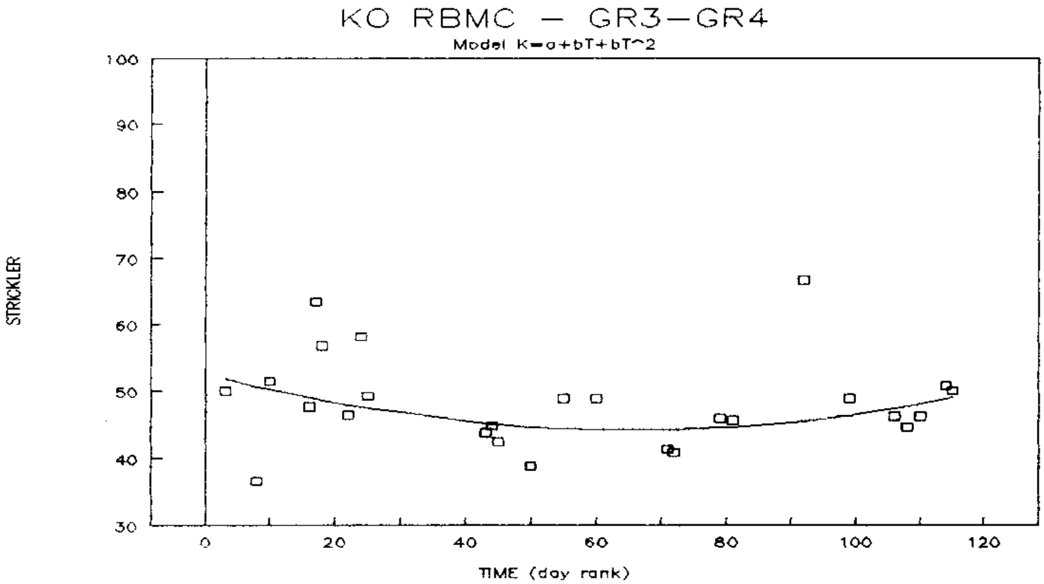
model : K=a+bT+cT^2+dQ				29	observations		
parameters estimates				model quality		low weigthed estimates of K	
variable	estimate	prob.level	seq R-sqr			< 0.1 %	< 25 %
a	32.447	0		R squared	0.917	215.2	103.9
T	1.143	0	0.033	F-ratio	91.94	97.3	108.4
T^2	-0.0083	0	0.243	Prob.level	0		108.4
Q	1.131	0	0.917				112.5
comment : adding T to Q to explain K increases R with only 5%							

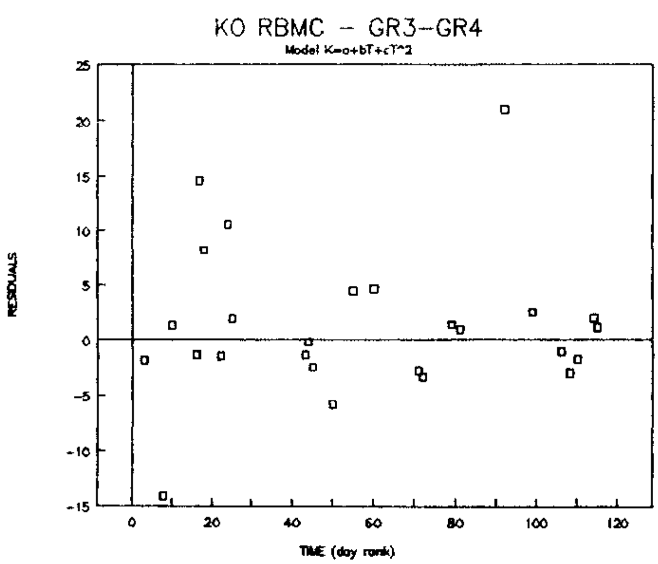
model : Q=a+b(Hu/s-Hd/s)				29	observations		
parameters estimates				model quality		low weigthed values of Q	
variable	estimate	prob.level	seq R-sqr			< 0.1 %	< 25 %
a	1.461	0		R squared	0.844	1.688	1.233
b	20.668	0	0.844	F-ratio	124.52	1.661	4.734
				Prob.level	0	2.408	
						4.705	
comment : very strong correlation							

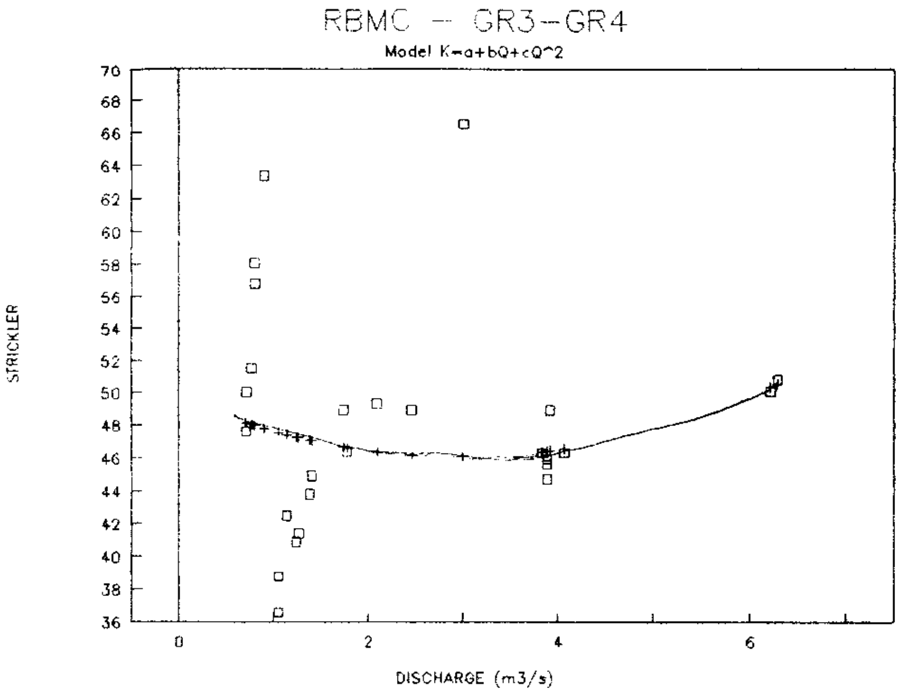
KO RBMC - GR3-GR4

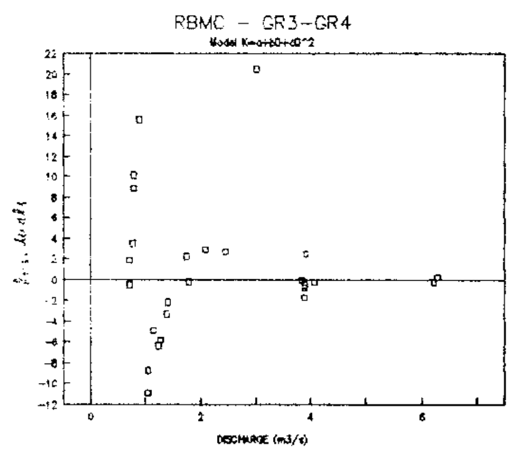
T	K
3	50.0
8	36.6
10	51.5
16	47.6
17	63.4
18	56.8
22	46.4
24	58.1
25	49.3
43	43.8
44	44.9
45	42.5
50	38.8
55	48.9
60	48.9
71	41.4
72	40.9
79	45.9
81	45.6
92	66.6
99	48.9
106	46.3
108	44.7
110	46.3
114	50.8
115	50.1

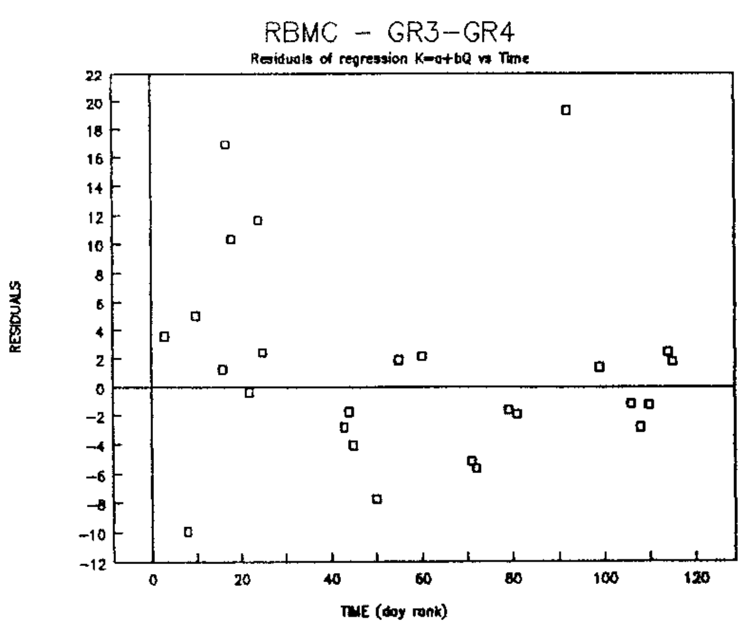







RBMC – GR3-GR4
Model K=a+bQ+cQ^2
STRICKLER
DISCHARGE (m3/s)


RBMC – GR3-GR4
Model K=a+bQ+cQ^2
DISCHARGE (m3/s)


RBMC – GR3-GR4
Residuals of regression K=a+bQ vs Time
RESIDUALS
TIME (day rank)

RBMC – GR3–GR4
Influence of the head loss on the value of K

T is time in day rank (T=1 for date=09/15/91)
Q is U/S discharge in m3/s
Hu/s and Hd/s are water elevations in m
Head loss in cm

SFP	T	Qu/s	Hu/s	Hd/s	K	Hu/s–Hd/s head loss
1	3	0.712	44.175	44.117	50.0	5.80
2	8	1.051	44.245	44.087	36.6	15.80
3	10	0.769	44.155	44.087	51.5	6.80
4	16	0.710	44.125	43.997	47.6	12.80
5	17	0.897	44.115	43.997	63.4	11.80
6	18	0.801	44.145	44.077	56.8	6.80
7	22	1.782	44.295	44.037	46.4	25.80
8	24	0.801	44.155	44.097	58.1	5.80
9	25	2.099	44.315	43.837	49.3	47.80
10	43	1.383	44.255	43.967	43.8	28.80
11	44	1.404	44.255	43.997	44.9	25.80
12	45	1.142	44.215	43.677	42.5	53.80
13	50	1.054	44.225	43.887	38.8	33.80
14	55	2.467	44.365	43.967	48.9	39.80
15	60	1.744	44.275	43.537	48.9	73.80
16	71	1.267	44.245	43.907	41.4	33.80
17	72	1.242	44.245	43.937	40.9	30.80
18	79	3.891	44.515	43.877	45.9	63.80
19	81	3.891	44.515	43.887	45.6	62.80
20	92	3.006	44.325	43.537	66.6	78.80
21	99	3.921	44.495	43.817	48.9	67.80
22	106	3.838	44.505	43.907	46.3	59.80
23	108	3.887	44.525	43.937	44.7	58.80
24	110	4.070	44.525	43.887	46.3	63.80
25	114	6.290	44.655	43.897	50.8	75.80
26	115	6.218	44.655	43.877	50.1	77.80

RBMC - GR3-GR4

model : K=a+bT				26 observations			
parameters estimates				model quality		low weigthed estimates of K	
variable	estimate	prob.level	seq R-sqr			< 0.1 %	< 25 %
a	48.229	0		R squared	0.0183	56.8	36.6
T	-0.0119	0.519	0.0183	F-ratio	0.43	58.1	63.4
				Prob.level	0.519	66.6	38.8
							40.9
comment : not acceptable at all ; residuals suggest quadratic structure							

model : K=a+bT+cT^2				26 observations			
parameters estimates				model quality		low weigthed estimates of K	
variable	estimate	prob.level	seq R-sqr			< 0.1 %	< 25 %
a	52.631	0		R squared	0.415	36.6	56.8
T	-0.258	0	0.0219	F-ratio	7.82	63.4	58.1
T^2	0.00197	0	0.415	Prob.level	0.003	66.6	38.8
comment : not very good model							

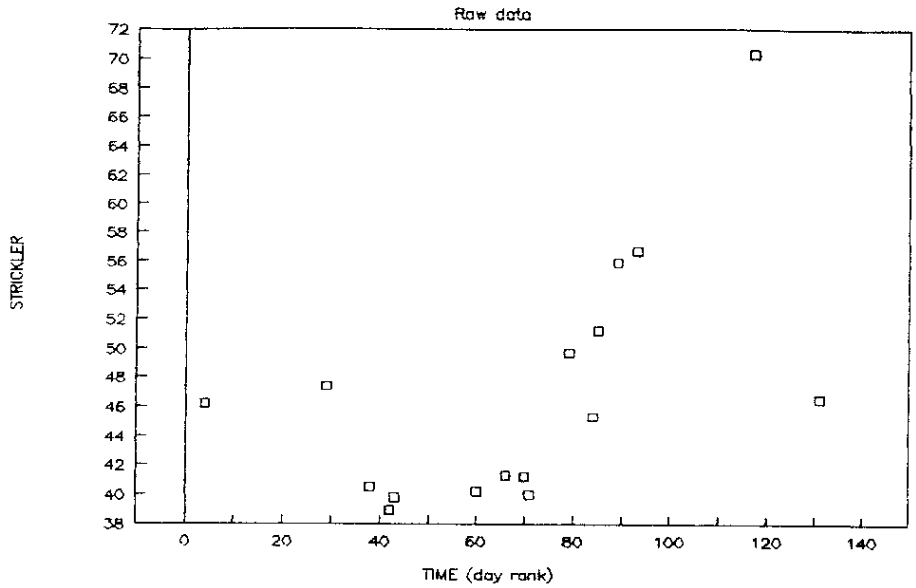
model : K=a+bQ+cQ^2				26 observations			
parameters estimates				model quality		low weigthed estimates of K	
variable	estimate	prob.level	seq R-sqr			< 0.1 %	< 25 %
a	49.628	0		R squared	0.167		
Q	-2.396	0.102	0.0214	F-ratio	2.2		
Q^2	0.404	0.063	0.167	Prob.level	0.134		
comment : not acceptable at all (same thing for K=a+bQ)							

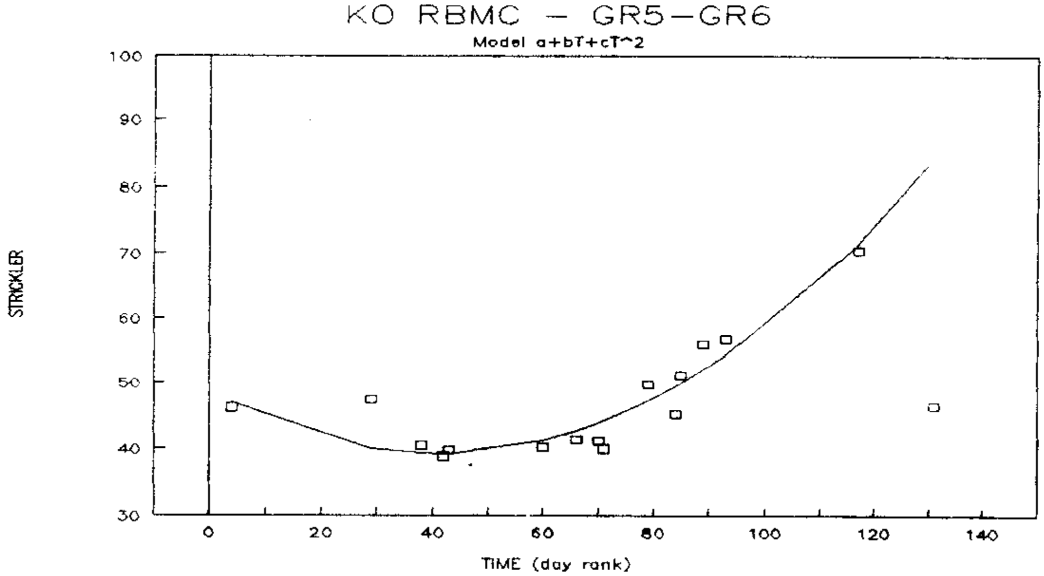
model : K=a+bT+cT^2+dQ				26 observations			
parameters estimates				model quality		low weigthed estimates of K	
variable	estimate	prob.level	seq R-sqr			< 0.1 %	< 25 %
a	49.727	0		R squared	0.909	36.6	51.5
T	-0.246	0	0	F-ratio	56.44	63.4	46.4
T^2	0.00123	0	0.62	Prob.level	0	56.8 58.1	38.8
Q	2.088	0	0.909			48.9 66.6	48.9
comment : T and Q carry distinct information							

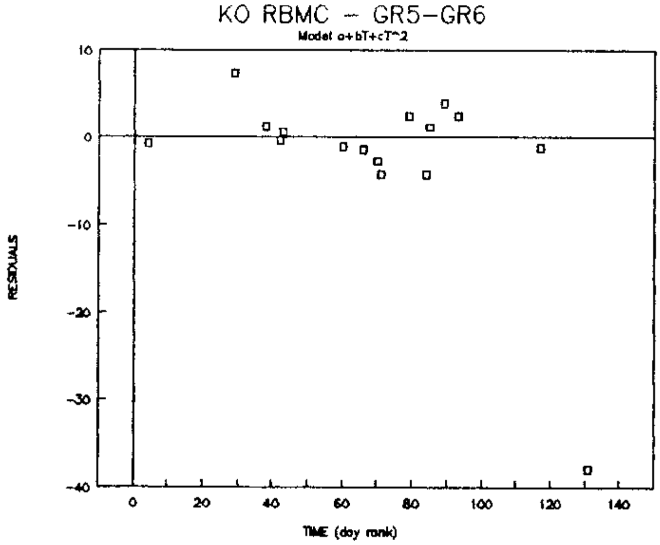
model : Q=a+b(Hu/e-Hd/e)				26 observations			
parameters estimates				model quality		low weigthed values of Q	
variable	estimate	prob.level	seq R-sqr			< 0.1 %	< 25 %
a	0.217	0.04		R squared	0.965	1.142	1.233
b	5.75	0	0.965	F-ratio	556.3	1.744	4.734
				Prob.level	0	1.242 3.006	
						6.290 6.218	
comment : very strong correlation							

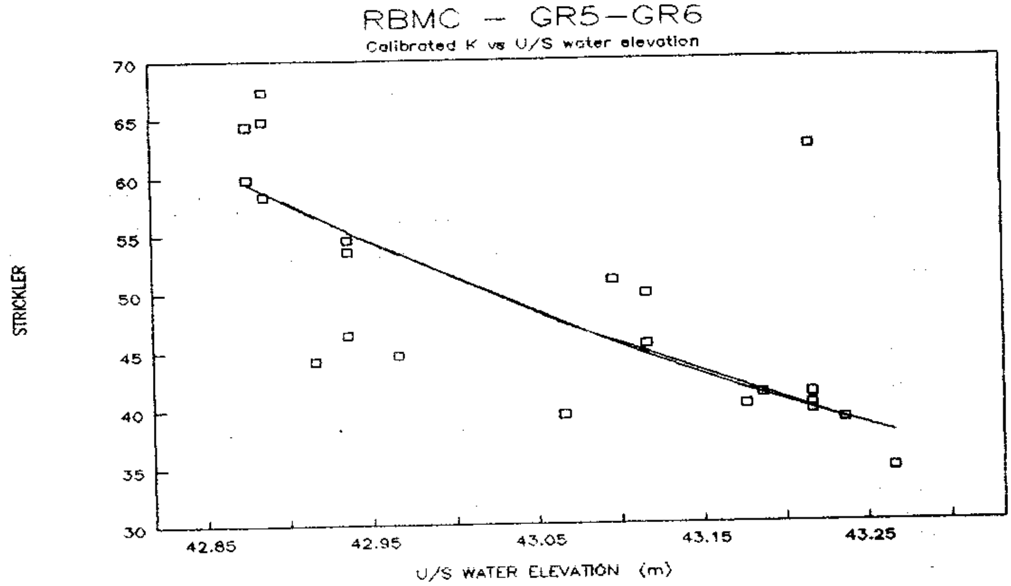
KO RBMC - GR5-GR6

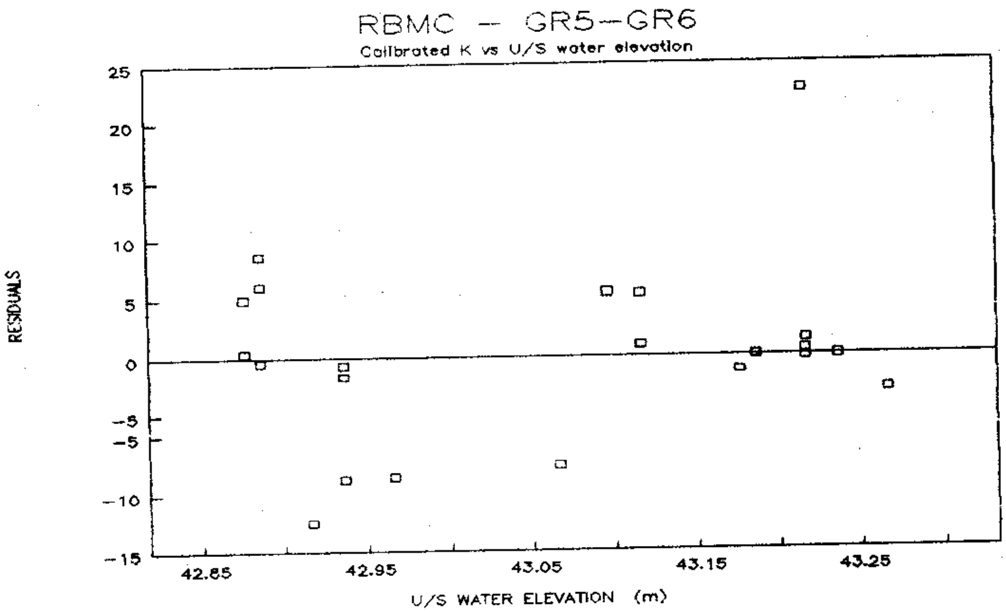
T	K
4	46.2
29	47.4
38	40.5
42	38.9
43	39.8
60	40.2
66	41.3
70	41.2
71	40.0
79	49.7
84	45.3
85	51.2
89	55.9
93	56.7
117	70.3

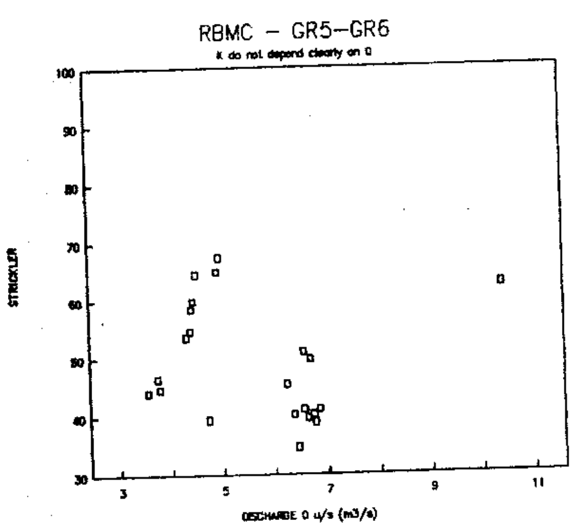


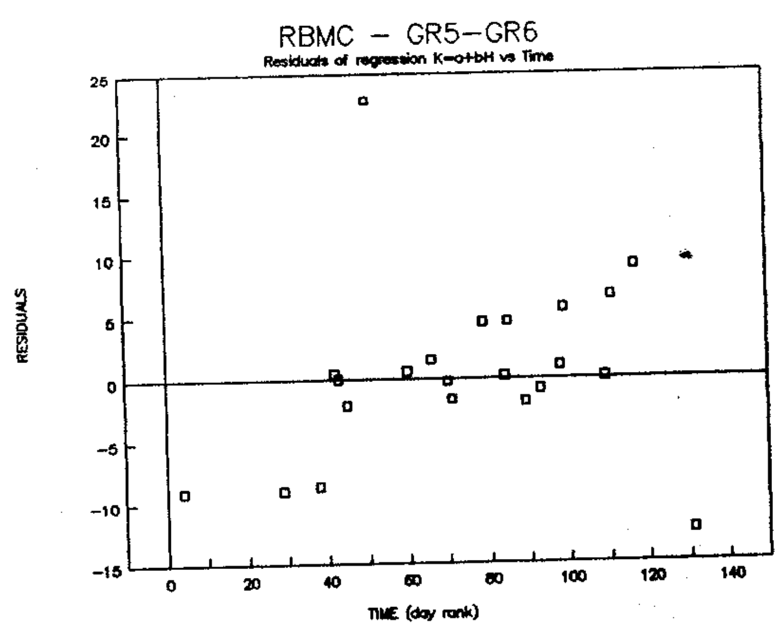





RBMC - GR5-GR6
Calibrated K vs U/S water elevation
STRICKLER
U/S WATER ELEVATION (m)


RBMC - GR5-GR6
Calibrated K vs U/S water elevation
RESIDUALS
U/S WATER ELEVATION (m)


RBMC - GR5-GR6
K do not depend clearly on Q
STRICKLER
DISCHARGE Q u/s (m3/s)


RBMC - GR5-GR6
Residuals of regression K=a+bH vs Time
RESIDUALS
TIME (day rank)

RBMC - GR5-GR6

influence of the head loss on the value of K

T is time in day rank (T=1 for date=09/15/91)
Q is U/S discharge in m3/s
Hu/s and Hd/s are water elevations in m
Head loss in cm

SFP	T	Qu/s	Hu/s	Hd/s	K	Hu/s-Hd/s head loss
1	4	3.774	42.966	42.784	44.6	18.20
2	29	3.745	42.936	42.744	46.4	19.20
3	38	4.726	43.066	42.744	39.4	32.20
4	42	6.770	43.236	42.764	38.9	47.20
5	43	6.640	43.216	42.744	39.6	47.20
6	45	6.455	43.266	42.754	34.7	51.20
7	51	10.401	43.216	42.744	62.4	47.20
8	60	6.745	43.216	42.744	40.2	47.20
9	66	6.854	43.216	42.744	41.1	47.20
10	70	6.561	43.186	42.724	41.1	46.20
11	71	6.371	43.176	42.684	40.2	49.20
12	79	6.692	43.116	42.744	49.7	37.20
13	84	6.247	43.116	42.694	45.4	42.20
14	85	6.572	43.096	42.724	50.9	37.20
15	89	4.311	42.936	42.744	53.5	19.20
16	93	4.390	42.936	42.744	54.5	19.20
17	98	4.451	42.876	42.634	59.8	24.20
18	99	4.523	42.876	42.684	64.4	19.20
19	109	4.408	42.886	42.654	58.3	23.20
20	111	4.923	42.886	42.644	64.8	24.20
21	117	4.957	42.886	42.674	67.3	21.20
22	131	3.559	42.916	42.694	44.1	22.20

RBMC – GR5-GR6

model : K=a+bT				16 observations			
parameters estimates				model quality		low weigthed estimates of K	
variabl	estimate	prob.level	seq R-sqr			< 0.1 %	< 25 %
a	38.761	0		R squared	0.222		70.3
T	0.991	0.065	0.222	F-ratio	4		
				Prob.level	0.065		
comment : not very good model ; residuals suggest quadratic structure							

model : K=a+bT+cT^2				16 observations			
parameters estimates				model quality		low weigthed estimates of K	
variabl	estimate	prob.level	seq R-sqr			< 0.1 %	< 25 %
a	48.686	0		R squared	0.942	46.6	47.4
T	-0.462	0	0.447	F-ratio	97.91		
T^2	-0.0056	0	0.942	Prob.level	0		
comment : very good model ; only two outliers							

model : K=a+bQ				16 observations			
parameters estimates				model quality		low weigthed estimates of K	
variabl	estimate	prob.level	seq R-sqr			< 0.1 %	< 25 %
a	53.888	0		R squared	0.088	64.4	62.4
Q	-1.506	0.18	0.088	F-ratio	1.93		
				Prob.level	0.18		
comment : K and Q are independant							

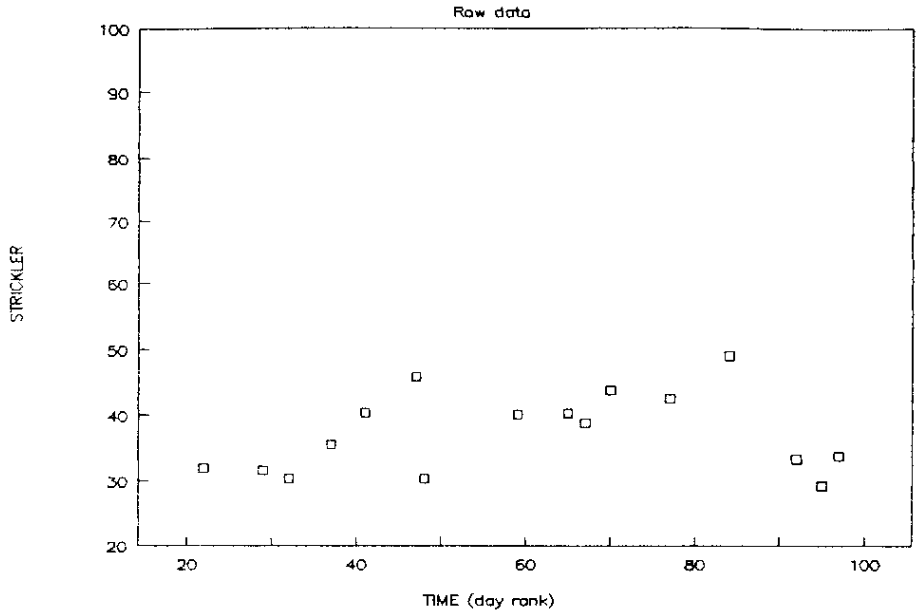
model : K=a+bHu/s				16 observations			
parameters estimates				model quality		low weigthed estimates of K	
variabl	estimate	prob.level	seq R-sqr			< 0.1 %	< 25 %
a	2475.51	0		R squared	0.873	62.4	44.6
Hu/s	-56.366	0	0.873	F-ratio	130.64		46.4
				Prob.level	0		39.4
							64.8 67.3 44.1
comment : like T, Hu/s explains K very well							

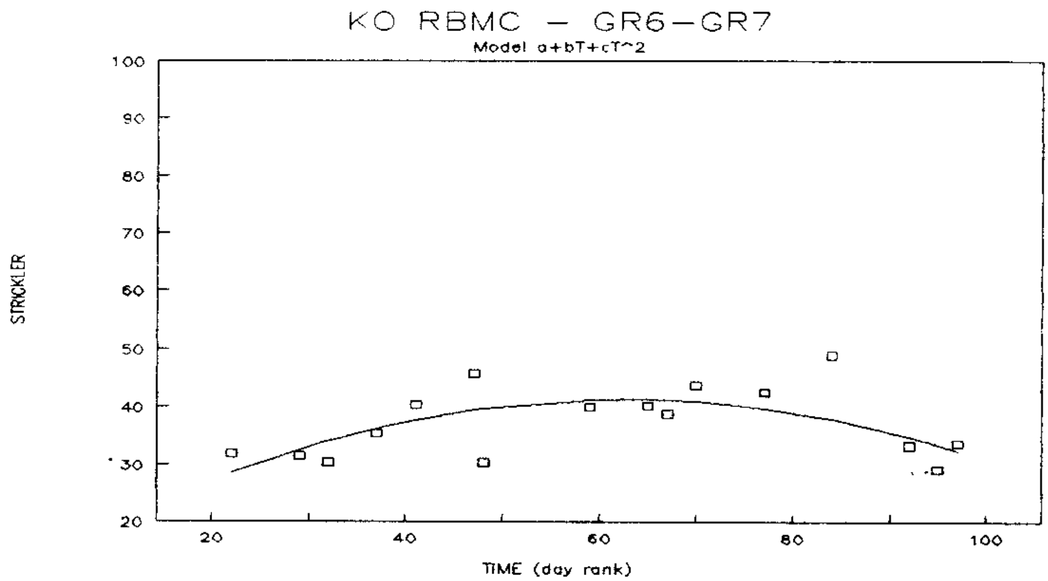
model : K=a+bT+cT^2+dHu/s				16 observations			
parameters estimates				model quality		low weigthed estimates of K	
variable	estimate	prob.level	seq R-sqr			< 0.1 %	< 25 %
a	1250.45	0		R squared	0.968	62.4	64.4
T	-0.146	0.0769	0.595	F-ratio	162.3	44.1	58.3
T^2	0.00261	0	0.913	Prob.level	0		
Hu/s	-28.033	0	0.968				
comment : T and Hu/s carry the same information							

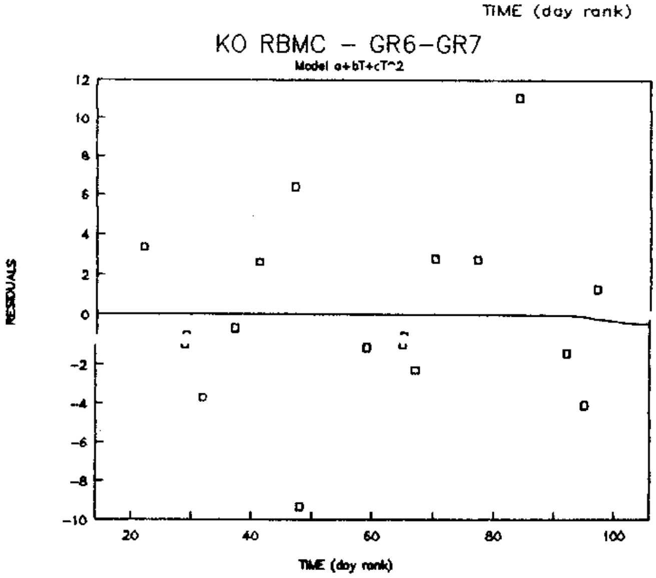
model : Q=a+b(Hu/s-Hd/s)				16 observations			
parameters estimates				model quality		low weigthed values of Q	
variable	estimate	prob.level	seq R-sqr			< 0.1 %	< 25 %
a	2.562	0		R squared	0.937	10.401	6.572
b	8.686	0	0.937	F-ratio	281.04	6.692	
				Prob.level	0	3.559	
comment : very strong correlation							

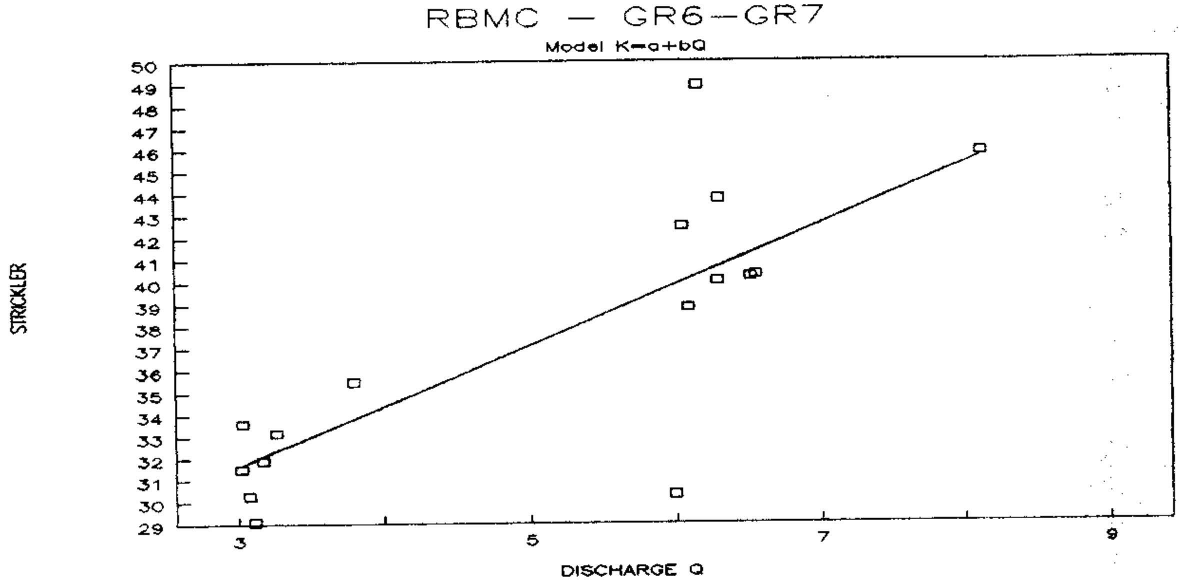
KO RBMC - GR6-GR7

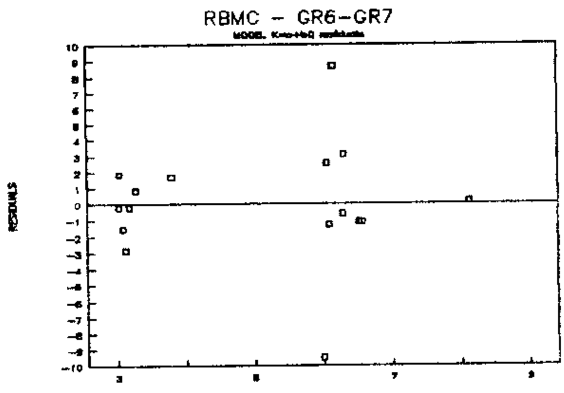
T	K
22	31.9
29	31.5
32	30.3
37	35.5
41	40.3
47	45.8
48	30.3
59	40.0
65	40.2
67	38.8
70	43.7
77	42.5
84	48.9
92	33.2
95	29.1
97	33.6

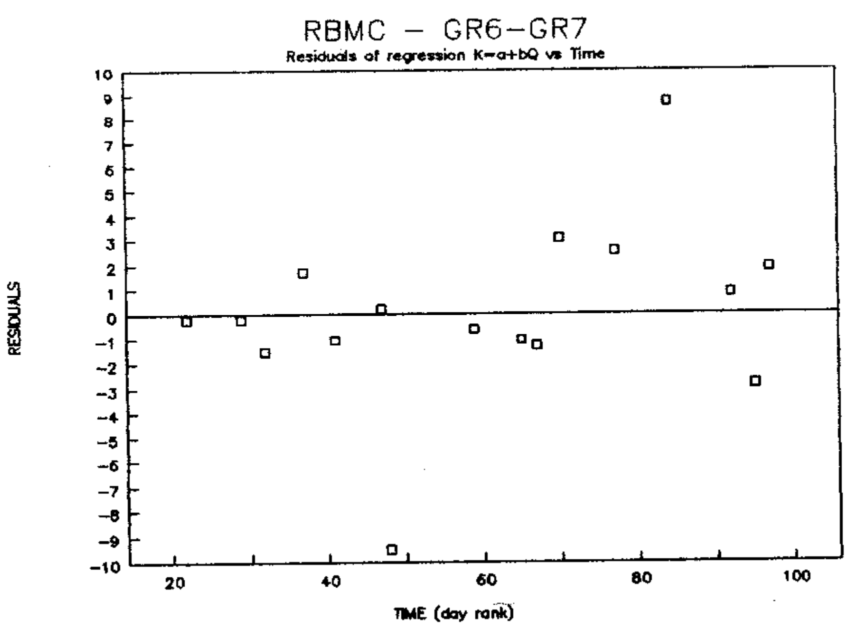







RBMC — GR6—GR7
Model K=a+bQ
STRICKLER
DISCHARGE Q


RBMC — GR6—GR7
RESIDUALS
DISCHARGE Q


RBMC — GR6—GR7
Residuals of regression K=a+bQ vs Time
RESIDUALS
TIME (day rank)

RBMC - GR6-GR7

Influence of the head loss on the value of K

T is time in day rank (T=1 for date=12/01/92)

Q is U/S discharge in m3/s

Hu/s and Hd/s are water elevations in m

Head loss in cm

SFP	T	Qu/s	Hu/s	Hd/s	K	Hu/s-Hd/s head loss
1	22	3.168	42.294	41.888	31.9	40.60
2	29	3.021	42.274	41.858	31.5	41.60
3	32	3.074	42.314	41.908	30.3	40.60
4	37	3.795	42.344	41.848	35.5	49.60
5	41	6.554	42.494	41.808	40.3	68.60
6	47	8.115	42.544	41.868	45.8	67.60
7	48	5.989	42.634	41.818	30.3	81.60
8	59	6.290	42.494	41.848	40.0	64.60
9	65	6.517	42.504	41.858	40.2	64.60
10	67	6.089	42.494	41.808	38.8	68.60
11	70	6.297	42.444	41.748	43.7	69.60
12	77	6.051	42.444	41.858	42.5	58.60
13	84	6.156	42.394	41.818	48.9	57.60
14	92	3.263	42.274	41.828	33.2	44.60
15	95	3.109	42.314	41.868	29.1	44.60
16	97	3.035	42.244	41.798	33.6	44.60

RBMC - GR6-GR7

model : K=a+bT				16 observations			
parameters estimates				model quality		low weigthed estimates of K	
variabl	estimate	prob.level	seq R-sqr			< 0.1 %	< 25 %
a	33.108	0		R squared	0.0817		
T	0.646	0.2858	0.0817	F-ratio	1.25		
				Prob.level	0.283		
comment : the model should be rejected							

model : K=a+bT+cT^2				16 observations			
parameters estimates				model quality		low weigthed estimates of K	
variabl	estimate	prob.level	seq R-sqr			< 0.1 %	< 25 %
a	11.015	0.066		R squared	0.6416		30.3
T	0.967	0	0.037	F-ratio	11.64		48.9
T^2	-0.00767	0	0.6416	Prob.level	0.001		
comment : quite a good model							

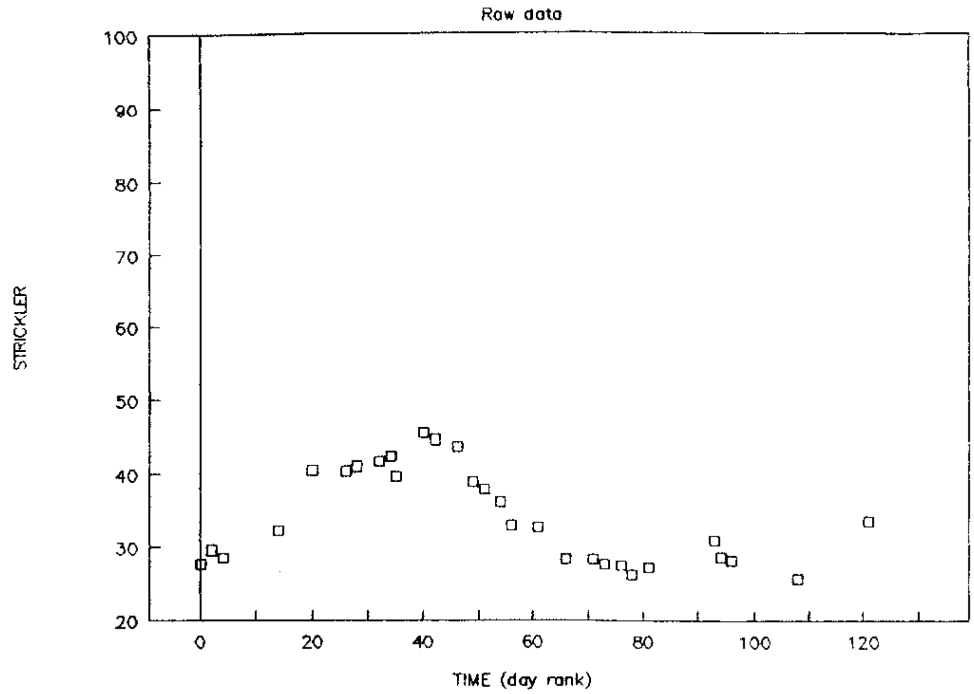
model : K=a+bQ				16 observations			
parameters estimates				model quality		low weigthed estimates of K	
variabl	estimate	prob.level	seq R-sqr			< 0.1 %	< 25 %
a	23.461	0		R squared	0.915	30.3	
Q	2.728	0	0.915	F-ratio	140.06	48.9	
				Prob.level	0		
comment : very good model							

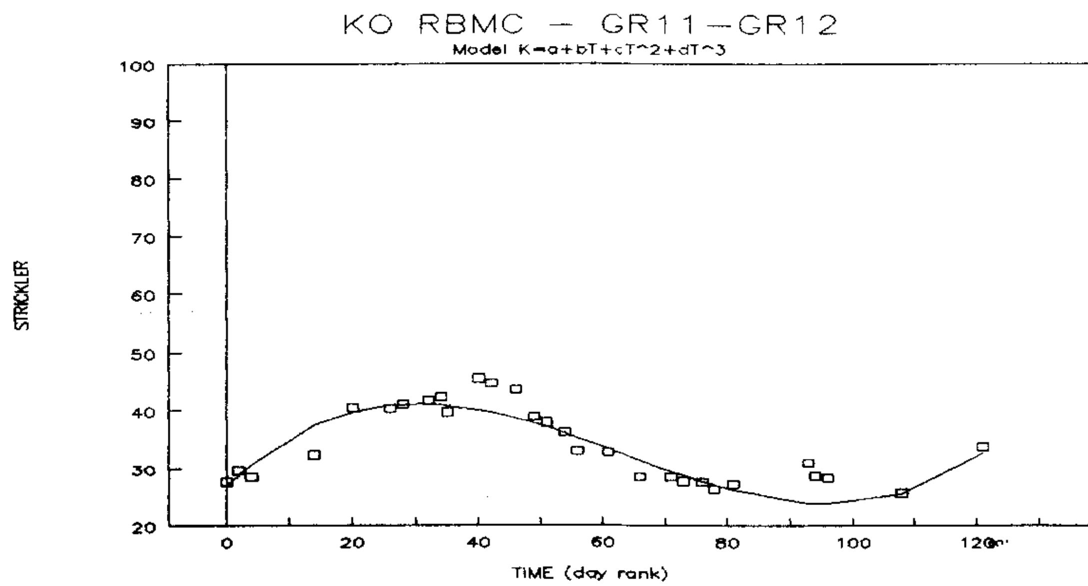
model : K=a+bT+cT^2+dQ				16 observations			
parameters estimates				model quality		low weigthed estimates of K	
variabl	estimate	prob.level	seq R-sqr			< 0.1 %	< 25 %
a	26.005	0		R squared	0.977	30.3	35.5
T	-0.201	0.113	0.012	F-ratio	126.39	48.9	42.5
T^2	0.00189	0.079	0.661	Prob.level	0	43.7	
Q	3.04	0	0.977			29.1	
comment : adding T to Q explains only 6% more of the variance							

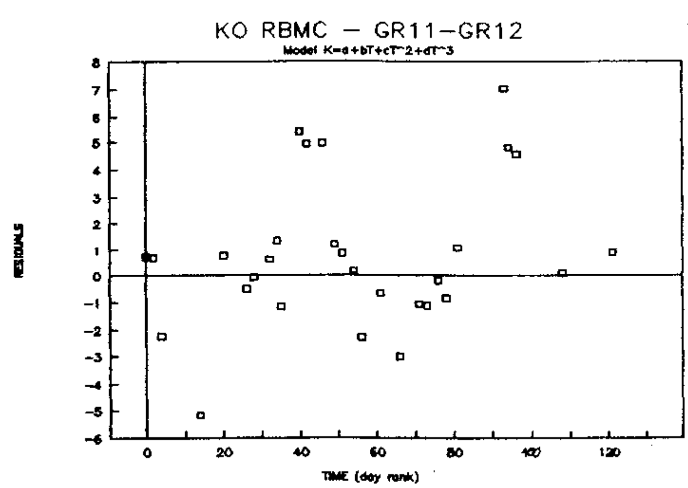
model : Q=a+b(Hu/s-Hd/s)				16 observations			
parameters estimates				model quality		low weigthed values of Q	
variabl	estimate	prob.level	seq R-sqr			< 0.1 %	< 25 %
a	-1.819	0.04		R squared	0.829		6.554
b	12.172	0	0.829	F-ratio	67.68		8.115
				Prob.level	0		5.989
comment : stong correlation							

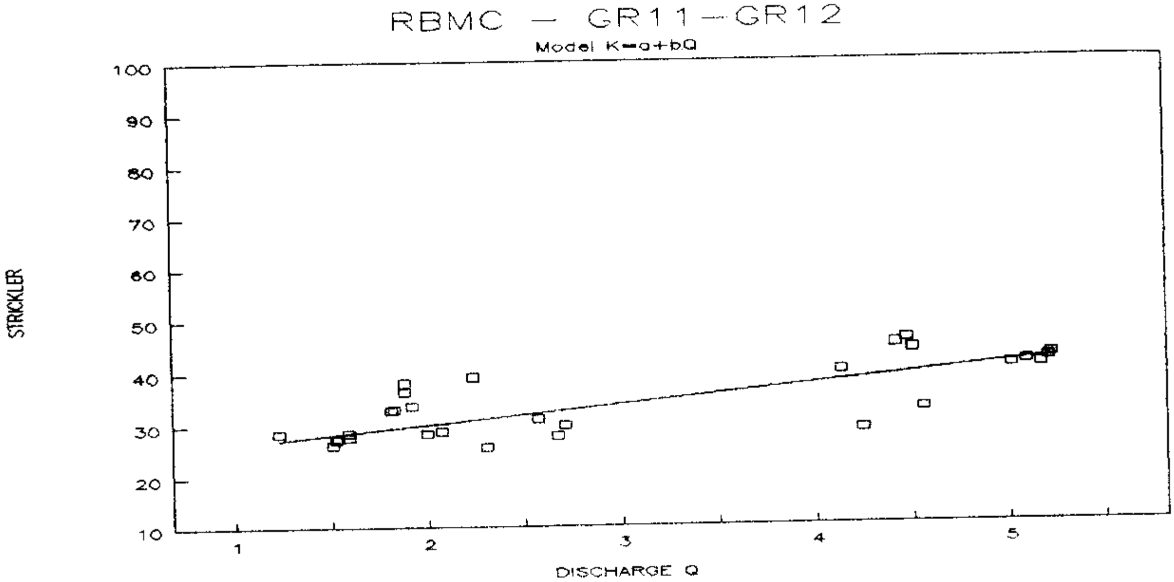
KO RBMC - GR11-GR12

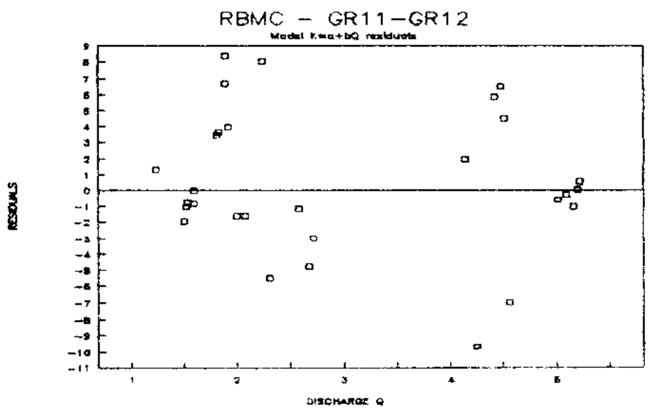
T	K
0	27.6
2	29.6
4	28.5
14	32.3
20	40.5
26	40.4
28	41.0
32	41.7
34	42.3
35	39.7
40	45.5
42	44.6
46	43.6
49	38.9
51	37.9
54	36.2
56	33.0
61	32.7
66	28.4
71	28.4
73	27.6
76	27.5
78	26.2
81	27.2
93	30.9
94	28.6
96	28.3
108	25.6
121	33.6

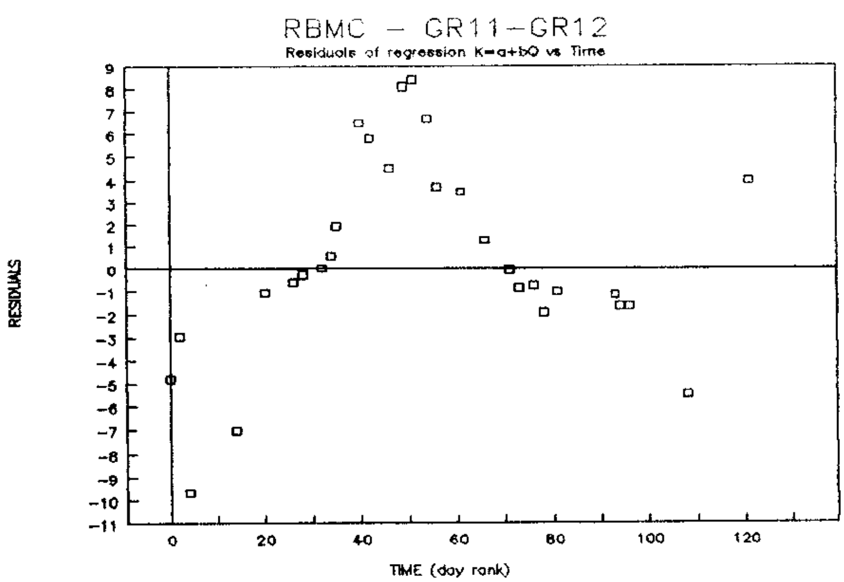







RBMC — GR11–GR12
Model K=a+bQ
STRICKLER
DISCHARGE Q
100
90
80
70
60
50
40
30
20
10
1
2
3
4
5


RBMC — GR11–GR12
RESIDUALS
DISCHARGE Q


RBMC — GR11–GR12
Residuals of regression K=a+bQ vs Time
RESIDUALS
TIME (day rank)
9
8
7
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
-11
0
20
40
60
80
100
120

RBMC - GR11-GR12
Influence of the head loss on the value of K

T is time in day rank (T=1 for date=01/08/92)
Q is U/S discharge in m3/s
Hu/s and Hd/s are water elevations in m
Head loss in cm

SFP	T	Qu/s	Hu/s	Hd/s	K	Hu/s-Hd/s head loss
1	0	2.669	39.644	39.280	27.6	36.40
2	2	2.712	39.624	39.290	29.6	33.40
3	4	4.244	39.824	39.280	28.5	54.40
4	14	4.556	39.784	39.270	32.3	51.40
5	20	5.167	39.754	39.340	40.5	41.40
6	26	5.016	39.724	39.290	40.4	43.40
7	28	5.092	39.724	39.280	41.0	44.40
8	32	5.206	39.724	39.270	41.7	45.40
9	34	5.220	39.704	39.230	42.3	47.40
10	35	4.134	39.624	39.120	39.7	50.40
11	40	4.473	39.654	39.330	45.5	32.40
12	42	4.418	39.644	39.290	44.6	35.40
13	46	4.505	39.664	39.290	43.6	37.40
14	49	2.236	39.494	39.290	38.9	20.40
15	51	1.881	39.494	39.330	37.9	16.40
16	54	1.881	39.504	39.330	36.2	17.40
17	56	1.827	39.504	39.300	33.0	20.40
18	61	1.808	39.504	39.300	32.7	20.40
19	66	1.226	39.444	39.250	28.4	19.40
20	71	1.586	39.534	39.340	28.4	19.40
21	73	1.591	39.514	39.290	27.6	22.40
22	76	1.531	39.514	39.270	27.5	24.40
23	78	1.502	39.514	39.250	26.2	26.40
24	81	1.523	39.494	39.230	27.2	26.40
25	93	2.570	39.654	39.430	30.9	22.40
26	94	2.073	39.584	39.340	28.6	24.40
27	96	1.994	39.554	39.290	28.3	26.40
28	108	2.307	39.644	39.330	25.6	31.40
29	121	1.917	39.504	39.260	33.6	24.40

RBMC - GR11-GR12

model : K=a+bT				29 observations			
parameters estimates				model quality		low weigthed estimates of K	
variable	estimate	prob.level	seq R-sqr			< 0.1 %	< 25 %
a	43.701	0		R squared	0.563	33.6	27.6
T	-0.167	0	0.563	F-ratio	34.83	32.3	29.6
				Prob.level	0		28.5
							45.5
comment : not too bad model ; residuals suggest cubic model							

model : K=a+bT+cT^2+dT^3				29 observations			
parameters estimates				model quality		low weigthed estimates of K	
variable	estimate	prob.level	seq R-sqr			< 0.1 %	< 25 %
a	26.906	0		R squared	0.93	32.3	44.6
T	1.051	0	0.165	F-ratio	109.82	45.5	43.6
T^2	-0.023	0	0.281	Prob.level	0	30.9	28.4
T^3	-0.00012	1	0.93				
comment : very good model							

model : K=a+bQ				29 observations			
parameters estimates				model quality		low weigthed estimates of K	
variable	estimate	prob.level	seq R-sqr			< 0.1 %	< 25 %
a	22.631	0		R squared	0.822	32.3	28.5
Q	3.659	0	0.822	F-ratio	124.62	45.5	44.6
				Prob.level	0	36.2	38.9
							37.9 25.6
comment : Q alone explains K almost as well as T							

model : K=a+bT+cT^2+dT^3+eQ				29 observations			
parameters estimates				model quality		low weigthed estimates of K	
variable	estimate	prob.level	seq R-sqr			< 0.1 %	< 25 %
a	22.564		0	R squared	0.91	32.3	
T	0.872	0.205	0	F-ratio	60.59		
T^2	-0.0178	0.274	0	Prob.level	0		
T^3	0.000092	0.876	0				
Q	1.385	0.91	0.006				
comment : T and Q carry the same information							

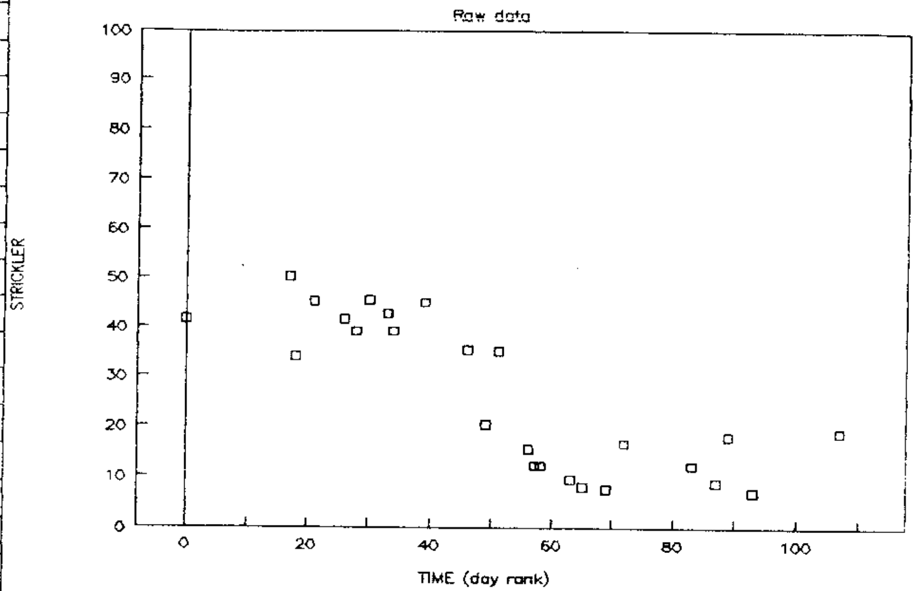
model : Q=a+b(Hu/s-Hd/s)				29 observations			
parameters estimates				model quality		low weigthed .	
variable	estimate	prob.level	seq R-sqr			< 0.1 %	< 25 %
a	-0.451	0.2		R squared	0.789		
b	10.927	0	0.789	F-ratio	100.82		
				Prob.level	0		
comment : strong correlation							

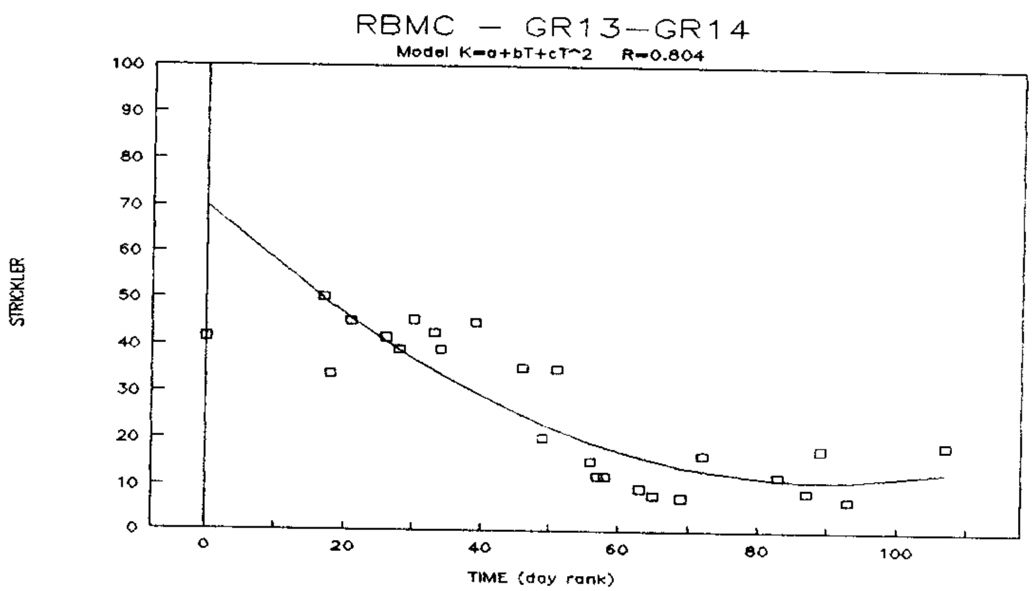
model : K=a+bT				18 observations for which Q < 3 m3/s			
parameters estimates				model quality		low weigthed estimates of K	
variable	estimate	prob.level	seq R-sqr			< 0.1 %	< 25 %
a	29.775	0		R squared	0.02		
T	-0.0117	0.579	0.02	F-ratio	0.32		
				Prob.level	0.579		
comment : for the cluster of low values of Q, K and T are not correlated							

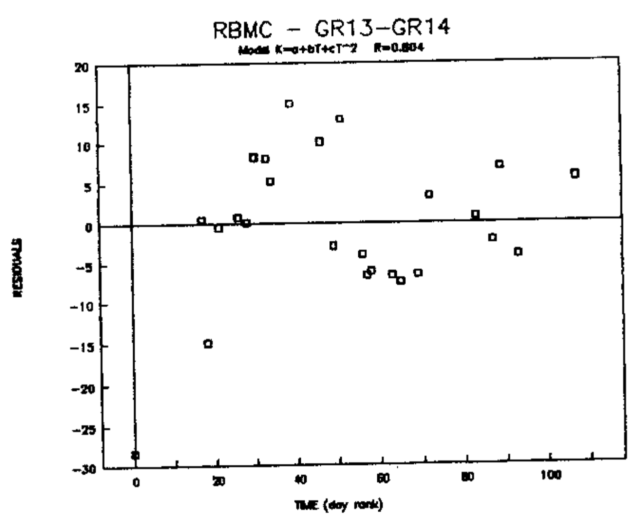
model : K-3093-76.875*Hu/s=a+bT				11 observations for which Q > 4 m3/s			
parameters estimates				model quality		low weigthed . values of Q	
variable	estimate	prob.level	seq R-sqr			< 0.1 %	< 25 %
a	-2.689	0.11		R squared	0.205		
T	0.0723	0.16	0.205	F-ratio	2.32		
				Prob.level	0.162		
comment : for this cluster, Hu/s explains 80% of the variability of K (details of this analysis are no and K and T are not significantly correlated							

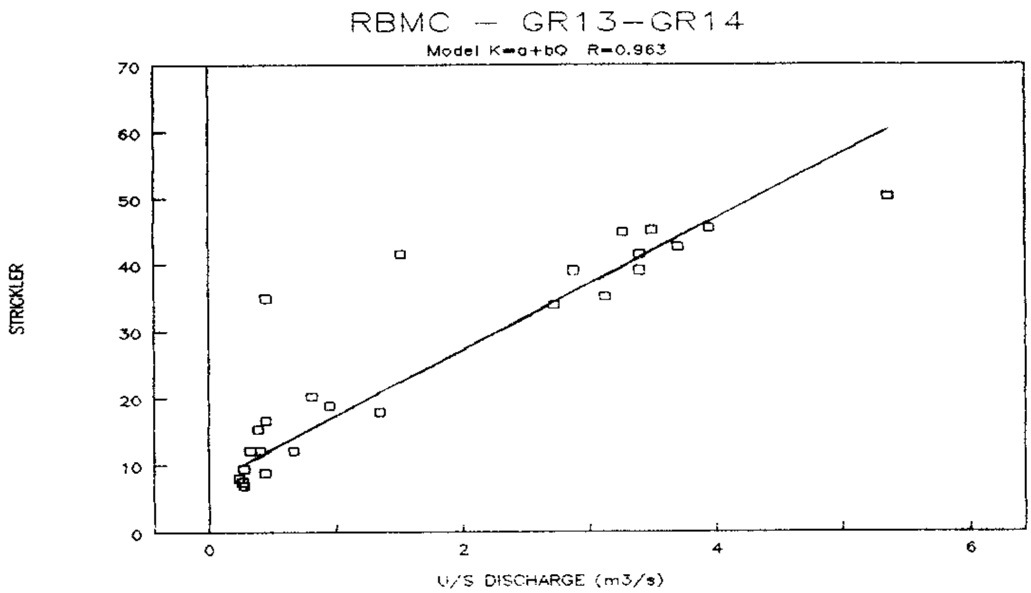
KO RBMC - GR13-GR14

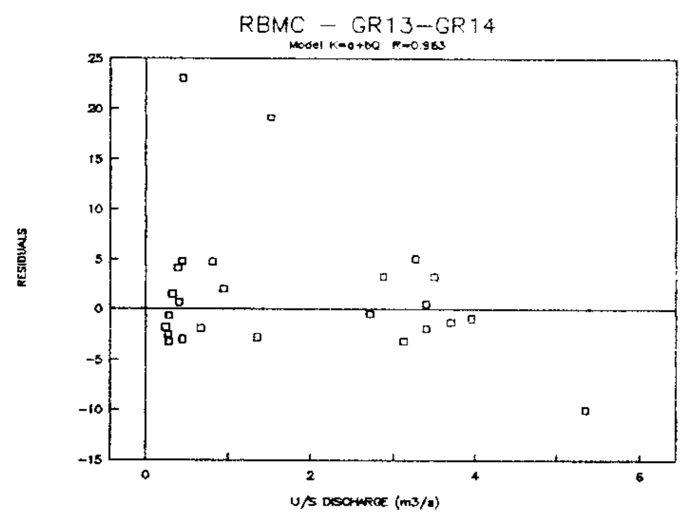
T	K
0	41.5
17	50.2
18	33.8
21	45.1
26	41.5
28	39.0
30	45.4
33	42.6
34	39.0
39	44.8
46	35.1
49	20.2
51	34.9
56	15.3
57	12.1
58	12.1
63	9.5
65	8.0
69	7.5
72	16.6
83	12.1
87	8.8
89	17.9
93	6.9
107	18.8

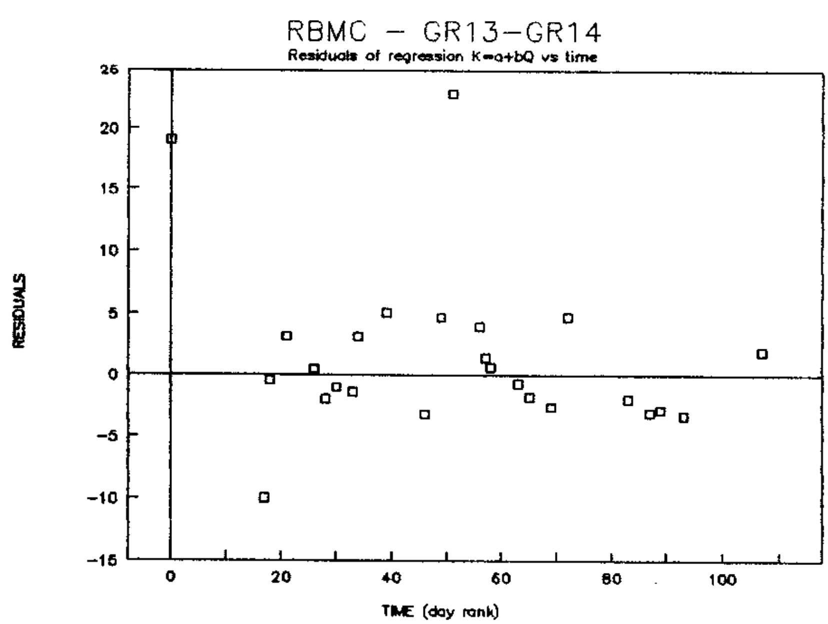







RBMC — GR13-GR14
Model K=a+bQ R=0.963
STRICKLER
U/S DISCHARGE (m3/s)
0
10
20
30
40
50
60
70
0
2
4
6


RBMC — GR13-GR14
Model K=a+bQ R=0.963
RESIDUALS
U/S DISCHARGE (m3/s)
-15
-10
-5
0
5
10
15
20
25
0
2
4
6


RBMC — GR13-GR14
Residuals of regression K=a+bQ vs time
RESIDUALS
TIME (day rank)
-15
-10
-5
0
5
10
15
20
25
0
20
40
60
80
100

RBMC - GR13-GR14
Influence of the head loss on the value of K

T is time in day rank (T=1 for date=01/08/92)
Q is U/S discharge in m3/s
Hu/s and Hd/s are water elevations in m
Head loss in cm

SFP	T	Qu/s	Hu/s	Hd/s	K	Hu/s-Hd/s head loss
1	1	1.513	38.172	38.030	41.5	0.14
2	17	5.352	38.532	38.320	50.2	0.21
3	18	2.719	38.362	38.080	33.8	0.28
4	21	3.495	38.422	38.220	45.1	0.20
5	26	3.399	38.452	38.250	41.5	0.20
6	28	3.399	38.452	38.210	39.0	0.23
7	30	3.949	38.482	38.250	45.4	0.25
8	33	3.701	38.482	38.230	42.6	0.25
9	34	2.875	38.412	38.130	39.0	0.28
10	39	3.270	38.472	38.320	44.8	0.15
11	46	3.126	38.512	38.280	35.1	0.23
12	49	0.814	38.382	38.330	20.2	0.05
13	51	0.448	38.322	38.310	34.9	0.01
14	56	0.386	38.222	38.150	15.3	0.07
15	57	0.322	38.292	38.230	12.1	0.06
16	58	0.402	38.352	38.290	12.1	0.06
17	63	0.277	38.232	38.170	9.5	0.06
18	65	0.236	38.252	38.170	8.0	0.08
19	69	0.265	38.232	38.140	7.5	0.09
20	72	0.444	38.252	38.180	16.6	0.07
21	83	0.666	38.362	38.230	12.1	0.13
22	87	0.441	38.322	38.190	8.8	0.13
23	89	1.346	38.432	38.290	17.9	0.14
24	93	0.278	38.272	38.150	6.9	0.12
25	107	0.949	38.372	38.290	18.8	0.08

RBMC - GR13-GR14

model : K=a+bT				25 observations			
parameters estimates				model quality		low weigthed estimates of K	
variable	estimate	prob.level	seq R-sqr			< 0.1 %	< 25 %
a	51.27	0		R squared	0.723	41.5	
T	-0.485	0	0.723	F-ratio	59.88	50.2	
				Prob.level	0	34.9	
comment : raw data are gathered in two separate clouds							

model : K=a+bT+cT^2				25 observations			
parameters estimates				model quality		low weigthed estimates of K	
variable	estimate	prob.level	seq R-sqr			< 0.1 %	< 25 %
a	69.926	0		R squared	0.804		
T	-1.134	0	0.691	F-ratio	45.2		
T^2	0.00733	0.002	0.804	Prob.level	0		
comment : good model but raw data are difficult to explain physically							

model : K=a+bQ				25 observations			
parameters estimates				model quality		low weigthed estimates of K	
variable	estimate	prob.level	seq R-sqr			< 0.1 %	< 25 %
a	7.492	0		R squared	0.963	41.5	
Q	9.852	0		F-ratio	576.56	50.2	
				Prob.level	0	34.9	
comment : Q alone explains K much better than T alone							

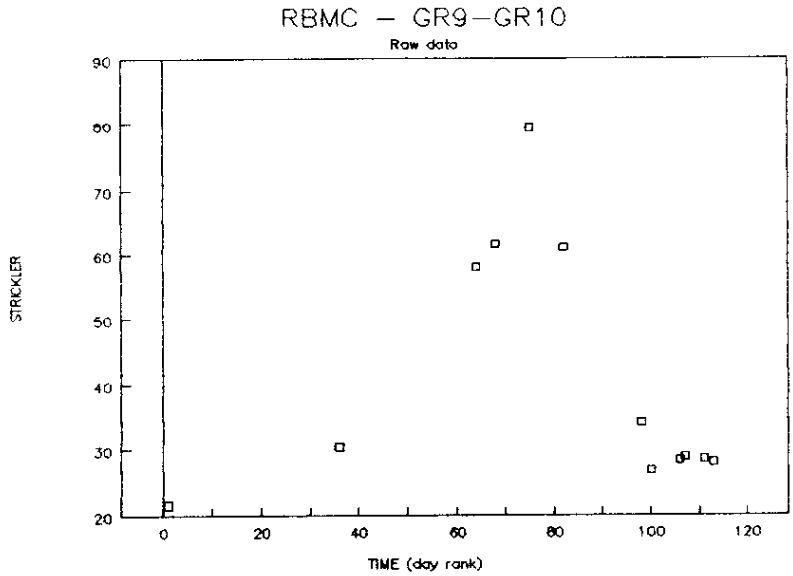
model : K=a+bT+cT^2+dQ		25 observations					
parameters estimates				model quality		low weigthed estimates of K	
variable	estimate	prob.level	seq R-sqr			< 0.1 %	< 25 %
a	30.416	0		R squared	0.979	33.8	50.2
T	-0.5393	0	0.682	F-ratio	303.3	44.8	
T^2	0.00317	0	0.723	Prob.level	0	34.9	
Q	7.008	0	0.979				
comment : adding T to Q does not explain K better							

model : K=a+bT		11 observations, cluster of high discharges					
parameters estimates				model quality		low weigthed estimates of K	
variable	estimate	prob.level	seq R-sqr			< 0.1 %	< 25 %
a	43.259	0		R squared	0.0332	33.8	50.2
T	-0.0479	0.592	0.033	F-ratio	0.31		
				Prob.level	0.592		
comment : K and T are not correlated for the cluster of high discharges							

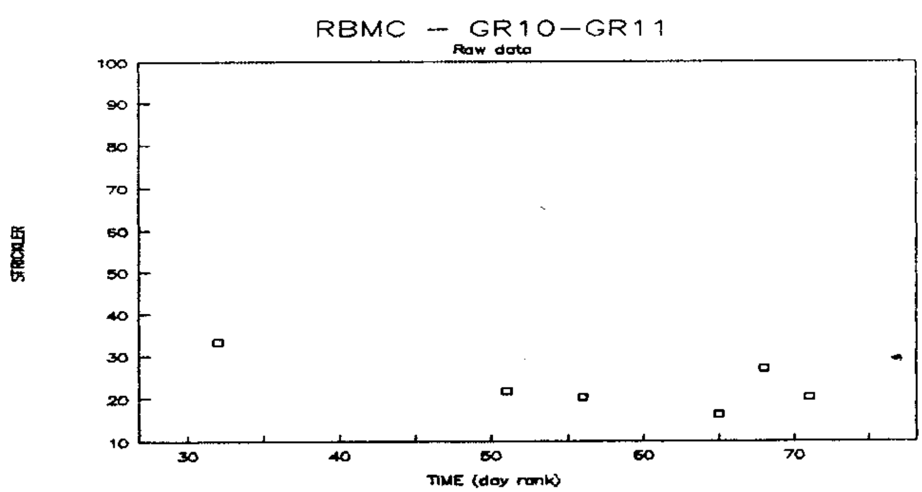
model : K=a+bT		14 observations, cluster of low discharges					
parameters estimates				model quality		low weigthed estimates of K	
variable	estimate	prob.level	seq R-sqr			< 0.1 %	< 25 %
a	17.395	0.025		R squared	0.0314	82.1	34.9
T	-0.0538	0.563	0.0314	F-ratio	0.36		
				Prob.level	0.563		
comment : K and T are not correlated for the cluster of low discharges							

model : Q=a+b(Hu/s-Hd/s)		25 observations					
parameters estimates				model quality		low weigthed values of Q	
variable	estimate	prob.level	seq R-sqr			< 0.1 %	< 25 %
a	-0.664	0.02		R squared	0.803		5.352
T	16.594	0	0.803	F-ratio	93.45		
				Prob.level	0		
comment : strong correlation							

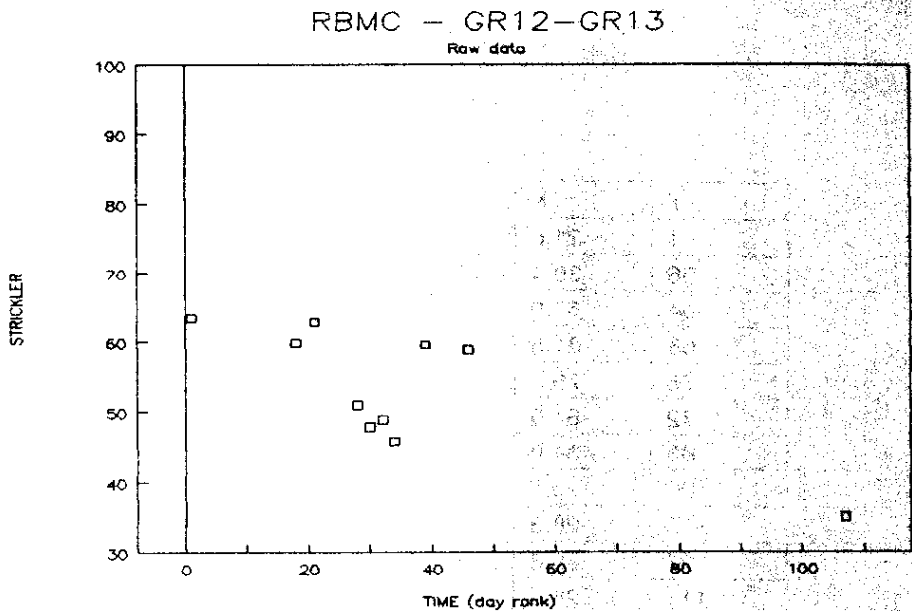
T	K
1	21.6
36	30.4
64	57.9
68	61.5
75	79.3
82	61.0
98	34.0
100	26.7
106	28.3
107	28.8
111	28.5
113	28.0



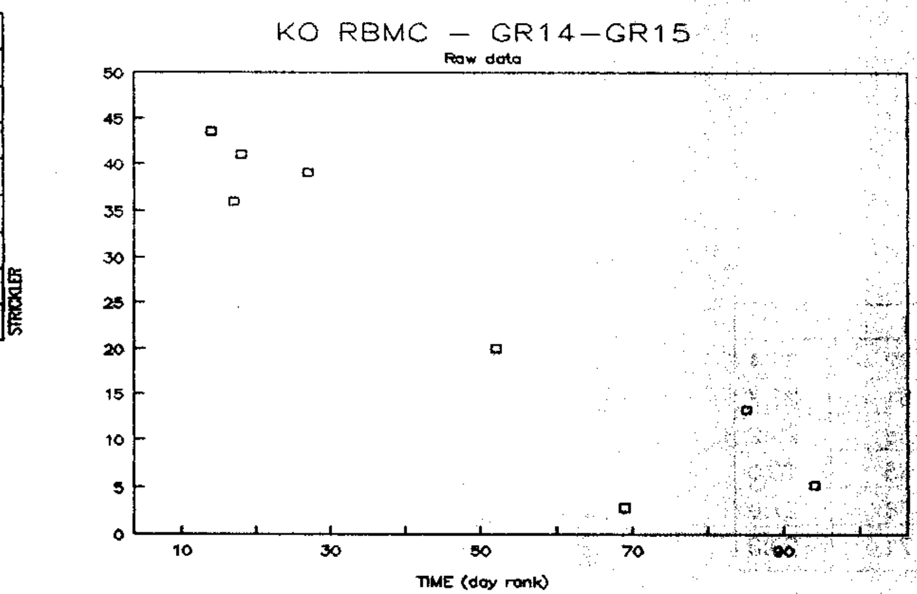
T	K
32	33.4
51	21.7
56	20.2
65	16.3
68	27.0
71	20.3



T	K
1	63.4
18	59.8
21	62.8
28	50.9
30	47.8
32	48.9
34	45.8
39	59.5
46	58.9
107	35



T	K
14	43.6
17	35.9
18	41.0
27	39.1
52	20.0
69	2.8
85	13.4
94	5.3



FILE REGULAT.DBF

Record#	TR_COD	ST_COD	CHAI	TBM	GAU_UP	GAU_DW
1	1	DAM	0	49.091	35.000	35.000
2	1	GR2	2415	47.369	1.415	1.545
3	1	GR3	4012	46.860	1.675	1.785
4	1	GR4	7007	45.961	1.724	1.834
5	2	GR5	8550	45.116	1.565	1.700
6	2	GR6	10532	44.562	1.618	1.768
7	2	GR7	12029	43.718	1.670	1.805
8	2	GR8	13732	42.727	1.275	1.405
9	2	GR9	15137	42.750	1.340	1.520
10	2	GR10	16166	42.275	1.388	1.463
11	5	GR11	18112	41.603	1.339	1.589
12	5	GR12	19860	41.155	1.515	1.825
13	5	GR13	22110	40.137	1.300	1.605
14	5	GR14	23342	39.705	1.175	1.520
15	5	GR15	24481	39.288	1.160	1.380
16	6	GR16	24726	39.310	1.650	1.840
17	6	GR17	25791	38.990	1.465	1.585
18	7	GR18	26408	38.109	1.685	1.800
19	7	GR19	27012	38.000	1.315	1.355

FILE DISTRIB.DBF

Record#	TR_COD	ST_COD	CHAI	TBM	GAU_UP	GAU_DW	CAREA
1	1	F6	935	46.564	0.535	0.540	
2	1	D2	1592	46.897	0.910	1.315	
3	1	D3A	2408	47.366	1.355	1.725	
4	1	D3B	2410	46.558	0.635	1.050	
5	1	D4	2977	46.625	1.005	1.380	
6	1	D5	3967	46.653	1.180	1.570	
7	1	F55	5316	45.181	0.510	0.995	
8	1	F56	5482	45.083	0.548	0.952	
9	1	F57	5949	44.973	0.525	0.925	
10	1	F58	6978	44.906	0.505	0.900	
11	2	D1	8515	44.662	0.835	1.235	
12	2	D2	10511	44.879	1.635	2.260	
13	2	D3	11701	43.139	0.905	1.225	
14	2	F34	11997	42.862	0.505	0.875	
15	2	D4	13145	42.977	1.305	1.710	
16	2	D5	13715	42.547	0.895	1.305	
17	2	D6	14594	42.330	1.080	1.570	
18	2	D7	14977	42.448	0.920	1.340	
19	2	F68	15229	41.737	0.655	1.050	
20	2	D8	16142	41.947	0.880	1.290	
21	2	D9	17788	41.339	0.965	1.180	
22	5	D1B	18017	40.317	0.310	0.865	
23	5	D1	18920	40.405	0.565	0.955	
24	5	D1A	19365	40.525	0.570	1.060	
25	5	BC2	19812	41.065	1.350	1.650	
26	5	F48	20108	39.440	0.530	0.930	
27	5	F49	21316	39.490	0.570	0.770	
28	5	D9	21698	40.060	1.075	1.475	
29	5	F54A	21858	39.484	0.560	0.965	
30	5	F54	22094	39.479	0.548	0.945	
31	5	F55	22906	39.037	0.515	0.930	
32	5	D11	23314	39.848	1.300	1.705	
33	5	D12	24282	38.958	0.715	1.130	
34	5	D13	24458	39.513	1.310	1.680	
35	6	D1	24632	38.750	0.805	1.190	
37	6	F24	24633	38.950	1.080	1.470	
38	6	F25	25000	38.570	0.930	1.323	
39	6	D2	25628	38.350	0.715	1.130	
36	6	F37	25781	38.580	0.832	1.237	
41	7	D1	26390	38.109	0.665	1.060	
42	7	F14	27010	38.438	0.870	1.280	
40	7	F15	28000		0.945	1.335	

. SET PRINT OFF

```
1.Find data files in :
D:\JM1\SFP\
Write results in  :
D:\JM1\1213\

2.Raw data file name :
Data file : AL_JM54
Index     : AL_JM54

3.Accessory data files :
Cross Str.  : REGULAT
 1st index  : REGUL_TS
 2nd index  : REGUL_S
Offtakes    : DISTRIB
 1st index  : DISTR_TS
 2nd index  : DISTR_C

4.Reach definition :
U/S Cross Str. : 5GR12
D/S Cross Str. : 5GR13
Reach code     : 12

5.Time interval :
Starting date : 01/09/92
Finishing date: 05/09/92

6.Seepage option :
Instant seepage : ON
Maximum value :   50
Accuracy on Cd (%) : 20
Fixed seepage   : OFF
Fixed value    :  -14

7.Measurements accuracy :
Water levels :
  U/S Cross Str. :  3cm
  D/S Cross Str. :  4cm
Discharges : 100l/s

8.Type of results :

ASCII (.TXT) file :
File : D:\JM1\1213\12
Result type : STANDARD

9.SFP minimal duration :
 6 hours

YOUR CHOICE (0=valid)  0

Command          |<D:>|AL_JM                54/4183     |Ins  |  Caps

Enter a dBASE III PLUS command.
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