EVALUATION OF SURFACE IRRIGATION SYSTEM DESIGN APPROACHES.

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A thesis submitted to the University of Nairobi in partial fulfilment of the requirement for degree of Master of Science in Agricultural Engineering (Soil and Water Engineering)

November 1996

DECLARATION

I, hereby, declare that this thesis is my original work and it has not been presented for a degree in any other university.

....
Peter Wan'gombe Muchangi

30/7/97
....
Date

This thesis has been submitted for examination with my approval as the university supervisor.

....
DR. F.N Gichuki

31/7/97
....
Date

DEDICATION

Dedicated to my wife and daughters:

Mrs. Lucy Wanjiru Wang'ombe;
Miss. Charity Njeri Wang'ombe;and
Miss. Grace Wairimu Wang'ombe.

ACKNOWLEDGEMENT

The author feels much obliged to all institutions and individuals who in one way or other helped during this study. It would be unkind not to mention; the Netherlands Assistance to the Small Scale Irrigation and Drainage Project of the Ministry of Agriculture for availing the scholarship; the Ministry of Agriculture for granting study leave; Dr. F.N. Gichuki, my project supervisor, for patiently guiding me through the study; Mr. G. Leereveld for his assistance especially on computer packages' literature; Mr. Jonathan Hide and Mr.John Skutch both of Overseas Development Unit of Hydraulic Research U.k., for taking their time to incorporate the suggested changes to MIDAS software for use in Kenya; my wife and daughter for their encouragement and understanding during the period I was away for study. finally, gratitude goes to all brethren who took their time to pray for me during this study.

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ABBREVIATIONS

A	-	Wetted Area of the Canal
B	-	Length of the Weir
C	-	Discharge Coefficient
DGM	-	Digital Ground Model
DPW	-	Irrigation Days Per Week
e_a	-	Application Efficiency
e_c	-	Conveyance Efficiency
ed	-	Editor
e_d	-	Distribution Efficiency
EC_w	-	Electrical Conductivity of irrigation water
EC_e	-	Electrical Conductivity of the soil Saturation extract for a given crop appropriate to tolerable degree of yield reduction.
ET_c	-	Crop Water Requirement
ET_o	-	Reference Crop Evapotranspiration
FAO	-	Food and Agriculture Organisation of United Nations
g	-	Acceleration due to gravity
GIR	-	Gross Irrigation Requirement
ha	-	Hectare
H	-	Hydraulic Head
HPD	-	Irrigation Hours Per Day
HR	-	Hydraulic Research
ICD	-	International Commission on Irrigation and Drainage
IDB	-	Irrigation and Drainage Branch of the Ministry of Agriculture
ILR1	-	International Institute of Land Reclamation and Improvement
IH	-	Institute of Hydrology

K_c - Crop CoefficientMoA

K_m - Manning's Roughness Coefficient

- Ministry of Agriculture

l/s - Litres per second

LR - Leaching Requirement

M - Metre

M^2 - Metre squared

mm - Millimetre

M^3 - Cubic Metre

NIR - Net Irrigation Requirement

ODU - Overseas Development Unit

ODI - Overseas Development Institute

PIU - Provincial Irrigation Unit

P_e - Effective Rainfall

Q - Flow in the Canal

R - Hydraulic Radius

S - Bed Slope of Canal

Sec. - Second

SSIDP - Small Scale Irrigation Development Project

UK - United Kingdom

ABSTRACT

To feed the increasing world population, the production of food crops from available land resource will need to be expanded. One of the ways to effect this is by increasing the output per unit area of land through use of irrigation. In Kenya the rate of irrigation development has been low. The Irrigation and Drainage Branch of the Ministry of Agriculture, charged with the responsibility of development of small scale irrigation schemes , identified availability of viable irrigation designs as one of the causes of low rate of irrigation development in Kenya. With this in mind, it has been looking for ways to improve the standard of designs and the rate of designing.

In this report the possibility of introducing the use of computers for design of small scale irrigation systems and in particular introduction of MIDAS (Minor Irrigation Design Aid Software) has been looked at. A start is made through establishing the main problems with the designs made. This was done through the study of the comments of the Irrigation Panel on the design proposals presented. A questionnaire survey was carried out to establish the main constraints experienced by the irrigation engineers during design of the schemes. This questionnaire was posted to them.

Gambela Irrigation Scheme in Isiolo District of Kenya was used for evaluation of MIDAS. This scheme was designed using MIDAS and normal design without using MIDAS. The aim of the evaluation was to establish whether it could be used to alleviate the problems identified through the study of Irrigation Panel minutes and questionnaire survey.During the evaluation, areas of MIDAS that required improvements for use in Kenya were identified. The improvements required were formulated and this information used

by Overseas Development Unit of Hydraulic Research to adapt MIDAS for use in Kenya.

It was established that, of the 61 investigation proposals presented to the panel, only 10% had been designed and approved by the panel by the time of the ninth panel meeting.
The designs presented were not complete and calculations were not done thoroughly. Availability of time was identified as one of the constraints. Most of the scheme design activities involve repetitive procedures which are tedious. There is no design criteria for most of the structures and irrigation application methods as used in small scale irrigation in Kenya

MIDAS handles design steps that take most time due to repetitive procedures,such as production of scheme layout alternatives, canal design, generation of longitudinal profiles for canals and plotting of the maps. It is faster than normal design process. Accurate and clear output is possible from use of MIDAS as compared to normal design process. However, MIDAS does not assist in processing of river flow data, rainfall data and climatic data. It does not assist in calculation of water requirements, design of field application methods and also does not do structural design.

1 INTRODUCTION

1.1 DEVELOPMENT OF DESIGNS OF IRRIGATION SYSTEMS IN KENYA

According to Moejes (1990), irrigation has been going on in Baringo, Elgeyo-Marakwet, and West Pokot Districts of Kenya for many centuries. SSIDP (1989) adds that flood water has been used traditionally along the lower Tana. There were no formal designs for these schemes. The farmers used water as a guide during the alignment of canals. According to Gibb et al (1987), the materials used for construction were stones, wood, leaves and mud.

The main problems experienced in these schemes were-:

- inadequate command due to poor canal alignment;
- lack of adequate drainage system;
- erosion of canal bed due to high velocities; and
- the systems were temporary requiring renovation after every season hence taking more time for the farmers which would otherwise be used in the farm.

Formal design for irrigation systems in Kenya was done during the state of emergency (1952-1956) where schemes such as Mwea, Yatta Furrow, Ishiara and Perkerra were designed (SSIDP, 1989). They used cheap labour for implementation from the detainees. Some of these schemes are centrally managed and farmers are tenants.

Increased emphasis on design of smallholder schemes started in Kenya after 1977 when Irrigation and Drainage Branch of the Ministry of Agriculture was formed.

The objective for the formation was to promote and develop smallholder irrigation and drainage projects (SSIDP, 1989). The major difference from the previous approach is that the schemes are farmer managed with each farmer having his holding with fixed farm boundaries to be considered during design. Only a portion of the holding may be irrigated.

To improve the standard of design, the Irrigation and Drainage Branch (IDB) of the Ministry of Agriculture started the Irrigation Panel. The panel is to be used to evaluate each design proposal on technical and socio-economic grounds and give constructive comments. The membership of the panel is from IDB, SSIDP, and University of Nairobi.

1.2 JUSTIFICATION

The major aims of irrigation in Kenya are:-

- Providing food security;
- Creating employment in rural areas;
- Improving the living standards of the rural

communities; and

- Improving national economy through export of horticultural crops.

According to SSIDP (1989), the total area under irrigation by the end of 1989 was 52,000 hectares, which is only 20% of the irrigation potential (244,000 hectares) in Kenya. During irrigation development planning workshop for the 6th development plan period (1989-1994), low rate of group scheme implementation was identified as one of the problems in smallholder irrigation and drainage development in Kenya (MoA, 1990). Shortage of viable project design proposals was identified as the major cause of this problem.

The main constraints for the design of small scale irrigation systems are:-

- Need to incorporate views of the farmers;
- The designer has to consider fixed farm boundaries; and
- Only a small portion of the farmers holding is to be irrigated.

These constraints calls for trial of various design alternatives. The design process involves repetitive steps and calculations. The tedious process involved, make the designer to neglect some steps . This results in incomplete designs.

According to Kohlhass and Nicolau, (1985), computers can be used in irrigation schemes' design for analysis, design and drafting. It is hypothesised that the improvement of the design process through use of computers for design will increase the rate of design and the quality and consequently, increase the rate of irrigation development.

1.3 OBJECTIVES

The overall objective of this study is to identify ways by which surface irrigation design process in Kenya can be improved by the use of computers. The specific objectives are:-

- To identify the major problems and constraints in surface irrigation design process;
- To evaluate the potential contribution of MIDAS (Minor Irrigation Design Aid Software) in overcoming some of these constraints; and
- To identify possible improvements of MIDAS for use in Kenya.

2. LITERATURE REVIEW

2.1 SURFACE IRRIGATION DESIGN CONSIDERATIONS

Before an irrigation project is designed and consequently implemented, it has to undergo the following phases.

- Scheme identification (Scheme initiation);
- Preliminary investigation;
- Detailed investigation;
- Design of the project;
- Implementation; and
- Monitoring and evaluation.

The essence of the above phases is to ensure that funds are not used on a project which will finally fail. According to the Ministry of Agriculture, Kenya, (1986 b), in most cases the project idea originates from the local farmers from their felt needs. The idea may also come from field extension officers who after seeing the possibility of an irrigation scheme in the area advises the farmers on how to exploit the water resource to improve their food security and increase employment in the rural areas.

The first step after the project idea, is for the technical staff to make a field visit and collect the available information on the project. The information collected is on natural resources,socio-economic, and farmers' organisation. On the natural resources, soils suitability, topography and water source, and availability are checked. A quick appraisal of the project based on these information is made and if there is no major constraints the next step, preliminary investigation starts. According to Ministry of Agriculture, Kenya, (1986 a), data on some areas such as hydrology, climate, water efficiencies and scheme water requirements are collected and analyzed during this step. A rough assessment is made on the required structures, scheme operation and management, the benefits of the project and project cost. Formulation of detailed investigations required is also done and costed during this phase.

Further investigations that may be required are semi-detailed soil survey,topographical survey of the area, quality analysis of the water and drainage of the area. During this phase of the project, the farmers' organisation is strengthened. After these investigations are done, the detailed design of the project follows. Water abstraction, conveyance, distribution, application and the required structures are formulated and designed during this phase. Project operation and maintenance and organisation are set up also. After the design of the project, the cost of the whole project and economic analysis are done. The implementation, monitoring and evaluation of the project is a continuous activity. Below are the sub-steps (activities) of the design phase.

2.1.1 Water Resource Analysis

Of importance to the designer is the water sources, water availability, flood conditions and water quality. In Kenya the main water sources are rivers, springs and Lakes. Dams and wells are used to a lesser extent.

The total area to be irrigated depend on the available water during the peak demand time. The risk taken during the estimate of available flow depend on the type of the crop. According to the Ministry of Agriculture, Kenya (1986 a), for high value crops a probability of exceedance of 90% is used so that there is enough water in 9 out of 10 years.

For general design of irrigation schemes a probability of exceedance of 80% is used. Monthly average river flow records are used to estimate the design flow for the required probability.

The knowledge of the flood condition is important to the designer for design of protective and control structures at the intake. According to Chow (1988), the magnitude of the floods is inversely proportional to the frequency of occurrence. The higher the floods the higher the return period and the cost of the protective structures also increases with the increase of return period . According to the Ministry of Agriculture (1986 a), a return period of 20 to 100 years is used in irrigation design. A common figure used is 25 years. Daily river flow records are used to estimate the flows with the required return period. Where flow records are not available, slope area method can be used to estimate the flood flows (Chow, 1973). The uniform flow formula is used, where the slope of flood marks and cross sectional area of the river for a uniform straight section are determined.

Soil salinity is affected by the water chemical quality. Salinity levels in the soil generally increases as the growing season advances. According to Doorenbos and Pruit (1977) the leaching requirement (LR), the minimum amount of irrigation water supplied that must be drained through the root zone to control soil salinity at a given specific levels, is given by the following formula for surface and sprinkler irrigation.

$$LR = \frac{EC_w}{5EC_e - EC_w} \quad \text{(Doorenbos and Pruit,1977)} \quad [1]$$

where LR = Leaching requirement, ECw = Electrical conductivity of irrigation water (mmhos/cm), and ECe = Electrical conductivity of the soil saturation extract for a given crop appropriate to tolerable degree of yield reduction (mmhos/cm).

2.1.2 Irrigation Water Requirements and Design Flow

To determine the irrigation water requirement and scheme design flow the following activities are undertaken.

1. Determination of crop water requirement.
2. Determination of effective rainfall.
3. Determination of other water requirements such as for leaching and land preparation.
4. Estimation of efficiency.
5. Deciding on the area to be irrigated.

Crop water requirement determination requires information on reference crop water requirement (ET_o). Four main methods of calculating reference crop water requirement are Blaney-cridle, Radiation, Penman and Pan evaporation method (Doorenbos and Pruit, 1977). The method to be used will depend on the available data. The crop coefficient (K_c) is required for determination of crop water requirement. This will vary over crop development stages. To determine the crop coefficient, cropping pattern, time of planting and length will be required. the crop water requirement is given by :-

$$ET_c = K_c.ETo \qquad [2]$$

Where ET_c = Crop Water Requirement (mm/day),

ET_o = Reference Crop Water Requirement (mm/day),

and K_c = Crop Coefficient.

To determine net irrigation water requirements, effective rainfall will be required (assuming no contribution from ground water and no water stored in the soil). According to Smith (1992), effective rainfall is defined as that part of rainfall which is used effectively by the crop after rainfall losses due to surface runoff and deep percolation have been accounted for. Monthly rainfall data is used to calculate effective rainfall (Doorenbos and Pruit, 1977). The net irrigation requirement is given by

$$NIR = ET_c - P_e \quad [3]$$

Where NIR = Net Irrigation Requirement (mm/day), ET_c = Crop Water Requirement (mm/day), and P_e = Effective Rainfall (mm/day).

To account for water losses, an efficiency factor is used. The efficiency depend on scheme area, farm size, water supply method (continuous or rotational) and field irrigation method and soil type (Bos and Nugteren, 1983). The scheme design flow will take into consideration all the water losses and other water requirement such as for land preparation and leaching requirement.

2.1.3 Scheme Layout

The main goals of an irrigation scheme design is to devise ways to control, convey and distribute water to the service areas. Scheme layout refers to special organisation of plots and canals. Factors that affect the scheme layout are:-

- Water source;
- Scheme area topography;
- Soils; and

- Farm boundaries.

According to Horst (1990), farmers' view and expectation for the layout is to conform to such factors as land tenure, right of way, groups working together, Kinship and other preferences (Social as well as cultural). This calls for consideration of alternative layouts.

The group organisation and management will depend on the group size. For small scale irrigation schemes in Kenya a group size of 10 to 30 farmers have been found to work well (MoA, 1987). The size of the group also determines the unit flow (flow to the group). This should be such an amount of water that a farmer will effectively handle and manage. The Irrigation and Drainage Branch of the Ministry of Agriculture, recommends unit flow of 10 to 20 l/sec (MoA, 1987). The group size is also limited by maximum irrigation interval. This depends mainly on the crops and soil type. The interval should be such that the crops do not experience water stress.

According to Horst (1990), one aims at compact groups not too far from source of water to economise on length and drainage channels. Seepage losses are also proportional to the length of canals.

2.1.4 Design of Field Irrigation System

The three main surface irrigation methods are basin, furrow, and border strip. The factors that dictate the choice of the irrigation methods to be used are:-

- Topography of the farm;
- Soils;
- Crops to be grown; and
- Cost of the system.

According to the Ministry of Agriculture (1987), furrow irrigation can be practiced upto a ground slope of 5% while basin irrigation is limited to ground slope of upto 2% due to high levelling required. According to Bassett (1983), the main design variables for surface irrigation system design are:-

- Depth of water to be applied;
- Field slope;
- Surface roughness; and
- Infiltration characteristics of the soil.

The main parameters to be determined are the dimensions, application time and the flow rate. The main equations used are Kostiakov, Philip, and Soil Conservation services (SCS) intake family curves.

2.1.5 Canal and Drainage channel Design

The main activities involved in the canal and drainage channel's design are:-

- Generation of the ground profiles;
- Determination of the dimensions of the channel; and
- Drawing of the canal long-section including drop structures.

The roughness, the channel bottom slope, side slope, free board and cost aspects are the factors to be considered. The main variables are the normal depth of water and bed width of the channels. Manning's formula shown below is commonly used.

$$Q = K_m A R^{2/3} S^{1/2} \qquad (4)$$

Where Q = Flow in the channel (M^3/sec), A = Wetted area (M^2), R = Hydraulic radius (M), S = Energy slope, taken as bed slope of the canal (M/M), and K_m = Roughness coefficient $M^{1/3}$/sec.

During design of the canals, it is assumed that the canals will be well maintained. For farmer managed irrigation schemes this may not be true (Horst 1990). Meyer, (1989) advocates use of smaller value less than normal k_m, coefficient for small canals, as quoted by Horst (1990). This results in the use of larger cross sectional area (A) than normal. The Ministry of Agriculture (1987) recommends a K_m value of 15 m $^{1/3}$/sec for flows less than 40 l/sec and 20 m $^{1/3}$/sec for flows less than 100 l/sec but higher than 40 l/sec. The main check during canal design is the minimum and maximum permissible velocity. According to Chow (1973), minimum permissible velocity is the lowest velocity that will not start sedimentation and induce growth of aquatic plants. It depends on the silt carried by the water. Ministry of Agriculture (1987) recommends a value of 0.15 m/sec. The maximum velocity depends on the soil of the area traversed by the canal. Khushalani and Khushalani (1990) quotes the values for various soil types.

2.1.6 Design of Structures

The design of irrigation structures consists of three parts:-

- hydraulic design;
- functional design; and
- structural design.

Hydraulic design is to find the flows and head losses, functional design makes provision for free board, clearance and fluming while structural design is to decide on construction materials, thickness and reinforcement if required.

According to Tiffen and Guston (1983), the design of structures for farmer managed schemes should be such that farmers can construct and repair with available knowledge and materials. The operation of diversion and distribution structures depend on distribution method. Continuous flow in canals is advocated for small scale irrigation schemes to minimise the closing and opening of the gates.

2.2 DESIGN CONSTRAINTS FOR SURFACE IRRIGATION SYSTEMS

According to Pazvakavambwa (1984), prior to designing a scheme, the designer should have a feel of people's preferences, attitudes and aspiration. He further adds that for smallholder irrigation systems, the design should be farmer oriented. Farmers' view and expectation for layout is to conform to such factors as land tenure, right of way, groups working together and other preferences. (Horst, 1990). This calls for consideration of several design layouts and design alternatives. In addition to above conditions, the designer has to deal with physical boundary conditions such as soils, topography, rocks, water and existing infrastructure. To consider all these conditions,it requires time and patience from the engineer. The design process calls for trying of various values so as to get a design that is sound hydraulically and is economical. Some processes in surface irrigation design such as generation of canal longitudinal profiles, are lengthy and tedious. The designer confounded by time pressure to show immediate results and the Government and donors wishing to minimise the duration of their involvement as quoted by Speelman (1990), makes quick designs which are not to the required standard by ignoring some design steps.

Availability of design data may be a problem for various schemes. Some rivers on which the schemes depend on for water resource may not be gauged. In this case the designer uses estimated values and thus is prone to over designing or under-designing. Soils information and climatic data on which to base the design may also not be available.

2.3 USE OF COMPUTERS IN SURFACE IRRIGATION DESIGN

2.3.1 Introduction

The use of computers in the world has continued to grow. The introduction of Micro-computers in the early 1980's made it possible to diversify the use of computers to more areas as compared to the main frame computers used earlier.

Jurriens (1993) notes that compared to other sectors, the take-up of Micro-Computers has been slow in the irrigation world. He further adds that three other previous reviews on current state of irrigation computer programs concluded that there are surprisingly small number of irrigation programs that are upto standard, completely available, quick to learn and easy to use.

According to Kohlhaas and Nicolau, (1985) Computer packages in irrigation can be divided into three classes. These are:-

- Computer aided analysis;
- Computer aided design; and
- Computer aided drafting.

Computer aided analysis packages are used to determine the design parameters, while the design packages are used to determine the dimensions. Drafting packages are used to draw the diagrams that results from analysis and design. A survey carried out by International Commission on Irrigation and Drainage (ICID) in 1988 showed that the development of design packages lags behind that of analysis packages (Kohlhaas and Nicolau, 1985).

2.3.2 Computer Aided Analysis

Computer aided analysis packages are used in surface irrigation design to determine parameters on which to base the design. These are design flow, flood flow with the required return period, crop water requirement from climatic data and cropping information, dependable rainfall and effective rainfall from rainfall recorded.

A package that can be used to predict flows from ungauged rivers is available from the Institute of Hydrology (UK). HYRROM (Hydrological Rainfall Run-off Model) is a conceptional model. It uses rainfall and evaporation data to predict river flows for a catchment (Institute of Hydrology, 1992a). The same institute has developed a package for hydrological Frequency Analysis HYFAP (Hydrological frequency analysis package (Institute of Hydrology, 1992b). It uses annual maximum rainfall or flow to estimate the probable frequency of a particular maximum event recurring within a specified period. It can be used to predict flood flows for the required return period to be used for design.

During the design, the flow to the scheme will be determined. Crop water requirement forms a great portion of this. Crop water requirement calculation requires information on reference crop water requirement (ET_o). CROPWAT is a major package for calculation of water requirements. According to Smith (1992) the package can be used for the following purposes:-

- Calculation of reference crop water requirement;
- Calculation of crop water requirement;
- Calculation of irrigation requirement; and
- Calculation of scheme water supply.

It uses Penman-Monteith approach recommended by FAO expert consultation in Rome. Other packages to calculate crop water requirement have been mentioned by Lenselink and Jurriens (1993). These are CRIWAR, ETREF, IRSIS and CWRTABLE.

To get irrigation requirement from the Crop water requirement, the effective rainfall is required from the rainfall records. The rainfall figure to be used for calculation of effective rainfall have to be of a given probability of occurrence. PARADIGM (Parameters for

Rainfall Distribution in a Gamma Model) is a package produced by Overseas Development Unit (ODU) of Hydraulic Research (UK) that is used to calculate dependable rainfall from rainfall record (Lea, 1990). It uses daily rainfall data and requires a minimum of five years data.

2.3.3 Computer Aided design

In surface irrigation design, Computer Aided Design packages would be used to determine dimensions of basins, furrows and border strips. The packages could also be used to determine the dimensions of the canals and the structures. The drawings of such information can be produced through a drafting package. Three computer programs have been described by Lenselink and Jurriens (1993) for design of channels. These are PROFILE, CID and DORC. Profile is used to calculate unknown parameters in Manning's/Strickler equation for trapezoidal channels. Unlike PROFILE, CID can be used to determine parameters for both rectangular and trapezoidal, lined or unlined canal sections for uniform flow conditions. It gives numerical and graphical results which can be printed. DORC is a software package produced by Hydraulic Research, Wallingford (UK). It assists in the design of regime canals.

A package for design of basin irrigation system is available from International Institute for Land Reclamation and Improvement (ILRI). BASCAD (Basin Computer-Aided Design) can be used to simulate advance and infiltration in level basin (Boonstra and Jurriens, 1988). It can be used to determine variables such as basin length, inflow rate and application depth. It can also be used for analysis of operational alternatives. Another package BICAD (Border Irrigation Computer-Aided Design) has been described by Lenselink and Jurriens (1993).

It is used to calculate design variable in border irrigation system i.e border length, width, slope, flow rate and application time. Inputs are infiltration constant, surface roughness and water depth to be applied. Design of structures has not been computerised to a great extent. Kamphuis (1993) has described a Euroconsult in house programme WEIRDES. This programme is for designing traverse fixed overflow weirs in canals. It combines the three design parts, hydraulic, functional, and structural. The equation used is only valid for free flow conditions.

2.4 SURFACE IRRIGATION DESIGN USING MIDAS

2.4.1 Introduction

MIDAS (Minor Irrigation Design Aid Software) is a Micro-Computer based design package. It was developed by Overseas Development Unit (ODU) of Hydraulic Research Wallingford. Their initial work was based on surface irrigation systems in Zimbabwe. It is geared to assist with essential design operations of surface irrigation (Hydraulic Research, 1991).

The objectives of producing MIDAS were:-

- To provide structured design methodology incorporating step-by-step guidance through the design process from initial layout to final design;
- To speed the more routine and repetitive process of design;
- To allow greater variety of design alternatives to be considered in greater detail;
- To allow the designer to make conscious choices at key stages in the design process;
- To provide the means to actually carry out the design using computer;
- To utilize graphical rather than textual

displays wherever possible;

- To assess the effect of changes in ground levels through land levelling and to calculate quantities of cut and fill;
- To provide guidance on detailed design of canals and structures using a library of standard structures; and
- To provide working drawings including plans, long sections and structural details (Hydraulic Research, 1993).

Figure 1 is a flow chart for surface irrigation design showing areas covered by MIDAS having thick boundary.

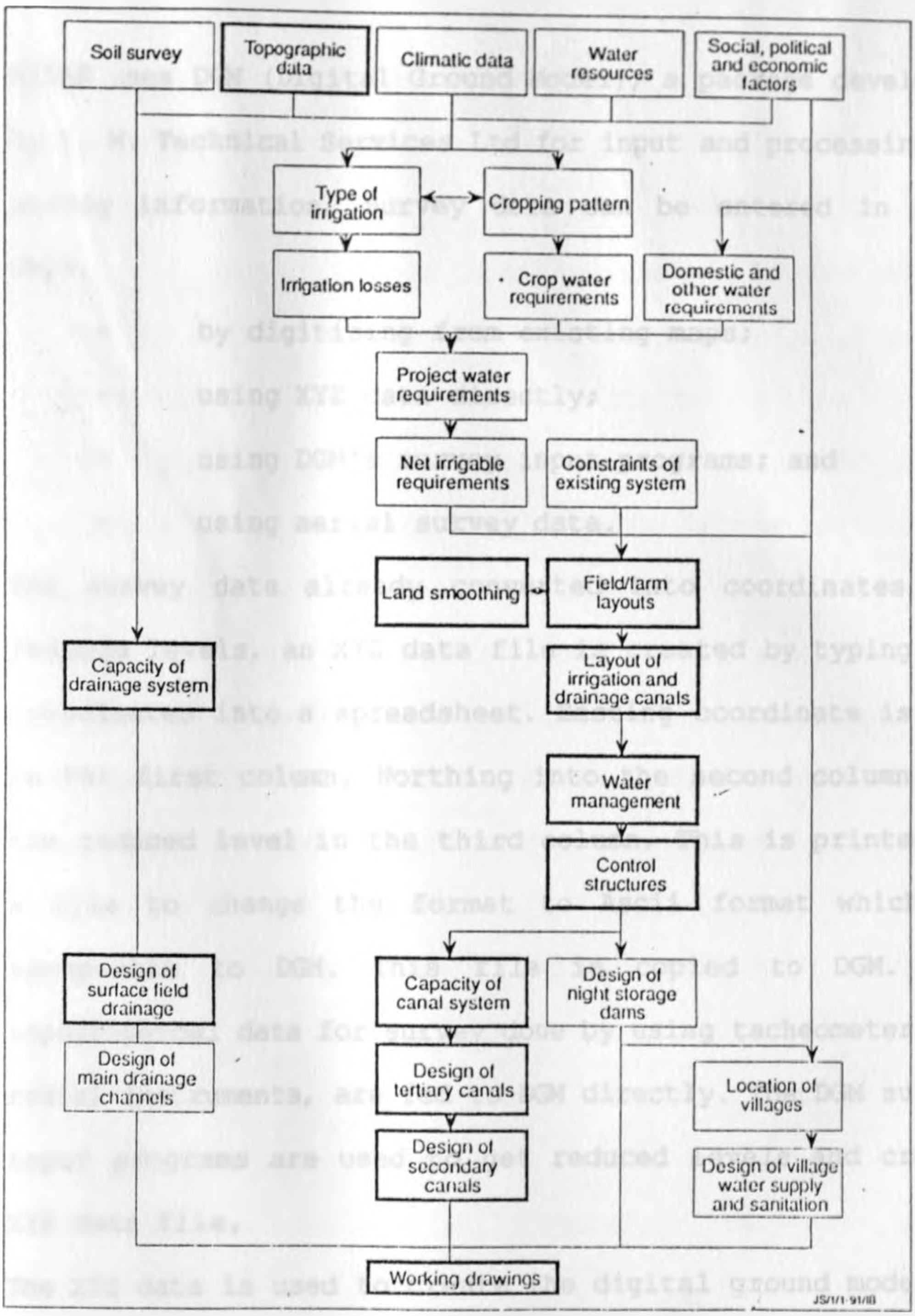


FIGURE 1 - Flow Chart for Surface Irrigation.
Source : Hydraulic Research. (1991)

2.4.2 Processing and Input of survey Information

MIDAS uses DGM (Digital Ground Model), a package developed by L. M. Technical Services Ltd for input and processing of survey information. Survey data can be entered in four ways.

- by digitising from existing maps;
- using XYZ data directly;
- using DGM's survey input programs; and
- using aerial survey data.

For survey data already converted into coordinates and reduced levels, an XYZ data file is created by typing the coordinates into a spreadsheet. Easting coordinate is put in the first column, Northing into the second column and the reduced level in the third column. This is printed to a file to change the format to Ascii format which is acceptable to DGM. This file is copied to DGM. Raw topographical data for survey done by using tacheometer and radial instruments, are fed to DGM directly. The DGM survey input programs are used to get reduced levels and create XYZ data file.

The XYZ data is used to create the digital ground model of the area. Data conversion is done automatically when starting a new design from the DGM to AutoCAD. The first design drawing is the topographical map of the scheme area and existing features.

2.4.3 Scheme Layout

MIDAS has various tools used to assist in the scheme layout. Using AutoCAD layers, various information on scheme area topography, farm boundaries, existing features such as roads, homesteads and canals can be switched on and off as required. These will assist to determine the location of canals and drains. Slope arrows (arrows generated by MIDAS showing direction of maximum slope at pre-specified grid spacing) are used to show positions of gullies and ridges and hence better positions for drained canals. Line command and drain draw commands are used to draw lines representing canals and drains respectively. Quick drawing of ground profiles is possible through " SECTION " command to verify whether the location of drain or canal is good. By pre-defining the lines for secondary canals a summary of the lengths of secondary, tertiary canals and drains can be generated to assist in comparing various layout alternatives.

2.4.4 Determination of Flows in the Canals and Drains

Canal discharges are calculated on the basis of the area they serve. The group areas are defined by drawing a line around the group. The following inputs are required:-

- Peak net irrigation requirement;
- Tertiary conveyance efficiency;
- Field application efficiency;
- Number of farms in the group; and
- Area irrigated per farmer.

For secondary canals, the following inputs are required:-

- Whether rotation or continuous flow;
- For rotation - irrigation interval and hours per rotation;
- For continuous, irrigation hours per day; and
- For both, one picks the tertiary labels for tertiaries fed by the secondary canals.

A summary of the flows to each tertiary from the secondary is produced.

The drain discharge is also calculated by specifying the area contributing run-off to the drain. The drainage coefficient (maximum rate of run-off) and the drain dimensions, side slope and Manning's K_m are the inputs required. The output is the drain discharge, drain capacity and the cut and fill of the drain.

2.4.5 Canal Design

This is the most important operation of MIDAS. The canals are first defined (specifying which are tertiary and secondary canals and the way they are joined). During this process the labels for the distribution structures are automatically inserted on the layout. The canals are then labelled where a label appears at the end of each canal. This label is used to generate the canal ground profile where the inputs are the label, lowest contour and vertical scale (vertical exaggeration). For canal design the following are inputs:-

- Down stream bed level;
- Mannings K_m;
- Canal side slope (deg);
- Bed slope (m/m);
- Drop height (m);
- Freeboard (m); and
- Bank height.

The normal water depth and maximum velocity are calculated. If the velocity is within the limit, the canal design is drawn on the ground profile automatically. Several designs can be made and stored and comparison can be made. The design can be modified by adding, removing, moving or changing the drop structures (editing).

2.4.6 Structures' Design

Once the canals have been designed, principle dimensions of the distribution structures (Division boxes and offtakes) can be determined. The inputs are the structure label, nearest contour and the type of offtake or division (continuing or end), label of continuing canal, structure type (orifice or Weir), vertical scale, discharge of canal and allowable head loss. If crest lengths are acceptable, the crest level is specified.

2.4.7 Inventory of Structures

MIDAS has tools to allow the production of structures' inventory table. Before the table is generated the inventory command scans through the entire drawing, extracting relevant information of the structure type. This information is displayed on a table after picking the canal label and the origin for the table.

3. METHODOLOGY

3.1 PROBLEMS AND CONSTRAINTS ON SURFACE IRRIGATION DESIGN IN KENYA

3.1.1 Irrigation Panel's Comments

Minutes of seven panel meetings were available for the study. The first and second panel meetings were not well documented. They were studied to establish the availability of design proposals as compared to the investigation proposals presented over the duration and to establish the problem areas in the design. To establish these, the following were determined from the minutes of the panel meetings:-

- Investigation proposals presented and those passed;
- Design proposals presented and those passed; and
- The comments for each proposal.

To determine the regularity of the design proposals, the number of design proposals for the projects whose investigation proposals had been presented and approved for all the panel meetings were compared. The comments were listed down and sorted out for each design activity. They were arranged in order of the design process for clarity.

3.1.2 Constraints in Surface Irrigation Design in Kenya

To determine the main constraints experienced by the irrigation engineer during the design of small scale surface irrigation projects, a questionnaire was used. The questionnaire covered the design process from processing of survey data in the office to economic analysis of the project. The main emphasis was on relative time taken for each design activity and other constraints identified by the engineers. The names of the engineers and the questionnaire are shown in Annex 3.

Except for a few questions where arithmetic mean was used in most of the questions, the mode was used as the decision criteria. The design steps were ranked, starting with the step that takes most time relative to the others. Each rank was given a score. The first rank was assigned a score of 11 and the last rank assigned a score of 1. For each activity, the number of Engineers who gave it a particular rank was noted. This number was multiplied by the score of the rank. This was done for all the ranks and the total score for the design activity over all the ranks noted. These total scores were arranged in a descending order. The resulting order was taken as the representative ranking order for the design activities.

The constraints mentioned by the engineers for each design activity were recorded. The ranking order that resulted from the analysis and the constraints identified were compared with the problem areas identified from the study of the irrigation panel minutes.

3.2 EVALUATION OF MIDAS

Evaluation of MIDAS was done for the following:-

- To establish whether it would be used to alleviate the design problems identified;
- To compare the rate of normal design approach (without using computers) to the rate of designing using MIDAS; and
- To compare the output of MIDAS design and that of normal design (accuracy and quality)

The evaluation was done on the following design activities carried out by MIDAS:

- Scheme layout;
- Preparation for and generation of canal ground profiles;
- Canal design; and
- Structures design.

Design data for Gambella irrigation scheme in Isio`lo District of Kenya was used for the evaluation. The data used was:-

- Topographical map (Grid survey);
- Semi-detailed soil survey report (Ground Water Survey, 1992);
- Climatic data; and
- Rainfall data.

The XYZ coordinates for the various points on plot boundaries, grid points, rivers, roads and existing canals were extracted from the map and processed.

CROPWAT package was used to get the peak net irrigation requirement for the project. The efficiencies for the scheme were also estimated (see Annex 1). These were used as inputs to MIDAS.

The evaluation for the various design activities was as shown below.

3.2.1 Scheme Layout

The topographical map prepared using MIDAS was used to prepare possible layouts without using the computer and also using MIDAS. Three possible layouts were considered. The time taken on coming up with the three possible layouts with and without using computer was noted and compared.

The best layout among the three was chosen using the criteria of the length of the canals and drains.

3.2.2 Canal Ground Profiles

To generate the ground profiles the layout chosen above was used. For normal design process (without using MIDAS), the process involved using a straight edge of a paper, marking the straight sections of the canals on this paper and noting the levels of the ends of these sections. The actual lengths of these sections were determined and the cummulative distance upto each point determined (chainnage).This information was plotted on the graph paper to get the ground profiles.

In, MIDAS the canal network was first defined (specifying which are secondary or tertiary canals and the way they are connected). The canals were then labelled. MIDAS recognises each canal through the label.

The profiles were then generated by picking the labels lowest contour on the canal and specifying the vertical scale. The time taken and the quality of the resulting profiles were noted and compared.

3.2.3 Canal Design

The flow in the canals was determined based on the peak net irrigation requirement, the irrigated area per canal, irrigation hours and the efficiencies. The main variables are the normal water depth (d) and bed width (b). Other parameters to be determined were side slope (z), freeboard, top width of embankment (w) and the bed slope (s) of the canal. The main check during the canal design was the maximum permissible velocity which depends upon the soil type of the area. According to Ground Water Survey Ltd. (1992), the main soil type of the area is clay loam. The maximum velocity for this soils vary from 0.6 - 0.9 m/sec (Booher, 1974). The tertiary canals had flows less than 40 l/sec. A K_m coefficient value of 15 m $^{1/3}$/sec was used while for sections of the main canal with flows over 40 l/sec, a K_m coefficient of 20 m $^{1/3}$/sec was used (MoA, 1987).

The side slope for the canals was taken as 1.5 for clay loam (withers and Vipond, 1988). These values were used to determine the dimensions of the canals without using MIDAS and the time taken was noted.

For MIDAS the same information was used. The inputs required were, down stream bed level, Manning's K_m coefficient, side slope, bed slope, bed width, the discharge, drop height and freeboard. The program calculated the water depth and maximum velocity. If the maximum velocity was higher than the required value the process was repeated with different bed slope or bed width. The canal design was generated automatically on the ground profile. The time taken to design all the canals with MIDAS was noted. The quality of the output was also compared with that one determined without using MIDAS.

3.2.4 Design of structures

The structures designed using MIDAS are offtakes and division boxes. The dimensions determined are length of the weir outlets or the area of the orifice opening for both offtakes and division boxes. The design of the structures was done using MIDAS. The discharge formula for free flow conditions was used.

$$Q = C\ B\ H^{3/2} \qquad [5]$$

Where Q = Flow through the structure (m^3/sec), C = Discharge coefficient, B = The length of the weir (m), and H = Head loss over the weir (m).

A value of 1.75 for C was used (MoA, 1989) for short crested traverse rounded weir. The water levels upstream and down stream were varied to get the length of the weir (B) within canal cross section

For MIDAS the required inputs were, structure type (whether weir or orifice), discharge, allowable head loss and nearest contour. The program calculated the length of the outlet weir for the tertiary and secondary canals.

3.3 IDENTIFICATION OF POSSIBLE IMPROVEMENTS ON MIDAS

The Kenyan Version of MIDAS was adapted from the original package prepared for Zimbambwe. The changed version was tested using a test scheme (Kwa Kyai). For each design activity, it was established whether the package meets the Kenyan design procedure and considerations. For areas where the package did not meet the Kenyan design requirement, they were noted and changes required identified. These changes were given to Overseas Development Unit (ODU) by Hydraulic Research who continued with improvement of the package. Later a visit to Hydraulic Research was arranged, through the British Council where the design of the cost scheme continued until the program ran without problems. The second phase of identification of the improvement was during the detailed design of the evaluation scheme. The output of MIDAS was compared with the expected output from normal design. The improvement of the package of Overseas Development Unit has been continuous process and is still in progress.

4. RESULTS AND DISCUSSIONS

4.1 CONSTRAINTS AND PROBLEMS IN SURFACE IRRIGATION DESIGN IN KENYA

4.1.1 Irrigation Panel Minutes

Table 1: shows the results of the study of the minutes of irrigation panel. The first and second panel meetings were not well documented. A total of 61 investigation proposals and 28 design proposals were presented during the six panel meetings. Out of these, 57 investigation proposals and 22 design proposals were approved by the panel and funds allocated for them. The design proposals lags behind the investigation proposals presented as can be seen from Table 1.

TABLE 1: Irrigation Proposals Submitted to the Panel

		INVESTIGATION PROPOSALS		DESIGN PROPOSALS	
PANEL MEETING	Month and Year	NUMBER PRESENTED	NUMBER APPROVED	NUMBER PRESENTED	NUMBER APPROVED
THIRD	6/1989	5	3	3	2
FOURTH	12/1989	13	13	7	4
FIFTH	6/1990	4	3	4	4
SIXTH	11/1990	14	13	7	6
SEVENTH	6/1991	12	12	1	0
EIGHTH	11/1991	7	7	3	3
NINTH	9/1990	6	6	3	3
TOTAL		61	57	28	22

Table 2: Shows the list of the projects presented to the

panel and corresponding dates of approval. From the list of the projects presented to the panel, out of the 61 investigation proposals presented only 6 had been designed and approved by the panel by the 9th panel meeting. Four of the six projects took one year from the allocation of funds for investigations to approval of the design. One took six months and one took two years. The proportion (10%) of investigations proposals reaching the design approval stage was low given that funds for investigation are allocated after assurance that capacity to carry out investigations is available. This enhances the conclusion reached by the planning workshop that lack of viable irrigation design proposals is the main cause of low rate of irrigation development in Kenya (MoA, 1990). All the design proposals presented and approved had corrections to be made as determined from the comments of the panel members. The areas of the designs that were not well done as indicated in the panel comments shown below:-

- The slope of the scheme area not well understood (area of maximum slope);
- The layout of the scheme not well done;
- No alternative layout considered;
- Farmers taking water directly from the main canal (group feeders and farm feeders should be used);

- The number of division boxes and culverts high;

Table 2: List of Projects Presented to the Panel

Scheme	Detailed Investigation Proposal presentation	Design Proposal Presentation	Panel Approval of the Design
Punda Milia	29/6/89	28/6/90	28/6/90
Nyamininia	"		
Mahawa	"		
Usia Masamba	"		
Owila Wanda	"	5/12/89	5/12/89
Masalani	-	29/6/88	
Kopundo	-	"	29/6/89
Anyiko Phase II	-	"	"
I Tito-Ikinda	5/12/89		
Subego	"	11/90	11/90
Kamoko	"		
Mtakuja	"		
Ngare ndare	"		
Muthuari	"	11/91	11/91
Kiorimba	"	11/91	11/91
Chakama	"		
Muhaka	"		
Adhola	"		
Kamusinde	"		
Gathigi	"	29/6/90	28/6/90
Barwesa	"	5/12/89	5/12/89
Munyu Gathanji	-	5/12/89	5/12/89
Ruricho	-	"	28/6/90
Abwao	-	"	-
Nyatini	-	"	5/12/89
Odhong	-	"	5/12/89
Kiamiciri	28/6/90		
Muthuthini	"		
Alungo B	"	6/91	
Kiboi	"	11/91	11/91
Kandakame	-	28/6/90	28/6/90
Kasokoni	11/90	9/92	9/92
Laza Minor	"	9/92	9/92
Ena	"		
BL1	"		
Kabaa	"		
Gambela	"		

- Date unknown

Table 2: Cont'd

Scheme	Detailed Investigation	Design	Panel Approval
Kambi Sheikh	11/90		
Kangoncho		11/90	11/90
Kamoko		"	"
Mbala Mbala		"	"
Njukini		"	"
Ruungu		"	-
Kwakyai		"	-
Kyee Kolo	11/90		
Mangelete	"		
Mbanya	"		
Mwiria	"		
Kudho	"		
Obino	"		
Loiminang	"		
Kitheo	6/91		
Kayatta	"		
Mashambani	"		
Mutunyi	"		
Tana River	"		
Inamakithi	"		
Burangi	"		
Kii	"		
Kauti	"		
Gikui Mweru	"		
Kiguru	"		
Kithithina	"		
Kiboko	"		
Rhamu Dimu	"		
Kimucu	"		
Thome	"		
Kii Murinduko	"		
Kunati	"		
Kyuu	"		
Umoja Nanighi	9/92		
Mongotini	"		
Semi Kano	"		
Vanga	"		
Maujengo	"		
Kimala	"		
Sabaki	-	9/92	9/92

- Date unkwown

- All canals are in fill;
- Canal dimensions and structures missing;
- No profiles for the canals given;
- The water levels are not collect (showing water flowing uphill);
- The ground, bed and water levels not shown on the profile;
- On the profile no drop structures shown;
- No detailed design of the structures;
- Impractical design of the division boxes;
- Drawing not well done; and
- Poor quality maps leading to confusion.

4.1.2 Response From Designers

4.1.2.1 Preparation of Maps

Table 7.2 in the annex shows the results of the survey questions. The main grids used are 20x20 m and 25x25 m. Of the two 20x20 m is used most. Table 3 below shows the information for 20x20 m grid. The average output per survey team is 3.6 hectares per day. The rate of surveying is affected by topography of the area and presence of bushes. Hence the variation in the rate of surveying. The main office work is the interpolation and plotting of the map. A contour interval of 1 m is commonly used. The average time taken by the office work is 1.6 hours per hectare. This is one area that can be used to reduce the time taken during investigations by the use of the computer for the office work.

Table 3: Survey Data Results Analysis from the Questionnaire

	OUTPUT (ha/day	GRID (m x m)	TIME TAKEN FOR REDUCTION OF DATA (hours/ha)	TIME TAKEN IN PLOTTING AND INTERPOLATION (hours/ha)
	4	20x20	0.5	1.0
	2	20x20	1.0	3.0
	6	20x20	1.0	1.5
	3	20x20	0.5	1.0
	3	20x20	4.0	3.0
	3	20x20	0.5	1.0
	4	20x20	0.5	1.0
MEAN	3.6		1.0	1.6

4.1.2.2 River Flow Data Availability

Table 4 shows the response of irrigation engineers on river flow data. 12 out of 17 respondents (70%) felt that river flow data is not available for many rivers. 8 out of 17 respondents (47%) felt that the data available is not continuous. The river flow data is used to estimate dependable low flows on which to base the estimate of area to be irrigated and flood flows on which to base the design of protective structures at the intake. The implication of wrong estimates of these values due to lack of data is that the project may be over-designed or under designed which results to high cost or failure of crops due to low flows.

Table 4: Availability of River Flow Data

Responce	Frequency
Data not available for many rivers	12
Data available in district office	2
Data available in Ministry of Water headquarters offices	5
Data available not continuous	8
Process of data collection lengthy	1

4.1.2.3 Availability of Climatic Data

Detailed climatic data for calculation of reference crop water requirement (ET_o) is not available for many scheme areas. The data available may not be continuous (See Table 5). This results to the designers using average values given in design manuals (See Table 8). These average values are for a broad area and may not accurately represent the actual values for the scheme.

Table 5: Availability of Climatic Data

Response	Frequency
Climatic data not available	8
Climatic data readily available	5
Pan evaporation data available	2
Data available not continuous	7

88% of the respondents felt that cropping calendar is not prepared or decided upon during process (see table 6). this means that an average value of crop coefficient is used for calculation of crop water requirement as seen in table 7. Crop water requirement vary over the growing season and the peak water requirement is used during the design process, however in many cases this is not used, an average value given in manuals is used (see table 8).

Table 6: Preparation of Cropping Calendar

Response	Frequency
Not done at all	6
Sometimes is done	9
Done for all schemes	2
Total	17

Table 7: Determination Crop Coefficient

Response	Frequency
Calculated from cropping patern	1
Use average value from manuals	16
Total	17

Table 8: Calculation of Crop Water Requirement

Response	Frequency
Calculated from climatic data and cropping pattern	4
Use pre-determined values from manuals	13
Total	17

Rainfall data is available for many scheme areas (See Table 9). For areas without rainfall records, figures from similar ecological zones are used.

Table 9: Availability of Rainfall Data

Response	Frequency
Data not available	0
Data Readily available	2
Data Available for some stations	13
The data is not continuous	2

4.1.2.4 Other Design Activities

The following are other design activities for small scale irrigation projects.

a) Establishing maximum irrigation interval;

b) Establishing the number of possible groups;

c) Canal layout;

d) Drainage system layout;

e) Design of the field irrigation system;

f) Generating canal ground profile;

g) Determination of dimensions of the canals;

h) Locating the canal longitudinal profile and drop structures on the ground profile;

i) Determination of the dimensions of the structures;

j) Determination of the bill of quantities; and

k) Economic analysis.

Table 7.3 in the annex shows the results of the ranking of the above design activities according to the time taken, in a descending order. Each activity is represented by the corresponding letters as shown above. Table 10, below shows the results of the analysis of the ranking done by the engineers. It shows the score for each of the activity (shown on top of the row and represented by the letters as shown above) for each rank. The last row shows the total score for each design activity.

Table 10: Design Activities Ranking Analysis

Rank	Score	Score for Design Activity										
		a	b	c	d	e	f	g	h	i	j	k
1	11	0	0	44	0	11	22	22	11	33	22	22
2	10	0	0	10	10	0	40	10	20	40	10	30
3	9	0	27	36	18	0	9	9	36	9	18	0
4	8	0	0	8	16	8	16	0	32	24	24	8
5	7	7	21	14	7	14	0	21	7	0	21	7
6	6	12	0	18	12	0	18	12	0	18	0	6
7	5	5	5	0	5	20	5	5	5	0	5	25
8	4	8	4	0	4	4	8	12	0	4	16	4
9	3	15	0	3	6	9	3	3	3	0	3	3
10	2	0	12	0	6	0	0	2	6	2	0	2
11	1	4	3	1	1	3	1	2	0	0	0	0
	Total	51	72	134	85	69	122	98	120	130	119	107

The resulting ranking order, starting with design activity which takes most time during design, relative to others is as shown below has been extracted from Table 10, according to the scores.

1) Canal layout (c);
2) Determination of the dimensions of the structures(i);
3) Generating canal ground profile (f);
4) Drawing the canal longitudinal profile (h);
5) Determination of the bill of quantities(j);
6) Economic analysis of the project (k);
7) Determination of dimensions of the canals(g);
8) Drainage system layout(d);
9) Establishing the possible number of groups(b);
10) Design of the field irrigation system (e); and
11) Establishing maximum irrigation interval (a).

From the ranking order, it shows that the design activities that take most of the time of the designer corresponds to the areas of the design identified by the panel members as problem areas. The comments of the engineers for each activity are shown in Annex 4.

Most of the engineers felt time was a major constraint for most of the activities. Most of the activities either involves trying various alternatives or the iterations to find the various parameters are repetitive. The engineers after making few trails, gives up on trying further. These results in unfinished designs or poorly calculated dimensions. Another constraint mentioned is that there is no clear design criteria and some design activities require rule of thumb. Lack of experience was also mentioned as another constraint.

4.2 EVALUATION OF MIDAS

Table 11 shows the various design activities and an indication of the activities undertaken by MIDAS and those undertaken by other packages. It also shows the design activities where no package was identified to accomplish. MIDAS does not handle the following major surface irrigation design activities -:

- analysis of hydrological information to establish the design low flows and flood flows;
- frequency analysis of rainfall data to determine probable rainfall for determination of effective rainfall;
- determination of irrigation water requirements; and
- field irrigation systems.

For these design activities it means the designer will have to go out of MIDAS to do them using other packages or do them without using the computer.

Table 11: Design Activities and Packages for them

Design Activity	Undertaken by MIDAS	Other Programs
1 Production of topographical Map	.	
(i) Reduction of survey data	Done by DGM in MIDAS	
(ii) Interpolation and Drawing the map		
2 Hydrological analysis		
(i) Prediction of flows		Hyrrom
(ii) Frequency analysis of flows		HYFAP
(iii) Probable rainfall determination		PARADIGM
3 Determination of water requirement		
(i) estimating ET_o and ET_c	-	CROPWAT, CRIWAR, ETREF, IRSIS, CWRTABLE
(ii) determination of effective rainfall.	-	CROPWAT
4 Scheme layout.	Done through MIDAS	-
5 Design of field irrigation systems		
(i) Basins	-	BASCAD
(ii) Border strip	-	BICAD
(iii) furrows	-	NONE
6. Channel design		
(i) determination of dimensions	Done through MIDAS	PROFILE, CID, DORC, CANDES
(ii) Production of profiles	Done through MIDAS	CID, CANDES
7. Structures' design	DoneThrough MIDAS	WEIRDES
8. Determination of bill of quantities		NONE
9. Economic analysis of the project		NONE

Table 12 shows the time taken for the various design activities both by use of MIDAS and when not using thecomputer. It is only the design activities carried out by MIDAS that were compared. Some steps have a number of sub-activities lumped together. It was not possible to separate them as MIDAS handles them simultaneously. Production of structures' inventory was not included as it is instantaneously done using MIDAS. Design of the drainage system was also not included as MIDAS only allow comparison of run off and drain capacity but doesn't assist in design of drainage system.

Except for design of structures, MIDAS design takes shorter time than design without using the computer. For structures' design if during the design of canal, the water levels are well adjusted to provide enough head at the structures point, MIDAS design would have been faster. The quick process in these design activities, allow many trials to be made of the design activity and by so doing high quality (accurate) design is possible by the use of MIDAS. The detailed evaluation of each design activity is as discussed below.

Table 12: Time Taken on the Design Activities

Design Activity	Time Taken	
	MIDAS Design Process (hours)	Normal Design Process (hours)
1. Determination of scheme layout	20	24
2. Preparation for determination of canal ground profiles and production of the profiles	5	18
3. Canal design and location of drop structures and canal profiles on the ground profiles	15	54
4. Design of structures	3	1

4.2.1 Scheme Layout

The normal layout process (without using MIDAS) took a longer period than use of MIDAS. However, much time had been spent thinking of the layout before the use of MIDAS so that if one started with MIDAS it would have taken more time than the time shown.

The use of MIDAS allowed better positioning of canals by the use of slope arrows and quick generation of ground profiles (See Figure 2). Through the use of AUTOCAD commands for editing the design, high quality work (neatness) was possible. The quick determination of the lengths of canals and drains makes it possible for different possible alternative layouts to be produced and compared. This would solve the problems of scheme laying out noted in section 4.1.1, the slope of the scheme area not well understood, no alternative layouts considered, canals in fill, the farmers taking water directly from the main canal and the layout not well done.

The resulting layouts are shown in figures 7.1 to 7.3 in the annex. Layout 2 was chosen. Figure 3 and Figure 4 shows resulting group layout and canal and drain layout with slope arrows.

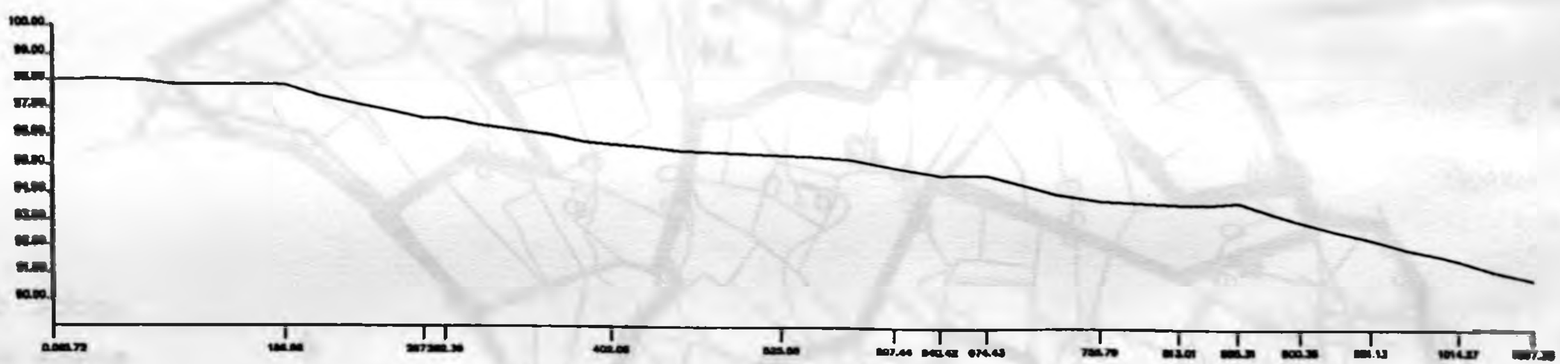


Figure 2 - Ground Profile of Proposed Canal

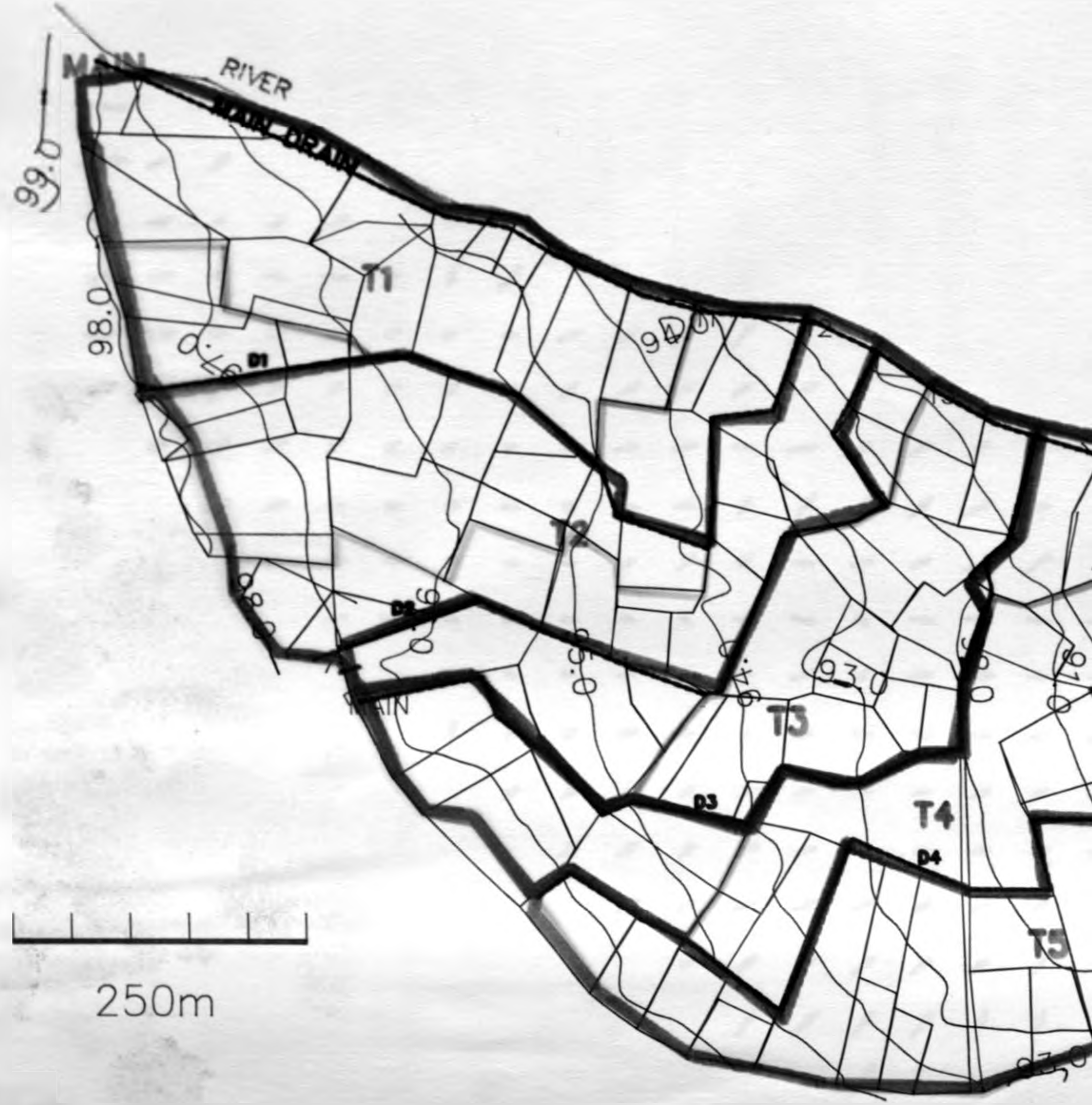


Figure 3 — Irrigation Group Areas

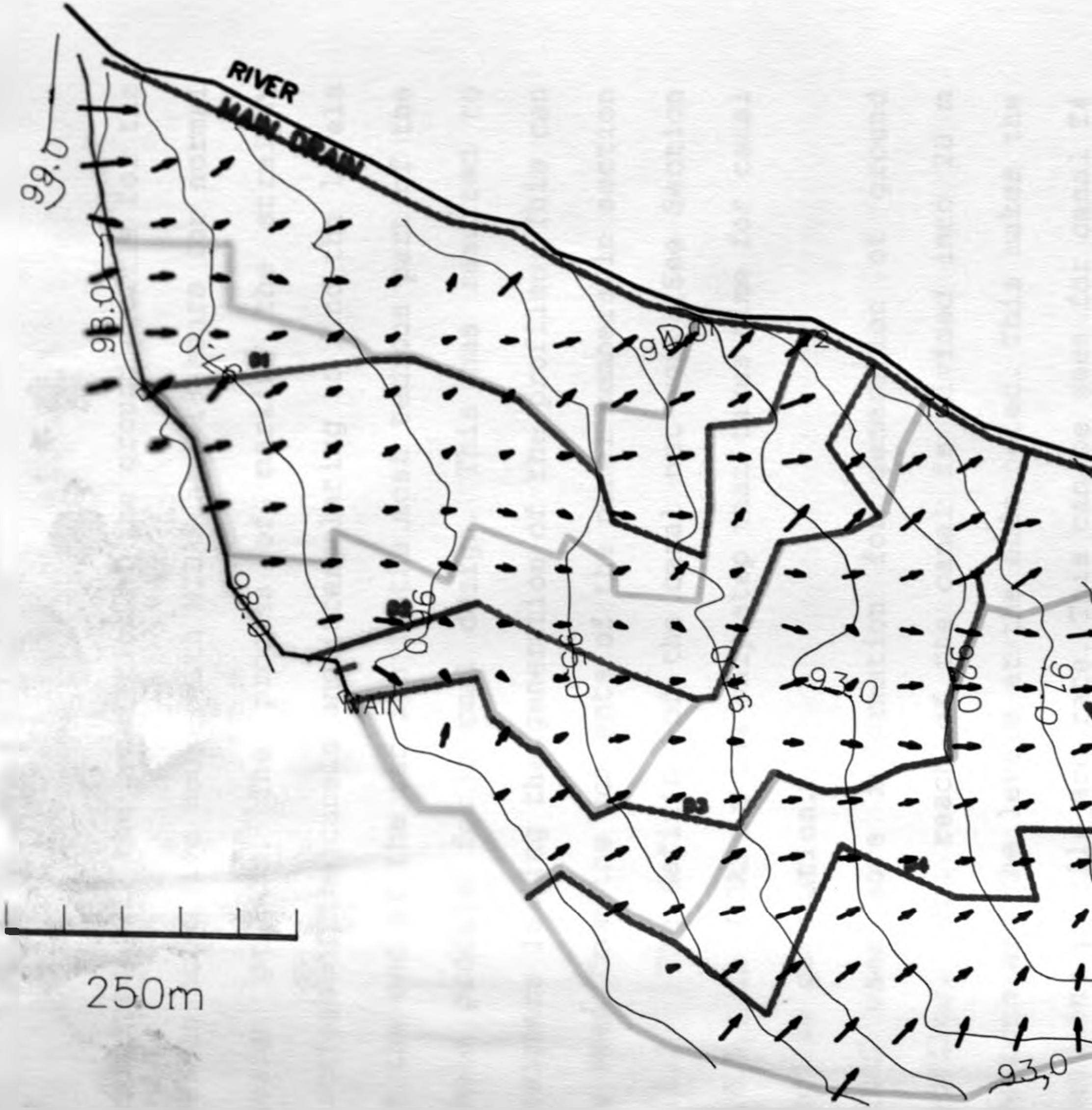


Figure 4 — Canal And Drain Layou

4.2.2 Canal Profiles

From Table 12, the generation of the ground profile for the canals took five hours with MIDAS and 18 hours for normal design process. The process of marking the straight sections of the canals and interpolating to find the levels at the end of the section is the most tedious part of the whole process for normal design. This has resulted to designers leaving the generation of the profiles. This can be seen from the comments of the panel members in section 4.1.1. The defining of the canal net work (See Section 2.4.5.) in MIDAS is the only step that takes time for canal profile generation.

MIDAS uses more information for generation of ground profiles. Each reach of the canal is divided into 20 m sections and the levels at the ends noted. This makes the resulting profile accurate. This can be seen for canal T4 Figure 7.8 and Figure 7.14. The canal generated normally shows a gradual fall for the first 300 m while for the canal generated by use of MIDAS shows a rise, especially at chainage 220 m. The length of the canal generated without use of MIDAS is 1020 m long while that generated by MIDAS is 1034 m.

Once the canal network has been defined the generation of the ground profile is fast and produces similar profiles.

For normal design to get another profile of the same canal, it will mean repeating the whole process of canal ground profile generation.

4.2.3 Canal Design

The canal design process and incorporation of the design and drop structures on the canal ground profile took 15 hours for MIDAS design and 54 hours for normal design process. In normal design process, the determination of the dimensions for the canal takes time as it involves trial and error method (Newton Raphson Iteration) to determine the right value of bed width and normal depth. Drawing the profile for the designed canal also takes more time as noted in Section 4.1.2 by the engineers. This step of the design is often poorly done as shown in Section 4.1.1.
The MIDAS process of this step is fast. The editing tools in MIDAS assists in adjusting the water levels in the canal by adding, removing, changing or moving drop structures. Check structures can also be added. This means the right command can be achieved and improve the design of structures due to increased head available. It also increases the design accuracy of the canals. This can be seen for canal T^1 where it has three reaches of 0.008, 0.003 and 0.009 bed slope for normal design and 0.003 and 0.008

for MIDAS design (See Figure 7.5 and figure 7.11 in the annex).

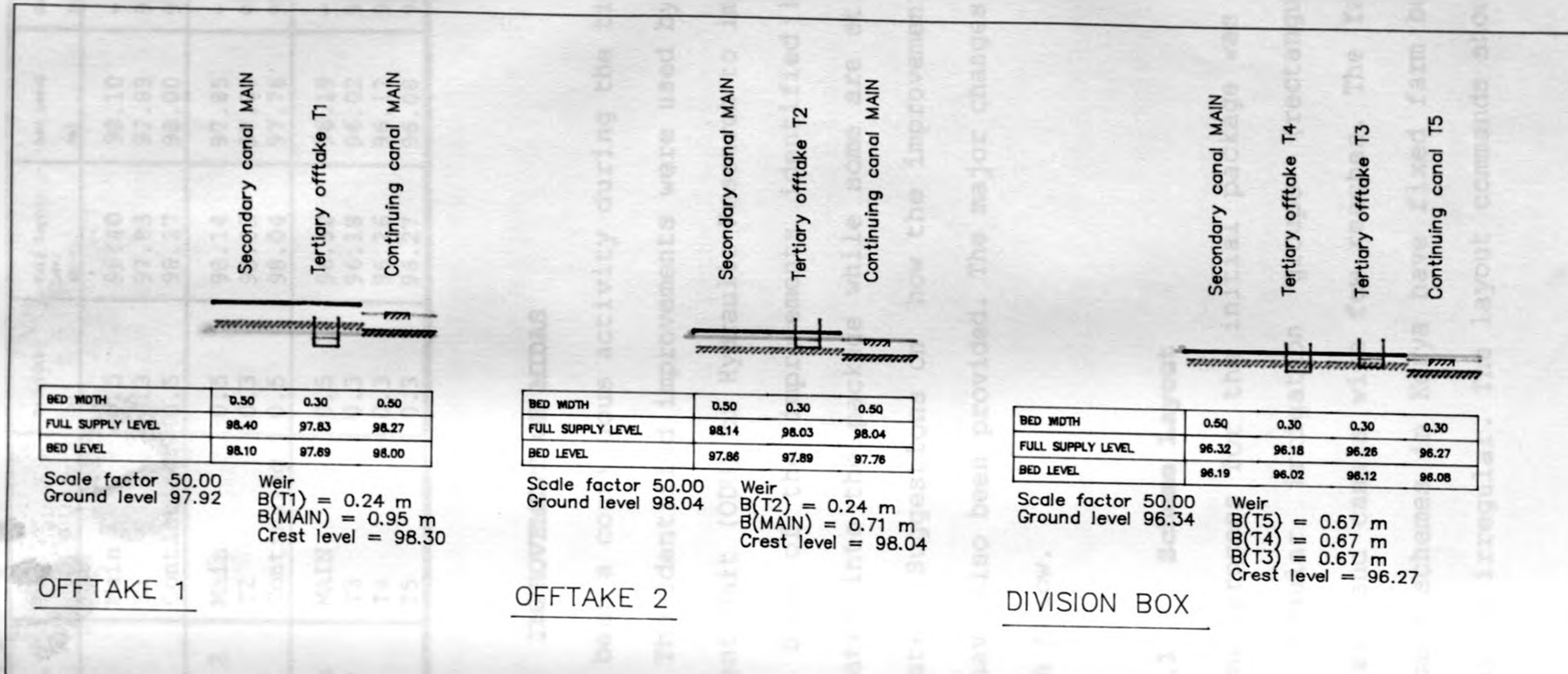
The complete canal design for MIDAS process is shown in Figure 7.4 to Figure 7.9 while for normal design is shown in Figure 7.10 to figure 7.15 in the annex.

4.2.4 Design of Structure

The results of structures design using MIDAS are shown in Figure 5 while the dimensions and water levels resulting from normal design are shown in Table 13.

The design using MIDAS took more time than the normal design process. this is attributed to more time being taken up by redesigning the canal to get the right head to allow the crest length to be within the cross-section of the canal.

Comparing the available headloss and the resulting crest length of the outlet weir, a discharge coefficient of 1.60 is used for the discharge equation. This coefficient is for rectangular weir (MoA, 1989). A rounded weir is commonly used in Kenya with a coefficient of 1.75. The assumption is that the rectangular weir will wear off to rounded weir finally.



OFFTAKE 1

	Secondary canal MAIN	Tertiary offtake T1	Continuing canal MAIN
BED WIDTH	0.50	0.30	0.50
FULL SUPPLY LEVEL	98.40	97.83	98.27
BED LEVEL	98.10	97.69	98.00

OFFTAKE 2

	Secondary canal MAIN	Tertiary offtake T2	Continuing canal MAIN
BED WIDTH	0.50	0.30	0.50
FULL SUPPLY LEVEL	98.14	98.03	98.04
BED LEVEL	97.86	97.89	97.76

DIVISION BOX

	Secondary canal MAIN	Tertiary offtake T4	Tertiary offtake T3	Continuing canal T5
BED WIDTH	0.50	0.30	0.30	0.30
FULL SUPPLY LEVEL	96.32	96.18	96.26	96.27
BED LEVEL	96.19	96.02	96.12	96.08

Figure 5 : Structure's Design

Table 13: Canal Structures for Normal Design

Structure	Canal	Bedwidth (m)	Full Supply Lev. (m)	Bed level (m)	Crest level (m)	Weir Length (m)
Offtake 1	Main T1 Continuing	0.5 0.3 0.5	98.40 97.83 98.27	98.10 97.89 98.00	- 98.30 98.30	- 0.24 0.95
Offtake 2	Main T2 Continuing	0.5 0.3 0.5	98.14 98.03 98.04	97.85 97.89 97.76	- 98.04 98.04	- 0.24 0.71
Division Box	MAIN T3 T4 T5	0.5 0.3 0.3 0.3	96.32 96.18 96.26 96.27	96.19 96.02 96.12 96.08	- 96.27 96.27 96.27	- 0.67 0.67 0.67

4.3 IMPROVEMENT OF MIDAS

This has been a continuous activity during the time of the project. The identified improvements were used by Overseas Development Unit (ODU) of Hydraulic Research to improve the package. Some of the improvements identified have been incorporated into the package while some are still being incorporated. Suggestions on how the improvements are to be made have also been provided. The major changes required are shown below.

4.3.1 Scheme Layout

The layout process for the initial package was meant to produce regular irrigation groups (rectangular and triangular) and canals with few reaches. The farmers in small scale schemes in Kenya have fixed farm boundaries which may be irregular. The layout commands should be in such a way as to allow irregular groups with group boundaries following the farm boundaries. The canals should also follow the farm boundaries. The commands should allow working with many canal reaches especially for the main canal.

Schemes in Kenya are managed and operated by the farmers themselves. This calls for a group size that will allow easy group communication and organisation. A group size of 10 to 30 farmers is recommended (MoA, 1987). A check on group size is required.

4.3.2 Calculation of Water Requirements

The field irrigation system used in the initial package was furrow irrigation. the water supply method used was mainly rotation to the groups. In kenya basin and furrow irrigation are used. The farmers are left to decide on the sizes of the basins and furrow with assistance from the field irrigation staff. The program needed to be changed to accommodate these requirements. continuous flow to the group and rotation flow within the group is practised in small Scale Irrigation Schemes.

The program calculates the flow to the group assuming that the whole area is to be irrigated. For small schemes in Kenya, farmers irrigate a portion of their holding. The area to base the calculation of the flow should be the irrigated area per farmer multiplied by the number of farmers in the group. The set up of the program assumes seven days irrigation per week. Most of the farmers do not work on Sundays. The number of irrigation days per week should be left open. This will mean the group flow (unit flow) will be different from the one for seven days.

4.3.3 Canal and Structures Design

During the evaluation process, during canal design, it was hard to remember inputs previously used for canal design. This becomes a bigger problem when a different person is editing the design or writing the design report. A file to hold the inputs (bedslope, bedwidth, side slope, the flow, freeboard, drop height and Mannings K_m) should be created during the design. It should be possible to update the file during editing.

During the design of structures, equation 5 and orifice discharge formula shown below are used.

$$Q = CA\,(2gh)^{0.5} \qquad [6]$$

Where Q = Discharge through the orifice (m^3/sec), A = Cross sectional area of orifice opening (m^2), C = Discharge coefficient, and H = Head over the orifice (M).

For submerged flow, C is 0.6 for rectangular orifice and 0.65 for free flow rectangular orifice (MoA 1989). In MIDAS submerged flow is assumed which may not be the case all the time. The program should be changed to allow for different shapes of orifice and for both submerged and free flow conditions.

4.3.4 Inventory of Structures

The following weaknesses were identified during the evaluation of MIDAS

- For orifice type of offtake, crest level and area of the orifice were not shown;
- The orifice option was not working at all for the division box; and
- For miscellaneous structures on the canal, it does not give the names. It terms them as unknown structures yet when inserting them one specifies whether a flume or culvert.

4.3.5 Calculation of Cut and Fill for Canals

In MIDAS, during the canal design, cut and fill are calculated for each reach of canal. The cumulative cut/fill is also calculated. The figures given for each reach do not represent the actual cut or fill but is the net. In small scale irrigation projects what is important is how much digging (cut) will be required and how much soil will be imported. The program should be changed to give the volume of cut and the volume of imported soil for the fill. The detail procedures on how these quantities could be calculated are shown in Annex 5.

4.3.6 Survey and Input of Existing Features' Data

The land surveying programs used in Digital Ground Model (DGM), which forms a part of MIDAS can only be used to input and process Radial and tacheometric survey data. In Kenya many survey teams use engineers level and plane table for surveying. From Section 4.1.2.1 it was established from engineers that the average time for reduction and plotting of maps takes 2.6 hours per hectare. So for a large scheme the time taken in the office on preparation of maps is much. Programs that will allow input and processing of survey data done with the engineers level and plane table would reduce the time taken in preparation of maps. Details on how to do the field survey and the methods to calculate the data are shown in Annex 6.

The Digital Ground Model does not have the capacity to sort out the survey data to produce separate XYZ files for the existing details. A separate program could be prepared to sort out the information. During the surveying these details should be identified and identification recorded. The data should be put in a spread sheet and sorted out using the sort facilities in these programs according to identification. separate XYZ files should be prepared and copied to DGM. The DGM will be used to prepare DXF files (Files used by AUTOCAD to transfer information from DGM). These will be imported to AUTOCAD for the preparation of the details on the map. The detailed procedure is shown in Annex 5.

4.4 Adoption of Computer Aided Design Technology

This is a new technology being introduced to the irrigation designers.The major constraints are on training of the staff and supply of the equipment and their servicing.

Only the head office has been provided with the necessary hardware for the computer aided design work. It is hoped that the provincial offices will be provided with the equipment the main hardware require for a smooth running design office are :-

- computer;
- Digitizer (tablet); and
- Plotter.

The main software required are :-

- Autocad
- Digital Ground Model or G.I.S
- Minor Design Aid Software; and
- Other support software such as spread sheets.

The initial training of the users of the software was done by the ministry of Agriculture in conjunction with Overseas Development Unit of Hydraulic research. The main areas that require training are general software operation, Autocad,Digital Ground Model, Digitization of the data into the computer and minor design Aid software.The main constraint is the continuing of the training for the users of the software.

5.CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

The shortcomins in the IDB irrigation projects' designs were identified as:

1. There are delays in completion of design documents;
2. Evaluation of design documents revealed that some of the designs that are prepared are normally not complete and the calculations not thoroughly done due to repetative steps;
3. The operational requirements for the schemes are often not properly met e.g low command area due to low water level, farmers taking water directly from main canals, the layout not the best option and too many farmers per group;
4. For many schemes design data on river flow and climatic information is usually not available. This results to use of average values and as a result the scheme is under-designed or over-designed;and
5. There is no clear design procedure for the various irrigation methods as used in smallholder irrigation such as small basins and short furrows irrigation.

Computer aided design through Minor Irrigation Design Aid Software was found to have the following :

1. It handles design steps that takes most time due to repetitive procedures such as canal design, generation of ground profile and plotting of the map and is faster than normal design process; and
2. Accurate and neat output is possible from MIDAS as compared to normal design.

However it was found to have the following weakness:

1 It does not assist in processing of river flow data, rainfall data and climatic data;
2 It does not assist in calculation of crop water requirements; and
3 It does not assist in the design of field application method such as basins and furrows.It does not incorporate structural design.

5.2 RECOMMEDATIONS

1 The survey data input method in MIDAS should be expanded to include surveys done with plane table and engineers level. Method of input of information on existing features such as farm boundaries, rivers, canals and homesteads should also be devised.
2 A way of linking MIDAS with other packages to be used on design activities not handled by MIDAS is required. These packages could be CROPWAT, BASCAD SIRMOD and any package for analysis of hydrological and climatic data.
3 The surveyors should be taught how to carry out field survey in a way that meets the data requirements of MIDAS.

4 A study on small basins and furrows as used in small scale irrigation in Kenya is required to establish their suitability and suggest design consideration.

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ANNEX 1 - DETERMINATION OF WATER REQUIREMENT

A - CLIMATE

Table 1.1: Shows climatic data for Isiolo Meteorogical Station (No. 8937/003) which is 17 km. west of the project area. Rainfall record (Daily) was available for the same station for 17 years (See Table 1.2). The climatic data was analysed using CROPWAT package, according to the FAO adapted Penman-Monteith approach (Smith, 1992)

The yearly evapotranspiration of the area is 2678 mm with the highest evapotranspiration being 8.6 mm/day in August. The area receives rainfall with 80% reliability of 340 mm occurring in two seasons. The long rainy season from March to May and short rainy season from October to December.

B - PEAK NET IRRIGATION WATER REQUIREMENTS

The crop water requirement (ET_c) is given by

$$ET_c = K_c ET_o$$

Where

ET_c = Crop Water Requirement (mm/day)

ET_o = Reference crop water requirement (mm/day)

K_c = Crop Coefficient

The crops to be grown in the scheme are maize, beans, tomatoes and onions. Table 1.4 shows crop coefficient and length of each growth stage for these crops.
The effective rainfall shown in Table 1.3 was calculated using CROPWAT package. In this package four methods of

determining effective rainfall are used. These are :-

- Fixed percentage of rainfall;
- Dependable Rain (emperical form);
- Emperical formular (locally dev.); and
- USDA Soil Conservation service method.

Dependable Rain method was used. It combines both determination of 80% reliability and detemination of effective rainfall. The input is the average monthly rainfall. Acording to Smith (1992), it is based on analysis carried out for different arid and Sub - humid climates.The test scheme, Gambela is in arid climate.

The annual effective rainfall of the scheme area is 348 mm. According to Ground Water Survey Ltd (1992) the ground water in many parts of the scheme is below one meter. The contribution of ground water for the crop water requirement was neglected. Table 1.5 - Table 7.1.12 shows the crop water requirement as calculated using CROPWAT. The peak net irrigation requirement varies for various crops and an average value of 8.00 mm/day was taken for design.

Table 1.1: Reference Evapotranspiration (ET_o) according to Penman-Monteith method

Country: Kenya Meteorological Station: Isiolo (8937/003)

Altitude:3621M Coordinates: 0.35 N.L 37.35 E.L

Month	Max. Temp C	Min. Temp C	Humidity %	Wind run Km/day	Sunshine Hours	Sol.Rad. MJ/day	ET_o-Penman mm/day
January	30.8	15.7	48	334	12.1	27.1	7
February	32.4	16.3	45	334	12.1	28.1	7.6
March	31.7	17.6	50	401	12.1	28.6	7.8
April	30.1	17.8	57	401	12.1	27.7	7.1
May	29.9	17.8	56	534	12.1	26.3	7.3
June	29.5	16.9	53	623	12.1	25.3	7.6
July	28.9	16.3	54	668	12.1	25.7	7.6
August	29.4	16.5	52	445	12.1	27	7.2
September	30.8	16.9	49	623	12.1	28.1	8.6
October	30.9	17.6	51	445	12.1	28.1	7.8
November	28.6	16.6	60	289	12.1	27.3	6.3
December	29	15.5	59	289	12.1	26.7	6.2
Year	30.2	16.8	16.8	449	12.1	27.2	2678

Table 1.2 - Rainfall data for [illegible]

year\mo	january	february	march	april	may	june
1974	41.9	47.6	54.0	125.4	31.3	0.0
1975	27.7	0.0	39.9	147.8	24.4	0.0
1976	44.4	104.5	33.6	102.1	16.0	22.7
1977	104.9	0.0	88.2	193.4	31.0	0.0
1978	45.2	45.4	170.8	177.4	0.0	0.0
1979	140.5	54.9	82.2	141.2	7.5	2.3
1980	0.0	20.0	46.8	125.5	62.1	0.0
1981	22.5	7.9	101.4	66.2	98.8	0.0
1983	28.0	37.1	24.2	195.1	13.4	0.0
1984	3.3	12.2	38.0	81.0	0.0	0.0
1985	47.2	12.5	109.4	146.0	8.9	17.8
1986	1.2	12.9	114.7	180.7	15.8	16.8
1987	18.6	5.8	76.2	204.1	3.3	59.2
1988	28.3	18.8	117.4	123.1	15.3	9.6
1989	33.4	46.8	99.8	118.8	33.2	0.0
1990	47.8	110.4	252.7	161.3	23.7	0.0
1991	72.6	8.0	112.8	54.9	21.0	0.0
AVERAGE	41.6	32.0	91.9	137.9	23.9	7.6

...olo Met. station(8937/003).

...uly	august	sept.	october	nov.	dec.	TOTAL
2.5	0.0	0.0	52.4	108.7	57.2	521.0
12.5	0.0	19.3	34.2	137.5	35.5	478.8
0.0	1.3	0.0	12.0	123.0	173.8	633.4
0.0	0.0	21.4	114.2	97.4	45.2	695.7
0.0	0.0	16.0	124.6	144.6	197.1	921.1
0.0	0.0	0.0	22.4	201.8	64.8	717.6
0.0	0.0	0.0	28.8	208.3	54.2	545.7
0.0	0.0	4.5	34.0	86.2	38.9	460.4
0.0	42.8	3.9	16.6	96.4	122.2	579.7
0.0	0.0	12.8	70.7	290.0	27.2	[illegible]
0.0	0.0	5.6	35.6	151.6	46.4	581.0
0.0	0.0	0.0	89.7	185.0	76.1	[illegible]
0.0	0.0	46.9	28.0	138.7	67.6	618.4
11.5	1.6	13.5	46.4	165.6	154.4	705.5
4.5	0.0	19.8	158.4	243.6	138.2	896.5
0.0	0.0	0.0	236.7	180.0	164.6	1177.2
3.5	0.0	0.0	82.3	151.4	159.3	665.8
2.0	2.7	9.6	69.8	159.4	95.5	673.9

TABLE 1.3: Effective Rainfall according to Empirical Formula (AGLW/FAO)

	ET_o	Average Rainfall mm/month	Eff.Rain mm/month
January	7.0	41.6	15.0
February	7.6	32.0	9.2
March	7.8	91.9	48.5
April	7.1	137.9	85.3
May	7.3	23.9	4.3
June	7.6	7.6	0.0
July	7.6	2.0	0.0
August	7.2	2.7	0.0
September	8.6	9.6	0.0
October	7.8	69.8	31.9
November	6.3	159.4	102.5
December	6.2	95.5	51.4
Year	267 7.6	673.9	348.1

Table 1.4: Crop Data

CROP	GROWTH STG.	INITIAL	DEVEL.	MID	LATE	TOTAL
Beans	Length(days) Coeff.	20 0.35	30 -	40 1.03	20 0.7	110
Maize	Length (days) Coeff.	25 0.4	40 -	45 1.13	30 0.88	140
Onions	Length(days) Coeff.	30 0.7	40 -	50 0.95	30 0.75	150
Tomatoes	Length (days) coeff.	30 0.45	40 -	40 1.15	25 0.85	135

Source: Smith, 1992

Table 1.5: Crop Evapotranspiration and Irrigation Requirements

Climate Station: Isiolo (8937/003)

Crop:		Beans		Planting Date:	15 March			
Month	Decade.	Stage	Coeff Kc	ETc mm/day	ETc mm/dec	Eff. Rain mm/dec	Irreg. mm/day	Irreg. mm/dec
March	2	init	0.35	2.73	13.7	8.1	1.11	5.6
March	3	init	0.35	2.65	26.5	20.3	0.62	6.2
April	1	in/dev	0.41	2.98	29.8	27.7	0.21	2.1
April	2	dev	0.58	4.09	40.9	33.4	0.75	7.5
April	3	dev	0.80	5.76	57.6	22.8	3.48	34.8
May	1	dev/mid	0.97	7.04	70.4	9.4	6.10	61.0
May	2	mid	1.03	7.52	75.2	0.0	7.52	75.2
May	3	mid	1.03	7.62	76.2	0.0	7.62	76.2
June	1	mid	1.03	7.73	77.3	0.0	7.73	77.3
June	2	mid/late	0.99	7.51	75.1	0.0	7.51	75.1
June	3	late	0.87	6.57	65.7	0.0	6.57	65.7
July	1	late	0.70	5.32	26.6	0.0	5.32	26.6
Total					635.0	121.7		513.3

Table 1.6: Crop Evapotranspiration and Irrigation Requirements

Climate Station: Isiolo (8937/003)

Crop:		Beans		Planting Date:	15 August			
Month	decade	stage	Coeff. Kc	ETc mm/day	ETc mm/dec	Eff.Rain mm/dec	Irreg. mm/day	Irreg. mm/dec
August	2	init	0.35	2.45	12.3	0	2.45	12.3
August	3	init	0.35	2.64	26.4	0	2.64	26.4
September	1	in/dev	0.41	3.36	33.6	0	3.36	33.6
September	2	dev	0.58	5.07	50.7	0	5.07	50.7
September	3	dev	0.80	6.80	68.0	2.9	6.51	65.1
October	1	de/mid	0.97	7.85	78.5	6.4	7.21	72.1
October	2	mid	1.03	8.03	80.3	9.6	7.07	70.7
October	3	mid	1.03	7.52	75.2	17.8	5.74	57.4
November	1	mid	1.03	6.94	69.4	29.3	4.00	40.0
November	2	mid/la	0.99	6.13	61.3	239.2	2.21	22.1
November	3	tlate	0.87	5.36	53.6	31.8	2.18	21.8
December	1	late	0.7	4.36	21.8	11.9	1.98	9.9
Total					631.1	149.0		482.2

Table 1.7: Crop Evapotranspiration and Irrigation Requirements

Climate Station: Isiolo (8937/003)

Crop:	Maize			Planting date:	15th March			
Month	Decade	Stage	Coeff.	ETc mm/day	ETc mm/dec	Eff. Rain mm/dec	Irreq. mm/day	Irreq mm/dec
August	2	init	0.4	3.12	15.6	8.1	1.50	7.5
August	3	init	0.4	3.03	30.3	20.3	1.00	10.0
September	1	init	0.4	2.93	29.3	27.7	0.16	1.6
September	2	dev	0.49	3.49	34.9	33.4	0.14	1.4
September	3	dev	0.67	4.83	48.3	22.8	2.55	25.5
October	1	dev	0.86	6.19	61.9	9.4	5.25	652.5
October	2	dev	1.04	7.58	75.8	0.0	7.58	75.8
October	3	mid	1.13	8.36	83.6	0.0	8.36	83.6
November	1	mid	1.13	8.48	84.8	0.0	8.48	84.8
November	2	mid	1.13	8.59	85.9	0.0	8.59	85.9
November	3	mid	1.13	8.59	85.9	0.0	8.59	85.9
December	1	mid/late	1.11	8.43	84.3	0.0	8.43	84.3
December	2	late	1.05	7.95	79.5	0.0	7.95	79.5
December	3	late	0.96	7.19	71.9	0.0	7.19	71.9
January	1	late	0.88	6.34	31.7	0.0	6.34	31.7
Total					903.7	121.7		782.0

Table 1.8: Crop Evapotranspiration and Irrigation Requirements

Climate Station: Isiolo (8937/003)

Crop:	Maize			Planting date:	15 August			
Month	Dec	Stage	Coeff. Kc	ETc mm/day	ETc mm/dec	Eff. Rain mm/dec	Irreq mm/day	Irreq mm/dec
March	2	init	0.4	2.80	14.0	0.0	2.80	14.0
March	3	init	0.4	3.01	30.1	0.0	3.01	230.1
April	1	init	0.4	3.31	33.1	0.0	3.31	33.1
April	2	dev	0.49	4.32	343.2	0.0	4.32	43.2
April	3	dev	0.67	5.70	57.0	2.9	5.42	54.2
May	1	dev	0.86	6.91	69.1	6.4	6.27	62.7
May	2	dev	1.04	8.10	81.0	9.6	7.14	71.4
May	3	mid	1.13	8.25	82.5	17.8	6.47	64.7
June	1	mid	1.13	7.61	76.1	29.3	4.68	46.8
June	2	mid	1.13	7.01	70.1	39.2	3.09	30.9
June	3	mid	1.13	7.01	70.1	31.8	3.82	38.2
July	1	mid/late	1.11	6.91	69.1	23.8	4.53	45.3
July	2	late	1.05	6.49	64.9	16.1	4.88	48.8
July	3	late	0.96	6.23	62.3	12.4	4.99	49.9
August	1	late	0.88	5.93	29.6	4.2	5.09	25.4
Total					852.2	193.6		658.6

Table 1.9: **Crop Evapotranspiration and Irrigation Requirements**

Climate Station: **Isiolo (8937/003)**

Crop:		Onions		Planting Date:	1st May			
Month	Dec	Stage	Coeff.	ETc mm/day	ETc mm/dec	Eff. Rain mm/dec	Irreq mm/day	Irreq mm/dec
May	1	init	0.70	5.06	50.6	9.4	4.12	41.2
May	2	init	0.70	5.11	51.1	0.0	5.11	51.1
May	3	init	0.70	5.18	51.8	0.0	5.18	51.8
Jun	1	dev	0.73	5.48	54.8	0.0	5.48	54.8
Jun	2	dev	0.79	6.03	60.3	0.0	6.03	60.3
jun	3	dev	0.86	6.51	65.1	0.0	6.51	65.1
july	1	dev	0.92	6.98	69.8	0.0	6.98	69.8
July	2	mid	0.95	7.22	72.2	0.0	7.22	72.2
july	3	mid	0.95	7.09	70.9	0.0	7.09	70.9
August	1	mid	0.95	6.84	68.4	0.0	6.84	68.4
August	2	mid	0.95	6.65	66.5	0.0	6.65	66.5
August	3	mid	0.95	7.16	71.6	0.0	7.16	71.6
Sep.	1	late	0.92	7.58	75.8	0.0	7.58	75.8
sep.	2	late	0.85	7.48	74.8	0.0	7.48	74.8
Sep.	3	late	0.78	6.63	66.3	2.9	6.34	63.4
TOTAL					970.1	12.3		957.8

Table 1.10: **Crop Evapotranspiration and Irrigation Requirements**

Climate Station: **Isiolo (8937/003)**

Crop:		Onions		Planting Date:	1st October			
Month	Dec	State	Coeff. Kc	ETc mm/day	ETc mm/day	Eff. Rain mm/dec	Irreq mm/day	Irreq mm/dec
Oct	1	init	0.70	5.65	56.5	6.4	5.00	50.0
Oct	2	init	0.70	5.46	54.6	9.6	4.50	45.0
Oct	3	init	0.70	5.11	51.1	17.8	3.33	33.3
Nov	1	dev	0.73	4.92	49.2	29.3	1.99	19.9
Nov	2	dev	0.79	4.92	49.2	39.2	1.00	10.0
Nov	3	dev	0.86	5.31	53.1	31.8	2.13	21.3
Dec.	1	dev	0.92	5.73	57.3	23.8	3.35	33.5
Dec.	2	mid	0.95	5.89	58.9	16.1	4.28	42.8
Dec.	3	mid	0.95	6.14	61.4	12.4	4.90	49.0
Jan.	1	mid	0.95	6.40	64.0	8.4	5.56	55.6
Jan.	2	mid	0.95	6.65	66.5	4.0	6.25	62.5
Jan.	3	Mid	0.95	6.84	68.4	3.7	6.47	64.7
Feb.	1	late	0.92	6.78	67.8	2.7	6.51	65.1
Feb.	2	late	0.85	6.46	64.6	2.1	6.25	62.5
feb.	3	late	0.78	6.01	60.1	6.8	5.33	53.3
Total					882.7	214.1		668.5

Table 1.11: **Crop Evapotranspiration and Irrigation Requirements**

Climate Station: Isiolo (8937/003)

Crop:		Tomatoes		Planting Date:	15 October			
Month	Dec	Stage	Coeff. Kc	ETc mm/day	ETc mm/dec	Eff. Rain mm/dec	Irreq mm/day	Irreq mm/dec
October	2	init	0.45	3.51	17.5	4.8	2.55	12.7
October	3	init	0.45	3.29	32.9	17.8	1.50	15.0
November	1	init	0.45	3.03	30.3	29.3	0.10	1.0
November	2	in/dev	0.49	3.06	30.6	39.2	0.00	0.0
November	3	dev	0.63	3.88	38.8	31.8	0.69	6.9
December	1	dev	0.8	4.99	49.9	23.8	2.61	26.1
December	2	dev	0.98	6.05	60.5	16.1	4.43	44.3
December	3	dev/mid	1.11	7.15	71.5	12.4	5.91	59.1
January	1	mid	1.15	7.74	77.4	8.4	6.91	69.1
January	2	mid	1.15	8.05	80.5	4.0	7.65	76.5
January	3	mid	1.15	8.28	82.8	3.7	7.91	79.1
February	1	mid/lat	1.12	8.29	82.9	2.7	8.02	80.2
February	2	late	1.03	7.83	78.3	2.1	7.62	76.2
February	3	late	0.91	6.98	69.8	6.8	6.30	63.0
Total					803.6	202.9		609.2

Table 1.12: **Crop Evapotranspiration and Irrigation Requirements**

Climate Station: Isiolo (8937/003)

Crop:		Tomatoes		Planting Date:	15 May			
Month	Dec	Stage	Coeff. Kc	ETc mm/day	ETc mm/dec	Eff. Rain mm/dec	Irreq mm/day	Irreq mm/dec
May	2	init	0.45	3.29	16.4	0.0	3.29	16.4
May	3	init	0.45	3.33	33.3	0.0	3.33	33.3
June	1	init	0.45	3.38	33.8	0.0	3.38	33.8
June	2	in/dev	0.49	3.75	37.5	0.0	3.75	37.5
June	3	dev	0.63	4.75	47.5	0.0	4.75	47.5
July	1	dev	0.8	6.08	60.8	0.0	6.08	60.8
July	2	dev	0.98	7.41	74.1	0.0	7.41	74.1
July	3	dev/mid	1.11	8.26	82.6	0.0	8.26	82.6
Aug.	1	mid	1.15	8.28	82.8	0.0	8.28	82.8
Aug.	2	mid	1.15	8.05	80.5	0.0	8.05	80.5
Aug.	3	mid	1.15	8.66	86.6	0.0	8.66	86.6
Sept.	1	mid/lat	1.12	9.26	92.6	0.0	9.26	92.6
Sept.	2	late	1.03	9.06	90.6	0.0	9.06	90.6
Sept.	3	late	0.91	7.70	77.0	2.9	7.42	74.2
Total					896.2	2.9		893.3

C. **Estimation of Efficiencies**

Small basin irrigation system will be practicsed in the scheme. The flow in the main canal and group feeders will be in rotation. According to Bos and Nugteren (1982), intermittent basin irrigation shows a constant application efficiency of 0.58 (See Figure 1.1). The flow to the group is 12 l/sec/ha for the 0.28 ha which will be irrigated per farmer. From Figure 1.2, the estimated application efficiency is 0.66. This gives an average application efficiency of 0.62. for design purpose application efficiency of 0.6 was used. From Figure 1.3 the distribution efficiency was estimated at 0.92 for the scheme operation. The conveyance efficiency was estimated at 0.95 giving an overall efficiency of 52%.

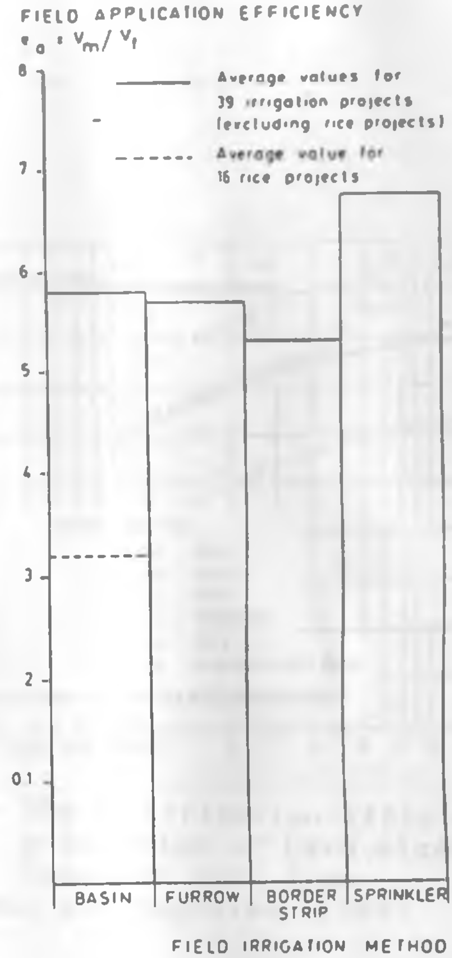


Figure 1.1: Field Application efficiency related to irrigation methods

Source : Bos and Nugteren , (1983)

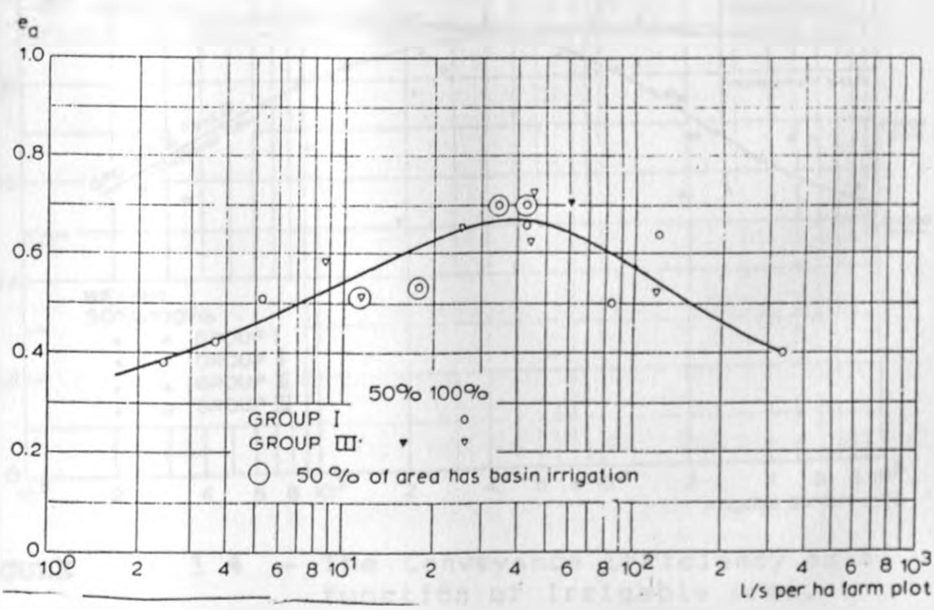


FIGURE : 1.2 Influence of Flow Rate Per ha. Farm Plot on Aplication Efficiency

Source: Bos and Nugteren , (1993)

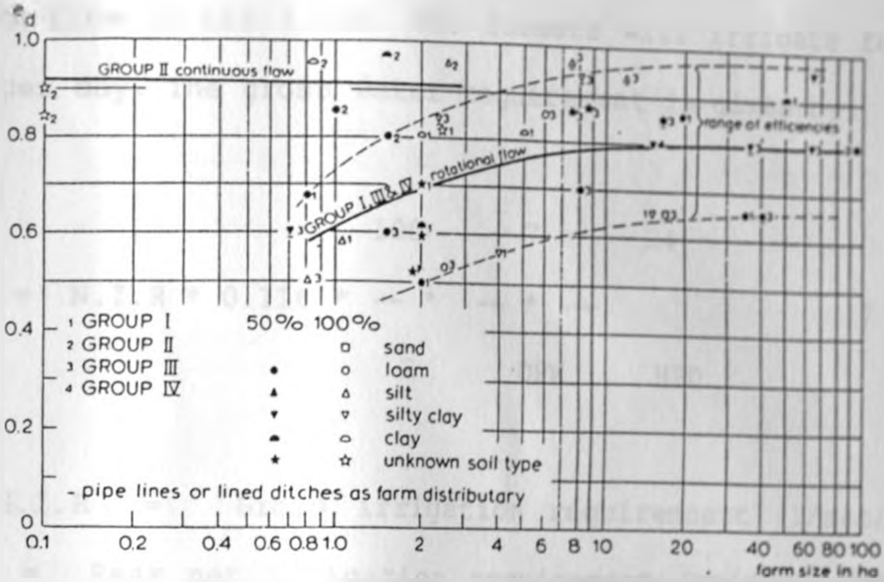


FIGURE 1.3 - The Distribution Efficiency as a function of Farm size and Dominant soil type.

Source : Bos and Nugteren.(1983)

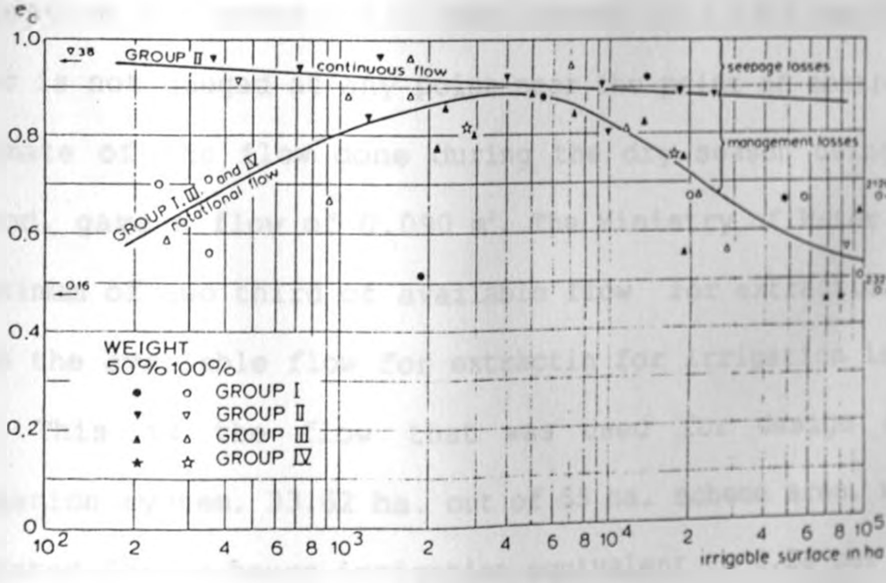


FIGURE 1.4 - The Conveyance Efficiency as a function of Irrigable area.

Source : Bos and Nugteren.(1983)

D. Gross Water Requirement

The farmers are to irrigate for seven days per week to utilise the low flow in the river. The farmers will irrigate for 24 hours per day. The gross water requirement is given by

$$G.I.R = N.I.R * 0.116 * \frac{100}{E} * \frac{7}{DPW} * \frac{24}{HPD} \qquad 7.1.1$$

Where G.I.R = Gross irrigation requiremnent (l/sec/ha), N.I.R = Peak net irrigation requirement (mm/day), DPW = Irrigation days per week, HPD = Irrigation hours per day, and E = Overall efficiency.

At 8.0 mm/day net irrigation requirement, for 24 hour irrigation the gross water requirement is 1.79 l/sec/ha. The river is not gauged at any point near the point of abstraction. Estimate of the flow done during the dry season using float method, gave a flow of 0.090 m^3. The Ministry of Water allows a maximum of two third of available flow for extraction. This means the available flow for extractin for irrigation is 0.060 m^3 . This is the flow that was used for design of the irrigation system. 33.62 ha. out of 55 ha. scheme area, will be irrigated for 24 hours irrigation equivalent to 0.28 per farmer for the 120 farmers.

E Water Distribution

The scheme is to be divided into five groups having 24 farmers per group (see figure 3). The flow will be continous to each group but within the group the flow will be rotated among the farmers at a time. Each farmer will Irrigate for seven hours with an irrigation interval of seven days.

The gross flow to each group is $0.012m^3$. Net irrigation application is 0.006 m^3 which is equivalent to 56mm for the seven hours on the 0.28 ha.per farmer. the irrgation interval varies with the rooting depth which also depends on the crop and growth stage.The farmers will organise themselves so that for crops that require shorter intevals, they can be provided with water for a shorter period but more frequent.

ANNEX 2 - CALCULATION OF CANAL DIMENSIONS USING MANNINGS EQUATION

Mannings equation is given by

$$Q = A\ K_m\ S^{1/2}\ R^{2/3} \quad (7.2.1)$$

Where Q = Flow in the canal (m^3/sec), K_m = Mannings roughness coefficient ($m^{1/3}/sec$), A = Wetted area (m^2), S = Bed slope of the canal (m/m), and R = Hydraulic radius (m).

Re-arranging the above equation we have

$$A*R^{2/3} = \frac{Q}{K_m*S^{1/2}} \quad (7.2.2)$$

The expression $AR^{2/3}$ is called the section factor for uniform flow computation (Chow, 1973). In most calculations, the flow in the canal is known. The roughness coefficient, can also be estimated and bed slope fixed. The right hand quantity can be known. Trapezoidal canal sections will be used.

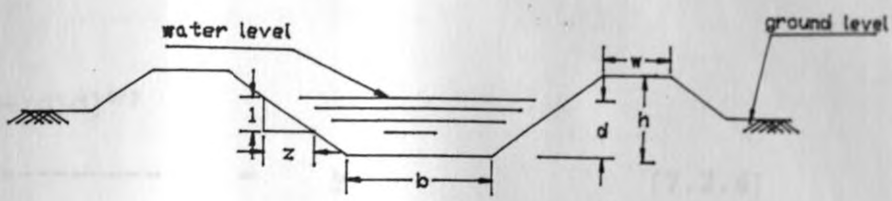


Figure 7.2.1- Canal cross-section.

Letting the quantity $\underline{Q}/KmS^{1/2}$ whose value is known to be Y, then the following expressions will be used to determine the bed width and normal depth of the flow in the canal. The wetted perimeter, wetted area and hydraulic radius for the section shown in figure 7.2.1 are given by

$$A = (b+zd)d \quad [7.2.3]$$

$$P = b+2(1+z^2)^{1/2} d \quad [7.2.4]$$

$$R = \frac{A}{P} = \frac{[b + zd] d}{b + 2[1 + z^2]^{1/2} d} \quad [7.2.5]$$

The section factor is given by

$$AR^{2/3} = \frac{(b+zd)d\ [(b+zd)d\ ]^{2/3}}{[b+2(1+z^2)^{1/2}d]^{2/3}}$$

but the value of section factor is known (y) so

$$\frac{[(b+zd)d]^{5/3}}{[b+2(1+z^2)^{1/2}d]^{2/3}} = y \qquad [7.2.6]$$

$$[(b+zd)d]^{5/2} = Y^{3/2}[b+2(1+z^2)^{1/2}d \qquad [7.2.7]$$

substituting z = 1.5 then

$$[bd+1.5d^2]^{5/2} = Y^{3/2}\ [b+3.61d] \qquad [7.2.8]$$

By fixing the value of b, the value of d can be found by trying values of d which satisfy the above equation both sides (trial and error method). The dimensions for the canals that resulted from above calculations are shown in Table 2.1

Table 2.1: Canal design using Midas

Canal No	Reach No.	Slope m/m	Flow l/sec	K_s m/sec	b m	d m	z m	f m	h m	V_{max} m/sec
1	1	0.008	12	15	0.3	0.11	1.5	0.1	0.21	0.33
	2	0.003	12	15	0.3	0.14	1.5	0.1	0.24	0.22
2	1	0.01	12	15	0.3	0.1	1.5	0.1	0.2	0.36
	2	0.003	12	15	0.3	0.14	1.5	0.1	0.24	0.22
	3	0.001	12	15	0.3	0.19	1.5	0.1	0.29	0.14
3	1	0.012	12	15	0.3	0.1	1.5	0.1	0.2	0.39
	2	0.003	12	15	0.3	0.14	1.5	0.1	0.24	0.22
4	1	0.01	12	15	0.3	0.1	1.5	0.1	0.2	0.36
	2	0.003	12	15	0.3	0.14	1.5	0.1	0.24	0.22
	3	0.002	12	15	0.3	0.16	1.5	0.1	0.26	[illegible]
5	1	0.007	12	15	0.3	0.11	1.5	0.1	0.21	0.31
	2	0.009	12	15	0.3	0.11	1.5	0.1	0.21	0.35
	3	0.001	12	15	0.3	0.19	1.5	0.1	0.29	0.14
Main	1	0.015	36	15	0.5	0.13	1.5	0.1	0.23	0.65
	2	0.001	36	15	0.5	0.27	1.5	0.1	0.37	0.23
	3	0.001	48	20	0.5	0.32	1.5	0.1	0.42	0.24
	4	0.001	59	20	0.5	0.36	1.5	0.1	0.46	0.24

Table 2.2: Parameters for normal canal design

Canal No.	Reach No.	Slope m/m	Flow l/sec	Km m/sec	b m	d m	z	f m	h m	V_{max} m/sec
1	1	0.0080	12	15	0.30	0.11	1.50	0.10	0.21	0.32
	2	0.0030	12	15	0.30	0.14	1.50	0.10	0.24	0.22
	3	0.0090	12	15	0.30	0.11	1.50	0.10	0.21	0.32
2	1	0.0100	12	15	0.30	0.10	1.50	0.10	0.20	0.36
	2	0.0060	12	15	0.30	0.12	1.50	0.10	0.22	0.29
	3	0.0010	12	15	0.30	0.18	1.50	0.10	0.28	0.14
3	1	0.0120	12	15	0.30	0.10	1.50	0.10	0.20	0.36
	2	0.0072	12	15	0.30	0.11	1.50	0.10	0.21	0.32
	3	0.0030	12	15	0.30	0.14	1.50	0.10	0.24	0.22
	4	0.0100	12	15	0.30	0.10	1.50	0.10	0.20	0.36
4	1	0.0100	12	15	0.30	0.10	1.50	0.10	0.20	0.36
	2	0.0030	12	15	0.30	0.14	1.50	0.10	0.24	0.22
	3	0.0090	12	15	0.30	0.11	1.50	0.10	0.21	0.32
	4	0.0030	12	15	0.30	0.14	1.50	0.10	0.24	0.22
5	1	0.0100	12	15	0.30	0.10	1.50	0.10	0.20	0.36
	2	0.0070	12	15	0.30	0.11	1.50	0.10	0.21	0.32
	3	0.0010	12	15	0.30	0.18	1.50	0.10	0.28	0.14
Main	1	0.0100	36	15	0.40	0.16	1.50	0.10	0.26	0.43
	2	0.0005	36	15	0.40	0.34	1.50	0.10	0.44	0.12
	3	0.0005	48	20	0.50	0.32	1.50	0.10	0.42	0.17
	4	0.0030	60	20	0.50	0.23	1.50	0.10	0.33	0.36

ANNEX 3: QUESTIONNAIRE

1. GENERAL INFORMATION

i) Name of the Province . . . .

ii) How many schemes have you designed within the Province............. (Group Schemes)

iii) Of the schemes you have designed within the Province or else where within the country, indicate the number of schemes you have designed under each category shown below.

a) Furrow irrigation . . . .

b) Wild flooding . . . .

c) Basin irrigation . . . .

d) Combination of furrow and basin . . . .

iv) How often do you design (determine) the size of furrows or basin. *(Tick the correct one)*

a) For every irrigation scheme designed . . . .

b) For a few schemes . . . .

c) Not done at all . . . .

2. Survey Information

i) What is the average output of one surveyor in your Province (District)........ha/day.

ii) What grid do they use....... m.......x........m

iii) How much time is taken in getting the reduced levels

.............hours/ha

iv) How much time is taken for interpolation and plotting of the contourMap..............hours/ha

v) In accomplishing (iii) and (iv). What are the major constraints...

....

3. River Flow Data

i) Tick the appropriate statement about river flow data that you think is true.

a) Data not available for many rivers..............

b) The data is not available in the district.......

c) Data available in Ministry of water's head - quarters.......................................

d) The process of data collection is lengthy........

e) Data available is not continuous

ii) State the major constraint in determining the low flow with the required reliability.................

iii) What is the major constraint in determining flood flows for a required return period............

4. Determination of Water Requirement and Design Flow

i) What method do you mainly use in determining crop water requirement (ET_c). *(Tick the correct one)*

a) Calculation from climatic data and cropping calendar

b) From Irrigation hand books and manuals

ii) In collection of climatic data, which of the following statements apply *(Tick)*

a) Climatic data not available (temp.,humidity, sunshine record, and radiation)...........

b) Climatic data is readily available.........

c) Pan evaporation data is available.........

d) Data available not continuous...............

iii) How often do you prepare a cropping Calendar for the schemes *(Tick)*

a) Not at all....................................

b) Some times....................................

c) For all the schemes designed................

iv) What value of crop coefficient (K_c) do you often use *(Tick)*

a) Calculated value from the cropping pattern.......................................

b) An average value given in books............

(v) Tick the most appropriate statement for the rainfall information.

a) The data is not available....................

b) The data is readily available................

c) The data is usually available for some stations..

d) The records are not continuous

vi) With all data available, what is the average time taken for the following tasks.

a) Determination of ETo from climatic data ....hours

b) Determination of crop coefficient from cropping Calender.................... hours

c) Analysis of rainfall data to get effective rainfall...................hours.

5 The following are major design tasks and activities. Rank them in order of the proportion of design time taken. Starting with the task that takes most time and ending with the one that takes least time.

a) Determination of maximum irrigation interval

b) Establishing the number of groups

c) Determining the position (location) of canals

d) Deciding on drainage layout

e) Determining the dimensions of basins and furrow

f) Generating canal ground profiles

g) Determination of dimensions of the channels

h) Locating the canal on ground profile and drop structures and construction materials

i) Determining the dimensions of the required structures and construction materials

j) Determining the bill of quantities

k) Economic analysis

Rank	1	2	3	4	5	6	7	8	9	10	11
Activity											

ii) For the first six activities state the major constraint

1. ....

2. ....

3. ....

...

4. ....

5. ....

6. ....

B. **MAILING LIST FOR QUESTIONNAIRE**

The target group was irrigation engineers who have been involved in the design of small scale surface irrigation schemes. A total of 31 questionnaires were sent but 17 were replied.

	NAME	STATION
1.	Kagiri A. W	Nakuru
2.	Kiragu G. M.	Laikipia
3.	Muiruri F. N.	Kajiado
4.	Ogango P.D	Elgeyo Marakwet
5.	Omwenga G. J.	PIU-Nakuru
6.	Chepsoi	PIU Nakuru
7.	Omedi	PIU Nyanza
8.	Kapkiyai D.	PIU Nyanza
9.	Kiplangat W.C	PIU Nyanza
10.	Maithya G. M	PIU Nyanza
11.	Githae A. M.	PIU Nyanza
12.	Kombo J. O.	PIU Nyanza
13.	Asawo L.W. O.	PIU Nyanza
14.	Kabok P. A	PIU Nyanza
15.	Ochieng J. O.	PIU Nyanza
16.	Muthigani P. M.	Garissa
17.	Wairangu J. K.	Garissa
18.	Onchoke O.W	Meru
19.	Njoka B. K.	PIU Eastern
20.	Mbandi J. W.	PIU Eastern
21.	Miya J. O.	PIU Eastern
22.	Magero B. J.	Isiolo
23.	Maina B. M.	Machakos
24.	Mutavi S. M.	Kirinyaga
25.	Simiyu J.A	kiambu
26.	Nderitu P. G.	Nairobi
27.	Nyanguti J. O.	Nairobi
28.	Sifuma J.	Nyeri
29.	Obimbo P.O.	Nyeri
30.	Opaka J.R.S.	Mombasa
31.	Mulwa J. W.	T/Taveta

ANNEX 4 - COMMENTS FROM ENGINEERS

FIELD IRRIGATION SYSTEM

- Too many iterations before suitable parameters are established;
- No clear procedure for determining or designing small basins as used in small scale schemes;
- Schemes operation is in farmers hands and they rarely adopt recommended methods; and
- Field system are left for field staff with farmers due to limitations of time on engineers.

SURVEY WORK

- Calculations are too involving;
- The final Map may not be accurate; and
- Dealing with a lot of data.

RIVER FLOW DATA

- The data is not consistent;
- Data does not cover sufficient period; and
- Data altogether not available.

LAYOUT OF THE SCHEME

Determining the correct group layout takes time;

- Some members would not like to belong to a given group because of personal differences;
- All possible layouts have to be considered;
- Farm and clan boundaries should not be disturbed as this is not acceptable to the farmers;
- The engineers may be involved with other general activities of the Ministry; and

- The maps may not be accurate.

CANAL DESIGN

- Repetitive calculations that are long; and
- No clear design criteria and some require rule of the thumb.

GENERATION OF GROUND PROFILES AND DRAWING CANAL LONGITUDINAL PROFILES

- Dealing with a lot of data;
- Amount of time involved in getting levels in the many canal is high;
- The work is tedious and time consuming;
- One must balance as much as possible cuts and fills;
- Proper longitudinal profiles are required;
- The Map and contours too small (scale); and
- Maps not drawn accurately.

DESIGN OF STRUCTURE

- Repetitive calculations that are time consuming;
- Lack of reference books;
- Lack of experience in the type of structures and economical sizes;
- No clear design criteria as for some structures e.g. intake works and division boxes; and
- Some structures being too expensive require a lot of adjustments to make them cheap.

DETERMINATION OF BILL OF QUANTITIES

- Estimates have to be redone to adjust to constant variation of basic prices;
- Lack of standard prices;

- Repetitive calculations; and
- Takes a lot of time.

ECONOMIC ANALYSIS

- Involves collecting information of non-engineering in nature;
- Unavailability of information on costs;
- Data is usually not available readily especially farm gate prices; and
- A lot of calculations involved.

ANNEX 5: CALCULATION OF EARTH MOVEMENTS

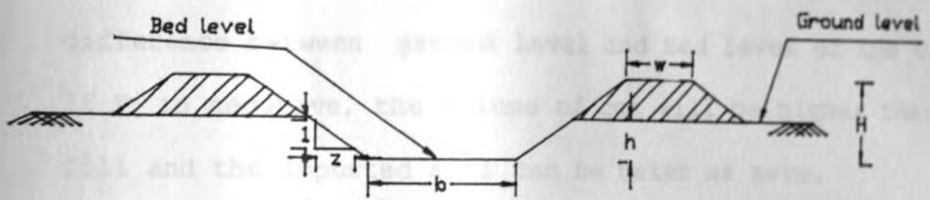


Figure 5.1 - Canal in cut.

The calculation will be done for each reach. Each reach will be divided into small segments, 20 m long. The values calculated for each segment are added together to get the total cut or fill and earth imported for the reach. The cumulated earth movement up to that reach from the tail end is also to be included. From these figures the earth work for each farmer can be calculated.

The bed level and ground level at the ends of the 20 m section are noted and their difference (h) found. The average difference h is determined and used for calculation. When h is negative it means the canal is in fill and when positive, the canal is in cut.

For each section, the volume of cut (V_c) is given by

$$V_c = hL(b+zh) \quad [7.5.1]$$

the volume of fill (V_f) is given by

$$V_f = 2L(H-h)\ (w+z(H-h)) \quad [7.5.2]$$

Volume of earth imported is given by

$$V_i = V_f - V_c \quad [7.5.3]$$

Where

L = Length of the section of canal (m), b = bed width of the canal (m), Z = Side slope of the canal (m/m), W = Top width of the embankment (m), H = Total depth of the canal (m), and h = The difference between ground level and bed level of the canal (m).

If V_i is negative, the volume of cut will be higher than the required fill and the imported soil can be taken as zero.

According to Bowles (1984), on excavation, soil increases in Volume (Swell). the Swell values may range from 15% for gravel to 40% for clay. The assumption is that when the earth is compacted for the canals the resulting soil bulky density should be the same as for the original soil. Taking the higher value 40% for clay, then imported soil will be 1.4 times the calculated value.

$$V_i = 1.4\ (V_p - V_c) \quad [7.5.4]$$

The total earth movement (E_m) will be given by

$$E_m = V_i + V_c \quad [7.5.5]$$

B - CANAL IN FILL

When the average difference between the ground level and bed level is zero or less it means the canal will be in fill. The volume of fill will be given by

$$V_f = L[(H-h)(Z(H-h) + 2W+b+2ZH)-H(b+ZH)] \quad [7.5.6]$$

Volume of imported earth (earth movement) will be

$$E_m = V_i = 1.4\ V_f \quad [7.5.7]$$

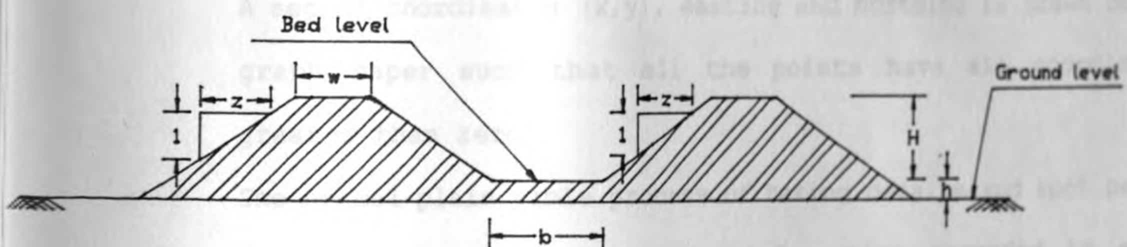


Figure 5.2 - Canal in fill.

ANNEX 6: PLANE TABLE AND LEVEL INSTRUMENT SURVEYING FOR USE IN MIDAS AND SORTING OUT DATA FOR EXISTING DETAILS

PLANE TABLE SURVEYING

In plane table surveying, the drawing of the Map for existing details and spot height positions, is done in the field. The office work is only the interpolation of the data for drawing contours. To allow for input and processing of the data using the computer, the following procedure of plane table surveying should be used.

- The normal control survey is done to establish position and relative levels of the control stations (bench marks)
- The information is plotted on a graph paper to be used to get other information on the plane table.
- A set of coordinates (x,y), easting and northing is drawn on the graph paper such that all the points have all coordinates greater than zero
- The normal plain table process of taking details and spot height is done. For each point the information recorded is staff station number,number along the particular detail, vertical angle, staff readings, the x and y coordinates of the point, the identification of the point e.g. road, canal, plot boundary etc. and distance deduced from staff readings.

The proposed data collection sheet would be as shown below.

Instrument station -

Height of instrument -

Date of surveying -

STAFF STATION	NUMBER	X	Y	VERTICAL ANGLE	STAFF READINGS		DISTANCE	ID
					Upper	Lower		

The reduced level (z) at the staff station is given by

$$z = H_i + v - R \qquad [7.6.1]$$

Where Z = Reduced level (m), H_i = Height of instrument (m), R = Principle stadia reading, and V = 1/2 CS Sin2θ (Banister and Raymond, 1984).

C = Constant for instrument normally taken as 100, S = Difference between upper and lower stadia readings, and θ = Angle of elevation or depression.

The distance from instrument to the staff station is given by

$$D = CS \cos \theta \qquad [7.6.2]$$

A program to calculate the value of Z from the stadia readings and the vertical angle and to give the output inform of an XYZ file suitable for Digital Ground Model could be prepared. Alternatively the worked out coordinates could be input in a spread sheet and processed to give XYZ file.

For the existing features, the number and identification could be used to sort them out according to the particular details and then separate XYZ files could be prepared.

LEVEL INSTRUMENT SURVEY

The normal control survey for the stations (bench marks) will be done first. The instrument is set above the survey station and normal procedure of the survey with the level done. The information collected is shown in the data collection sheet shown below.

			Staff readings			Reduced Level	Distance	Remarks
Staff Position	No	Horizontal angle	Upper	Middle	Lower			

CALCULATION OF COORDINATES

The bearing of the survey points with respect to the instrument station will be used to get the coordinates of the points. The height of collimation method will be used to calculate the reduced levels of the points (Z).

The distance (D) from instrument station to the survey point is given by

$D = Cs + K$ (Bannister and Raymonds,1984) [7.6.3]

Where D = Distance, K = Constant for the instrument

(Many times neglected), S = The difference between upper and lower stadia readings of the staff, and C = Constant for instrument

If (X_1, Y_1) and (X_2, Y_2) are the coordinates of the instrument station and reference station, then the bearing (θ) of the reference station with respect to instrument station would be given by the following relationships.

$$X = X_2 - X_1 \quad [7.6.4]$$

$$y = Y_2 - Y_1 \quad [7.6.5]$$

For $x > 0$ and $Y > 0$, $\theta = COS^{-1} Y/D$ [7.6.6]

For $x < 0$ and $Y < 0$, $\theta = 180 - Sin^{-1} Y/D$. [7.6.7]

For $x < 0$ and $Y > 0$, $\theta = 360 + Sin^{-1} X/D$. [7.6.8]

The bearing θ_2, of the survey point with respect to instrument station given by

$$\theta_2 = \theta + HA \quad [7.6.9]$$

Where θ = bearing of reference origin with respect to instrument station, and HA = Horizontal angle taken during the survey.

The coordinates of any survey points are given by

$$X = X_1 + DSin\theta_2 \quad [7.6.10]$$

$$Y = Y_1 + DCos\theta_2 \quad [7.6.11]$$

The height of the instrument (HI) is given by

$$HI = Z_{RO} + R_i \quad [7.6.12]$$

And the Z Coordinate is given by

$$Z = HI - R_i \qquad [7.6.13]$$

Where Z_{RO} = Z Coordinate of reference origin, R = Middle stadia readings for reference origin, and R_i = Middle stadia reading for any survey point.

These equations could be programmed to process the survey data of a level instrument and give it in a format suitable for DGM use. Alternatively the Digital Ground Model land survey program for tacheometric survey could be used with vertical angle taken as 90°.

For a grid survey with a level instrument, a spread sheet program to calculate the Z value from the height of collimation equation could be prepared. The inputs would be, x, y and middle stadia readings (See equation above).

SORTING OUT SURVEY DATA

The land survey programs provided with Digital Ground Model (DGM) Package do not have the capacity to come up with plot out of field features such as plot boundaries, roads and canals. To allow for sorting out these features, the following process should be used in the field when collecting the data:-

- During Control survey, the features should be identified and sketched;
- Points to be picked during the survey should be systematically numbered for each feature;

- For farm boundaries, each farm should be given plot number and the corners numbered consecutively;
- Each feature should be given an identification e.g. Pb for farm or plot boundary, R for road, R_1 for river etc;
- When picking these points during the survey process, the identification and the number are noted (recorded);
- For farm boundary the first three numbers would represent the plot boundary and the last digit would represent the corner (point) on the boundary; e.g. Pb 0152 would represent second corner of plot number 015. If a point is shared by a number of plots it should be recorded for all of them; and
- After the data have been processed for the production of XYZ file for creation of a digital Ground Model, this data is imported into a lotus or Quatro Spread Sheet and Sorted out for each feature. Separate XYZ files are created for each feature and DGM package used to create DXF files. These are imported in Auto CAD to form the plots of the features.

ANNEX 7:

Table 7.1: Drop Structures' Inventory for Normal Design

Canal	Chainnage m	Upstream lev. m	Drop m	Bedwidth m
T1	60	97.25	0.3	0.3
	225	96.4	0.3	0.3
	335	95.8	0.3	0.3
	592.5	95.4	0.3	0.3
T2	213	97.45	0.25	0.3
	802.3	93.55	0.3	0.3
	865	92.55	0.3	0.3
T4	907.5	90.8	0.35	0.3
	960	89.9	0.3	0.3
T5	542.5	95.6	0.3	0.3
	960	92.05	0.3	0.3
	1053	90.85	0.3	0.3
	1116	89.85	0.3	0.3
Main	187.5	97.85	0.2	0.5
	592.5	97.4	0.3	0.4

Table 7.2: Survey Data Results from the Questionnaire

Output (ha/day)	*Grid (mxm)*	*Time Taken for Reduction of Data (hours/ha)*	*Time Taken in Ploting and Interpolating Data*
4	20x20	0.5	1
2	20x20	1	3
6	20x20	1	1.5
5	100x100	0.5	-
20	25x25	2	6
5	25x25	4	2
3	50x50	3	6
3	20x20	0.5	1
3	20x20	4	3
5	25x25	-	-
3	20x20	0.5	1
4	20x20	0.5	1

Table 7.3: Design Activities Ranking Result

Rank	No: of responses per design activity.										
	a	b	c	d	e	f	g	h	i	j	k
1	0	0	4	0	1	2	2	1	3	2	2
2	0	0	1	1	0	4	1	2	4	1	3
3	0	3	4	2	0	1	1	4	1	2	0
4	0	0	1	2	1	2	0	4	3	3	1
5	1	3	2	1	2	0	3	1	0	3	1
6	2	0	3	2	0	3	2	0	3	0	1
7	1	1	0	1	4	1	1	1	0	1	5
8	2	1	0	1	1	2	3	0	1	4	1
9	5	0	1	2	3	1	1	1	0	1	1
10	0	6	0	3	0	0	1	3	1	0	1
11	4	3	1	1	3	1	2	0	0	0	0

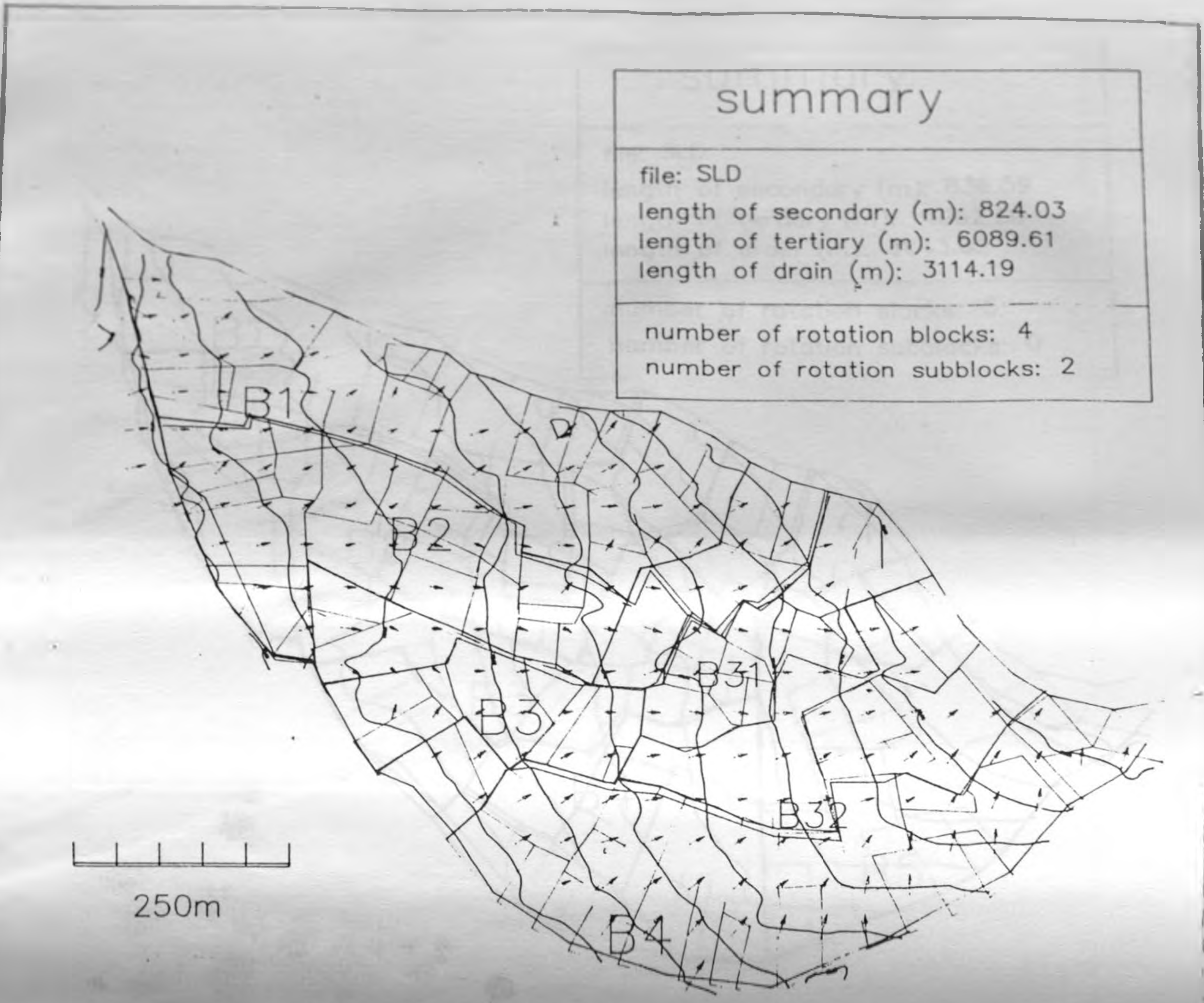


Figure 7.1 Canal and drain layout 1

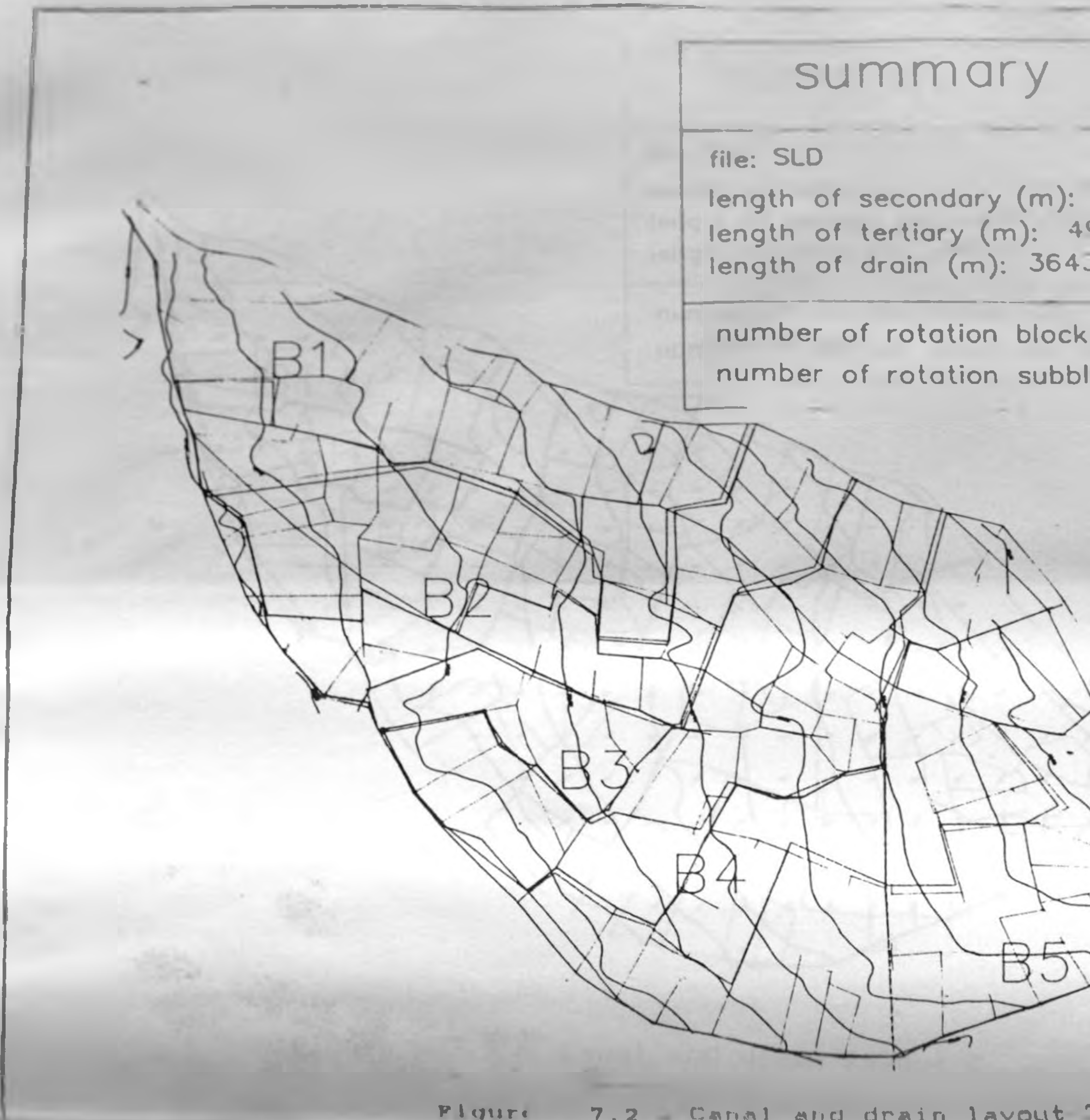


Figure 7.2 - Canal and drain layout

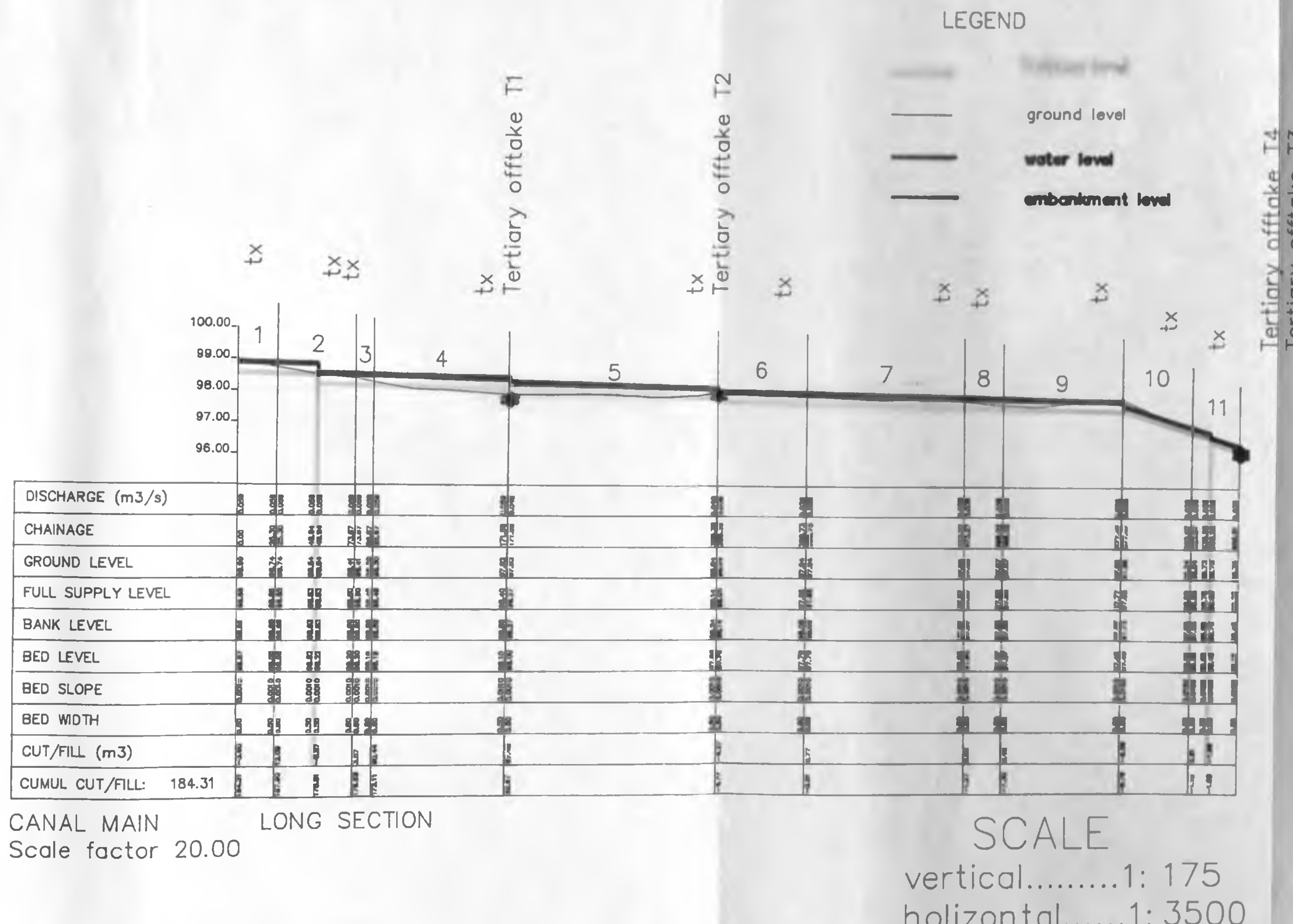


Figure 7.4 – Main Canal Profile

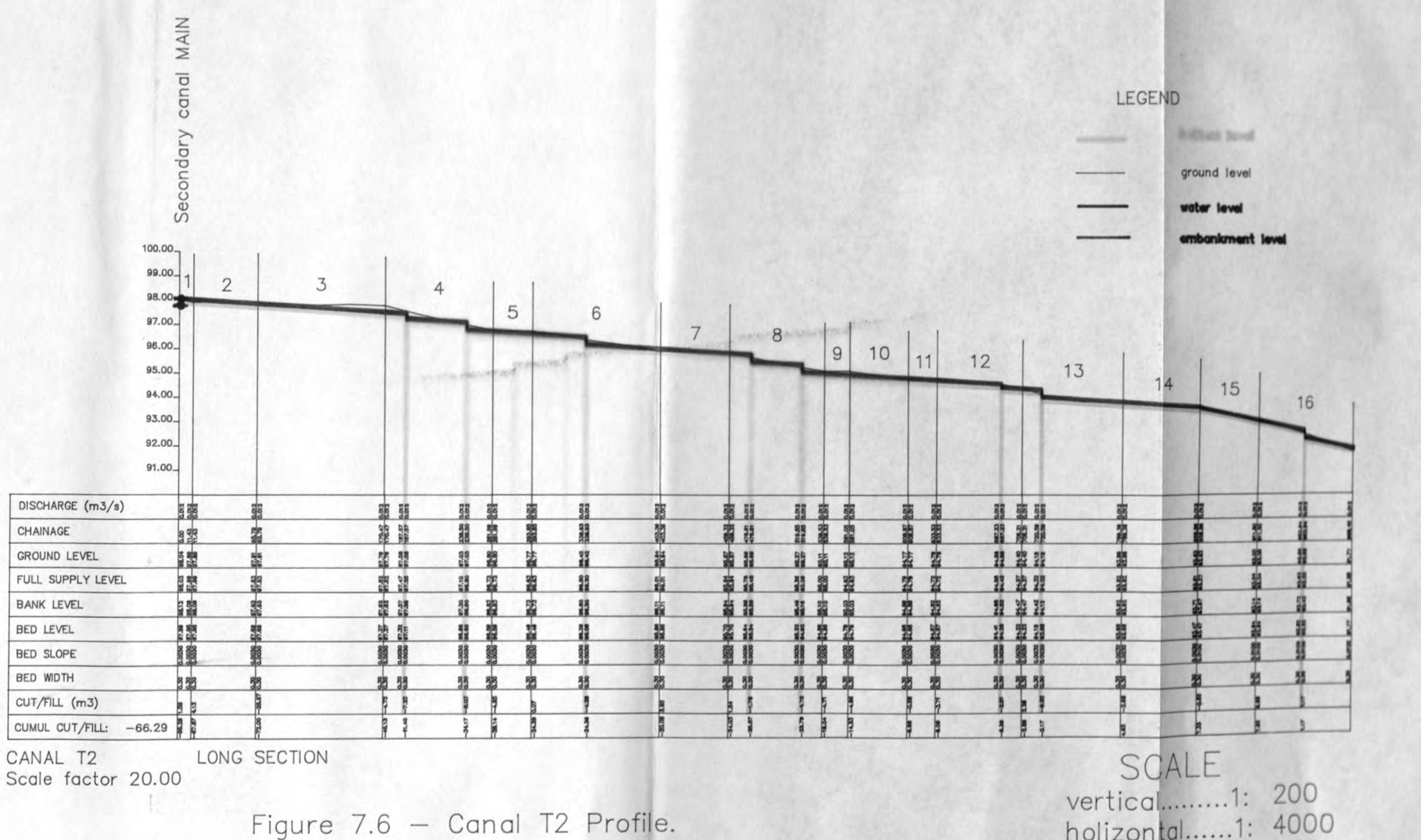


Figure 7.6 – Canal T2 Profile.

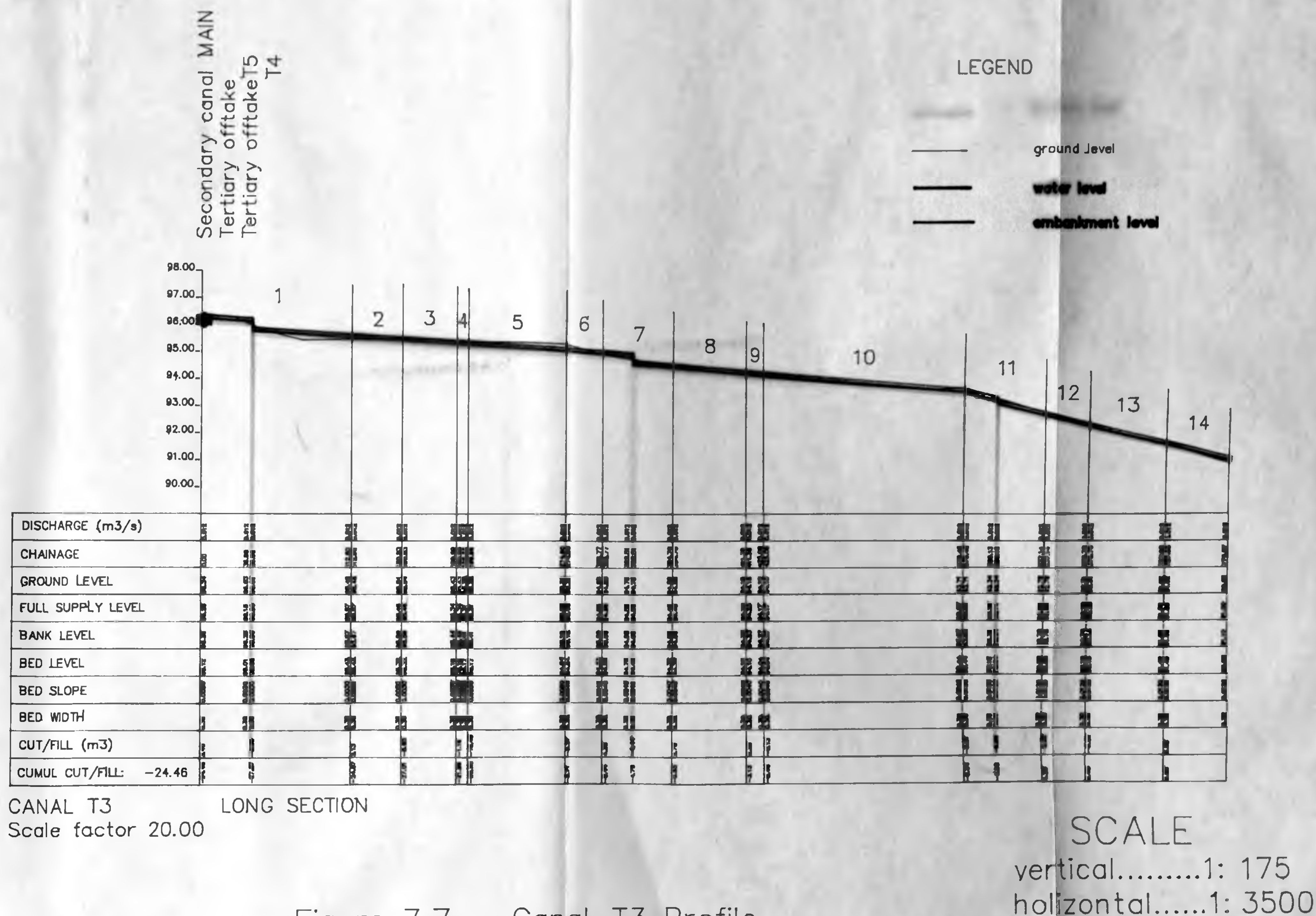


Figure 7.7 – Canal T3 Profile

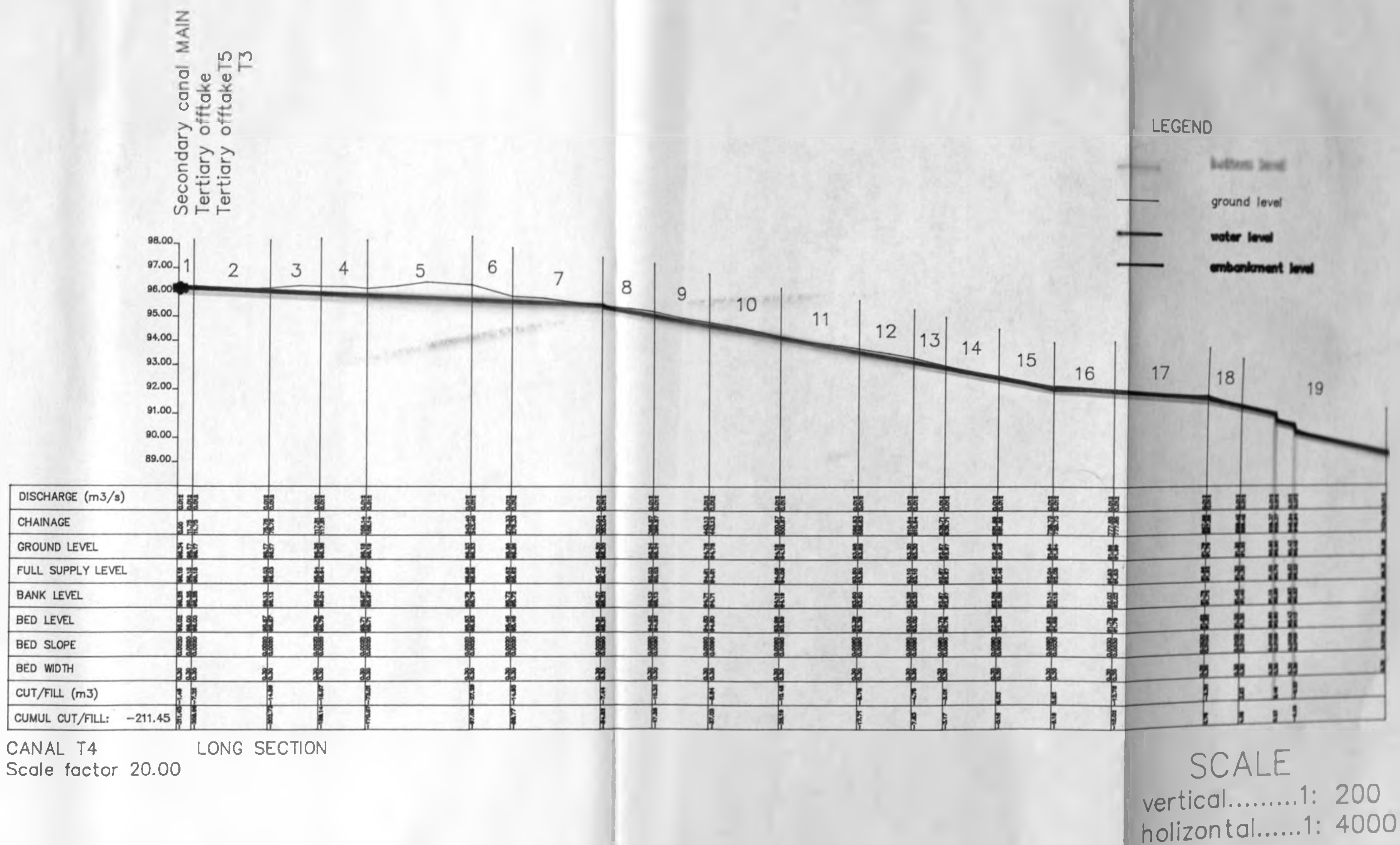
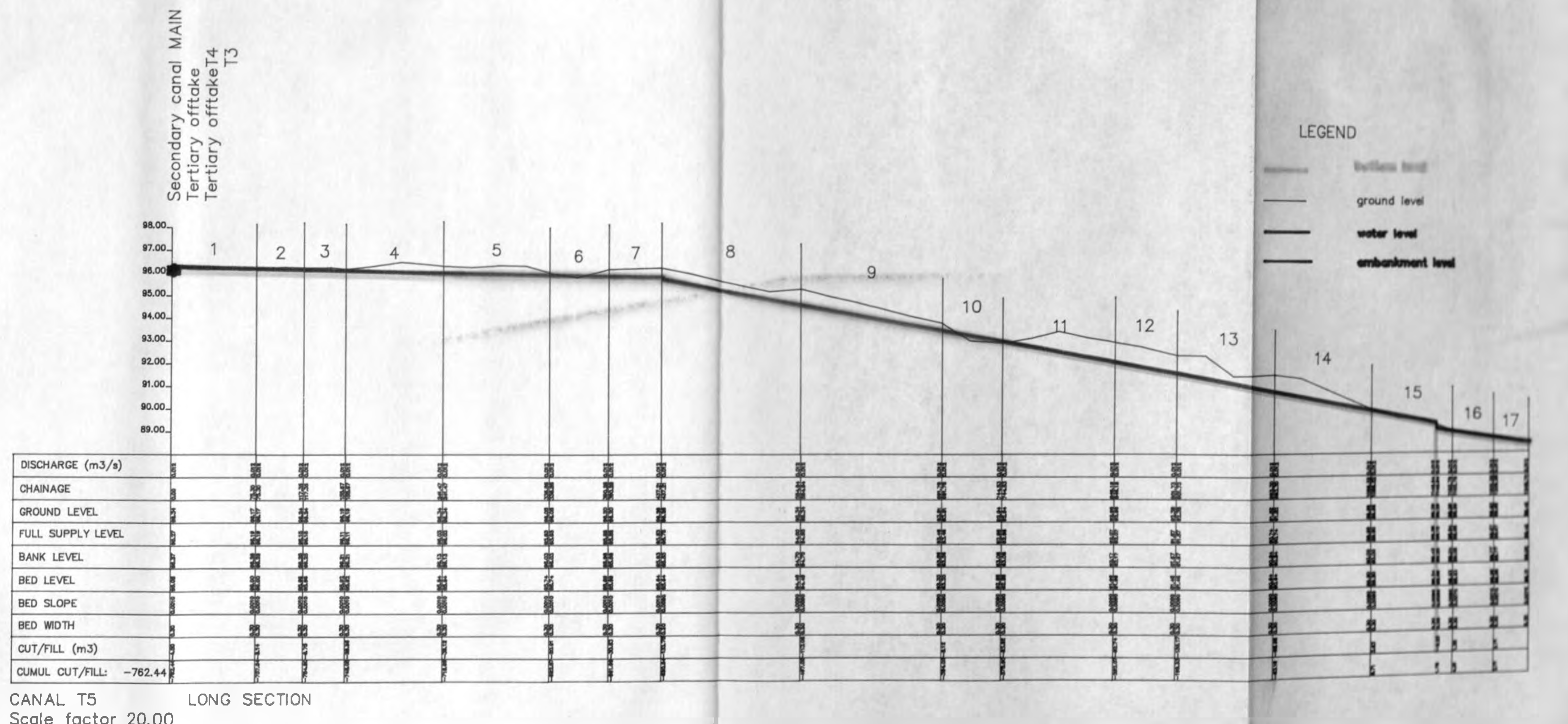


Figure 7.8 – Canal T4 Profile.



SCALE
vertical.........1: 225
holizontal......1: 4500

Figure 7.9 — Canal T5 Canal

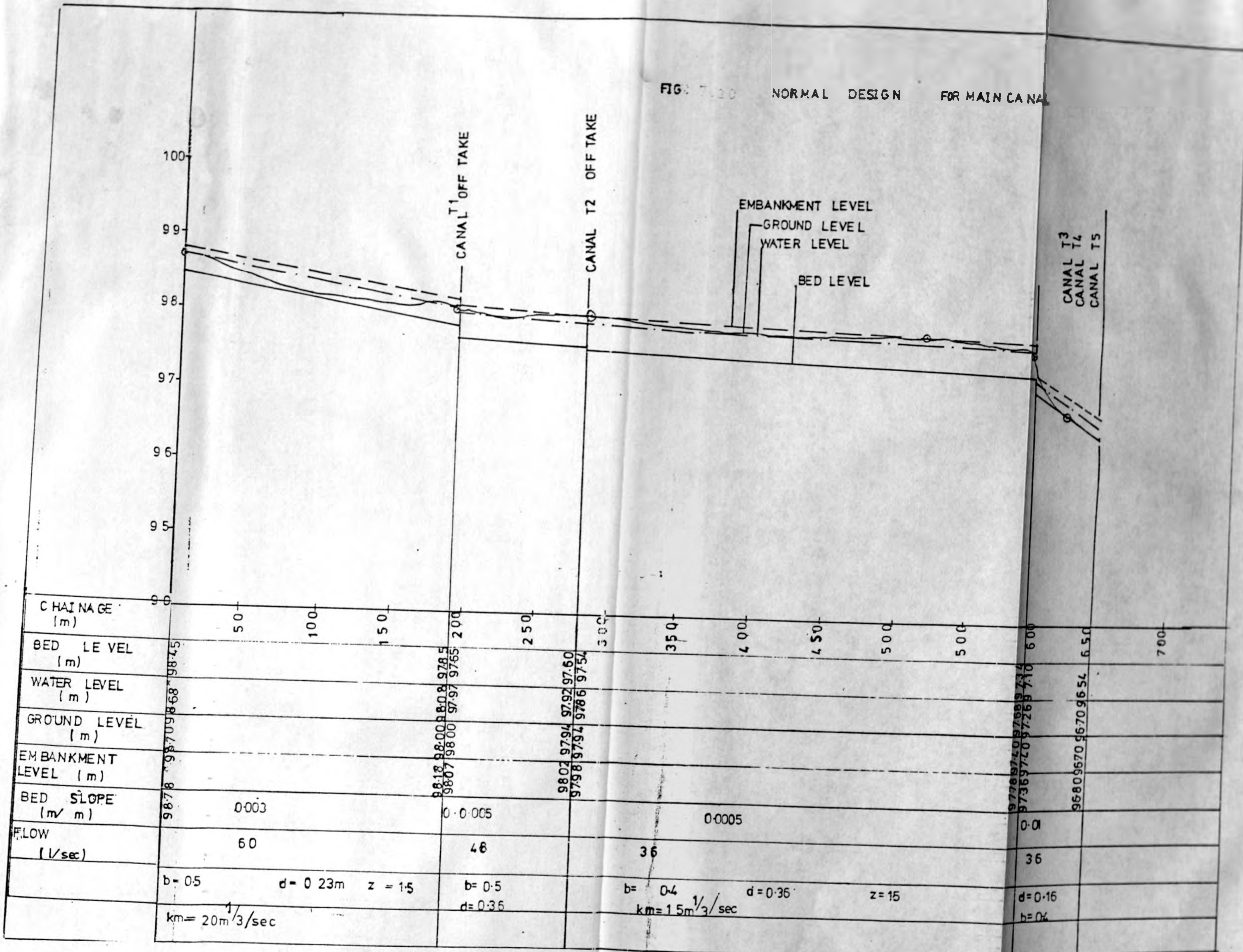
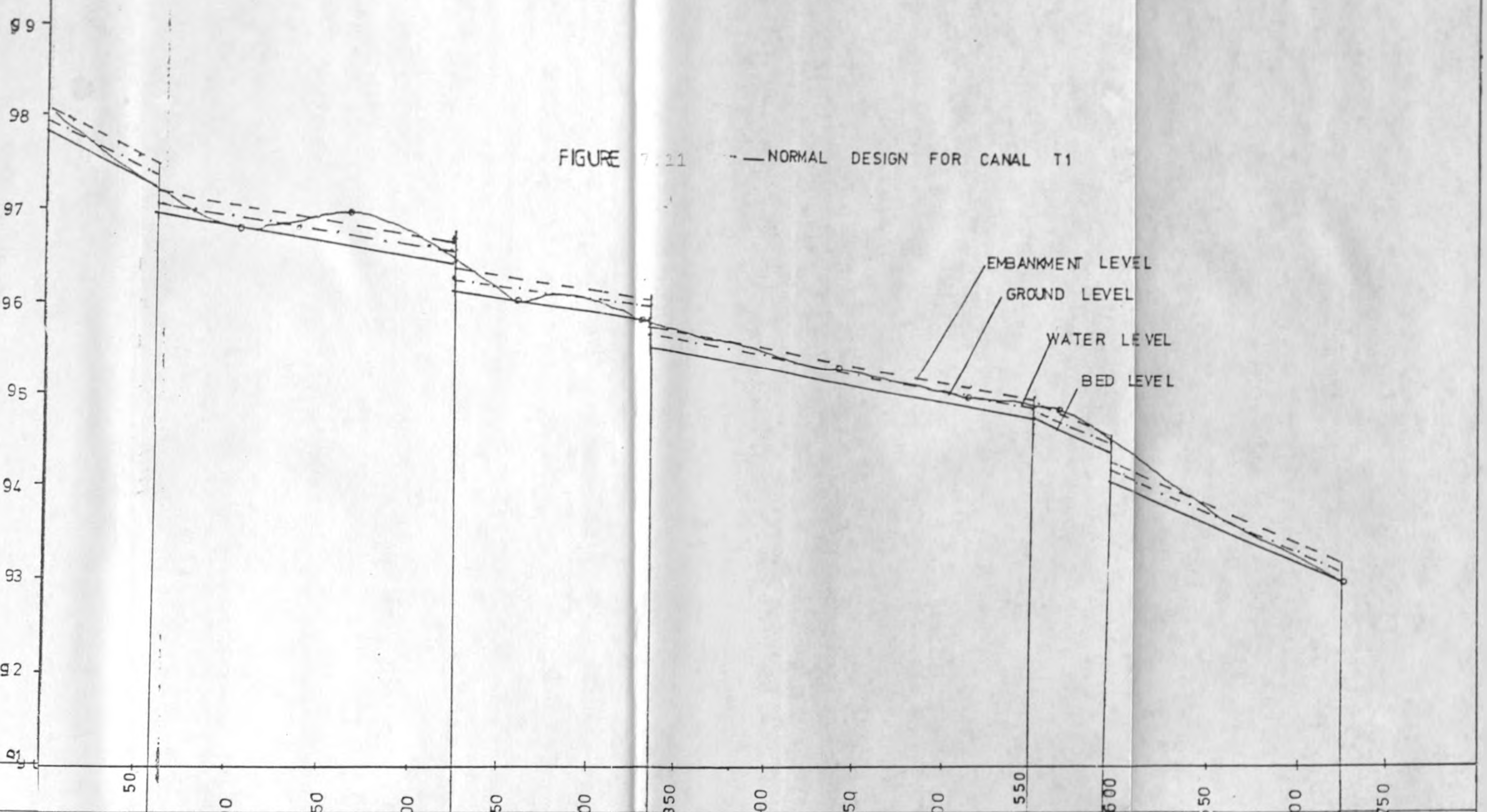


FIG. 7.20 NORMAL DESIGN FOR MAIN CANAL

FIGURE 7.21 — NORMAL DESIGN FOR CANAL T1



BED LEVEL (m)	97.80	97.25 96.95	96.40 96.10	95.80 95.50	94.75 94.75	94.40 94.10	93.00
WATER LEVEL (m)	97.91	97.39 97.09	96.54 96.24	95.96 95.69	94.89 94.86	94.51 94.11	93.11
GROUND LEVEL (m)	98.00	97.25	96.40	95.80	94.90	94.45	93.00
EMBANKMENT LEVEL (m)	98.04	97.49 97.29	96.74 96.34	96.06 95.74	94.99 94.96	94.61 94.21	93.21
BED SLOPE (m/m)		0.003				0.008	
FLOW (l/sec)	12	12			12		12
		b = 0.3 m	d = 0.14m	z = 1.5	b=0.3m	d= 0.11	

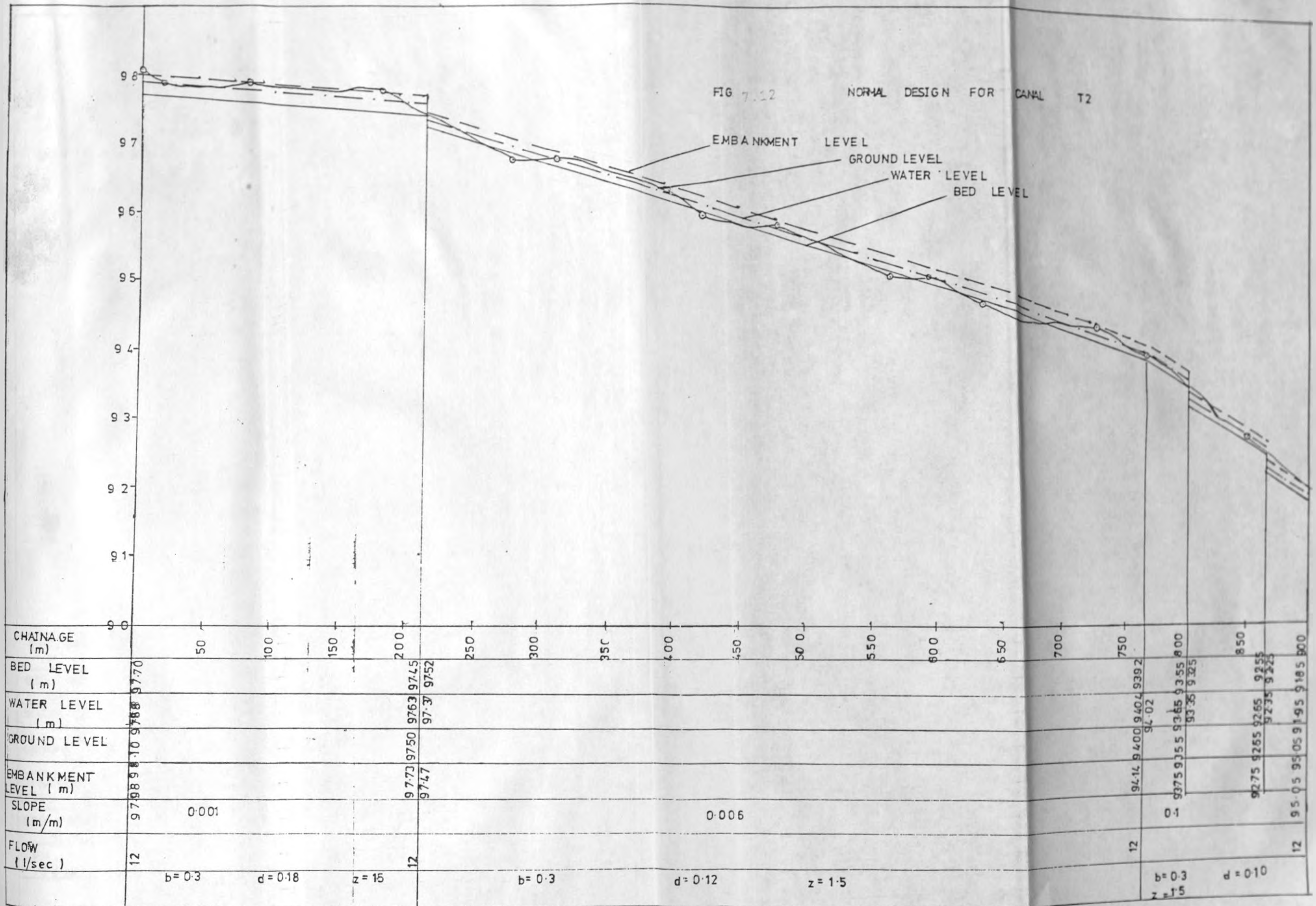


FIG 7.12 NORMAL DESIGN FOR CANAL T2
EMBANKMENT LEVEL
GROUND LEVEL
WATER LEVEL
BED LEVEL
98
97
96
95
94
93
92
91
90
CHAINAGE (m)
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
850
900
BED LEVEL (m)
WATER LEVEL (m)
GROUND LEVEL
EMBANKMENT LEVEL (m)
SLOPE (m/m)
0·001
0·006
0·1
FLOW (l/sec)
12
b= 0·3
d = 0·18
z = 15
b= 0·3
d = 0·12
z = 1·5
b= 0·3
z = 1·5
d = 0·10

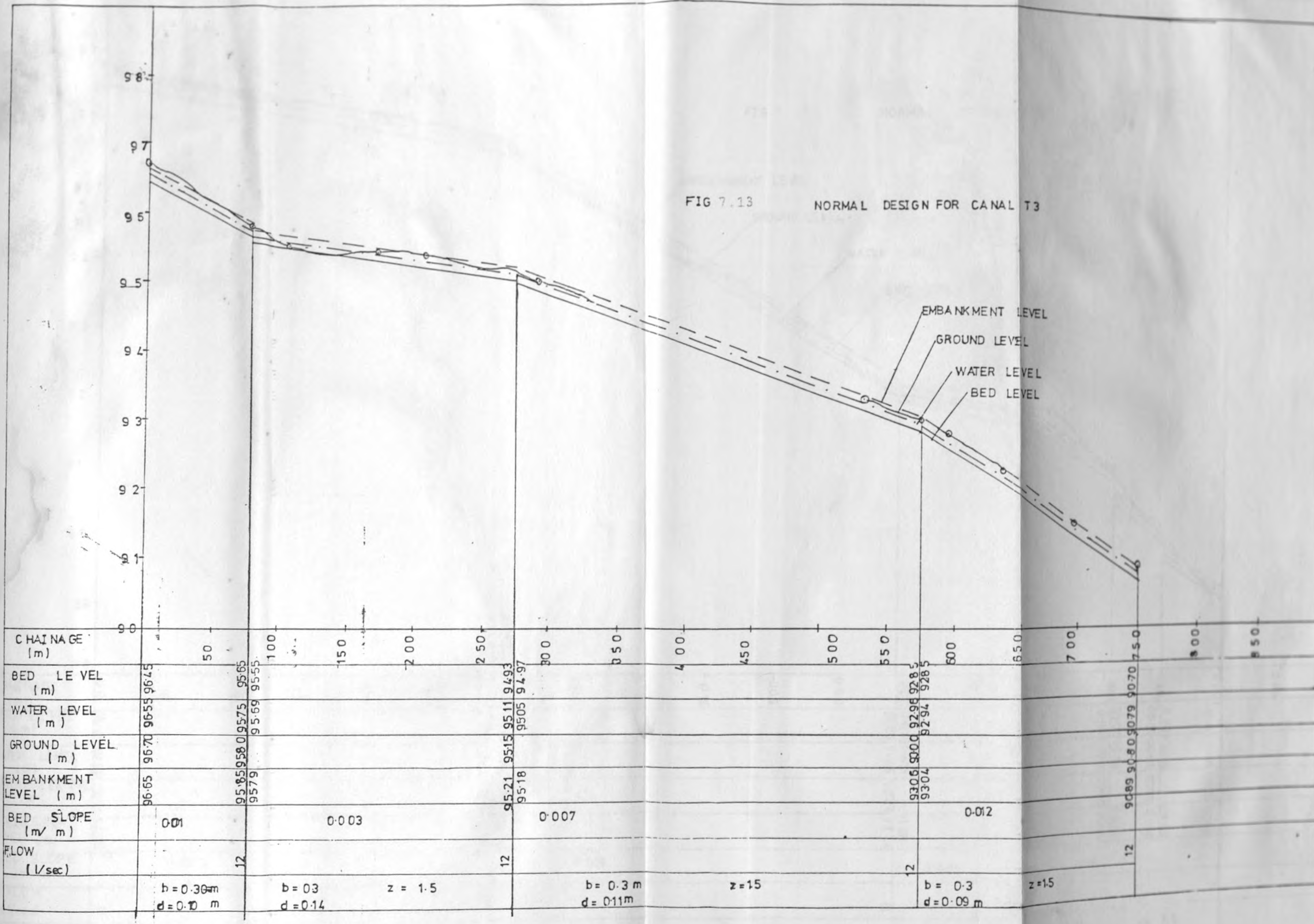
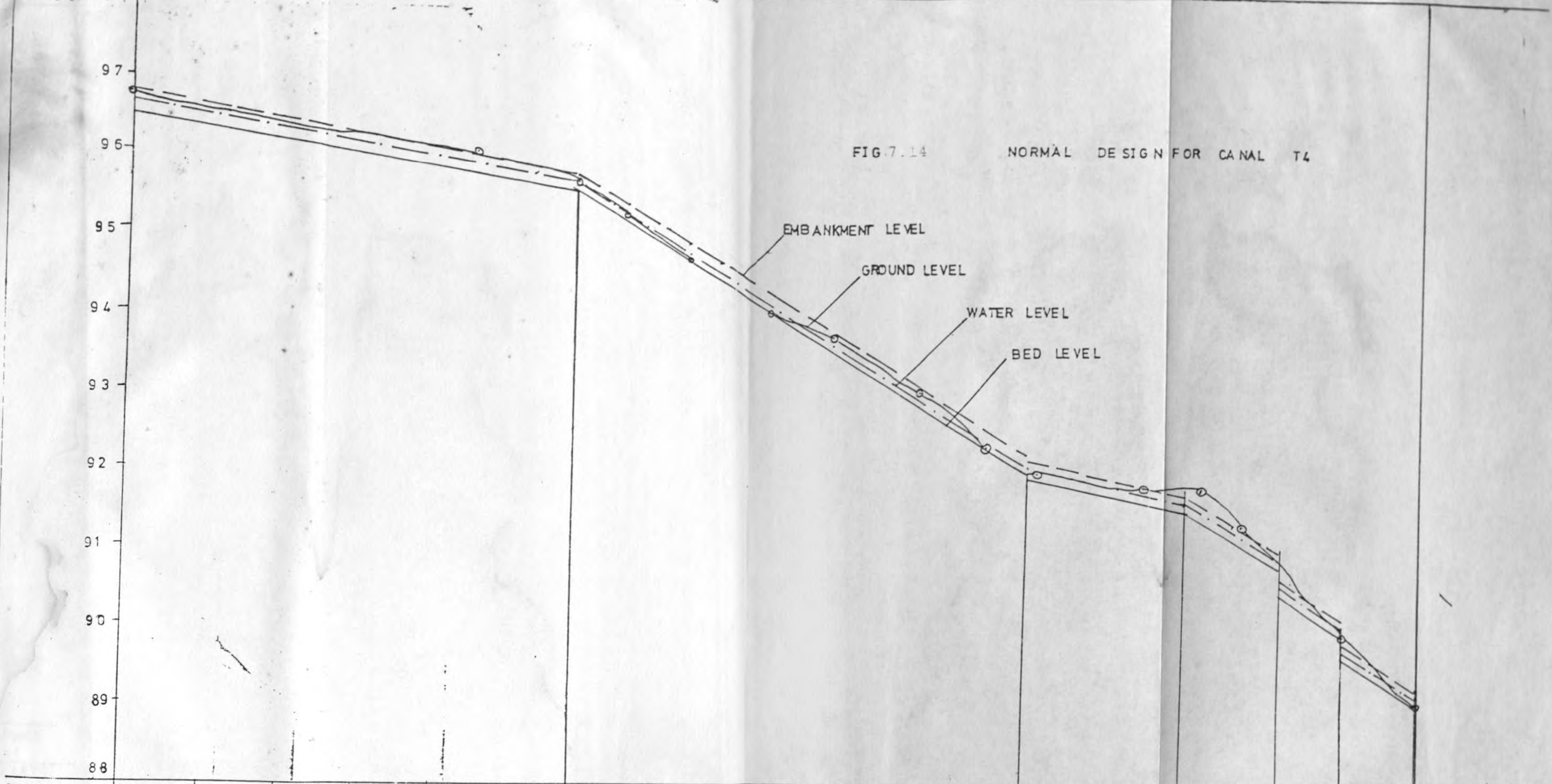


FIG 7.13 NORMAL DESIGN FOR CANAL T3



CHAINAGE (M)	0 0	60	120	180	240	300	360		420	480	540	600	660	720		780	840			900		960	1020	1080
BED LEVEL (m)	96.50						95.5 0	95.5 0						9200	91.9 0		91.5 0	91.50	908 0	9045	89 90	895 0	8900	
WATER LEVEL (M)	96.65						95.69	9561						9214	9204		91.64	91.60	9090	89.55	90.00	8970	8910	
GROUND LEVEL (m)	96.70						9565							92.05			91.60		9080		8900		8900	
EMBANKMENT LEVEL (m)	96.75						95 74	9571						92.24	9214		91.74	9170	91.00	9065	9010	89.80	89.20	
BED SLOPE (m/m)	0.00 3							0.009							0.003			0.01						
FLOW (l/sec)	12						12							12			12						12	
	b = 0.3 z = 1.5		d = 0.14		km = 15 $m^{1/3}/sec$			b = 0.3M		d = 0.1 1M		z = 1.5			b= 0 3 d = 0.14	z = 15		b = 0.3 d = 0.1			z = 1.5 km = 15			

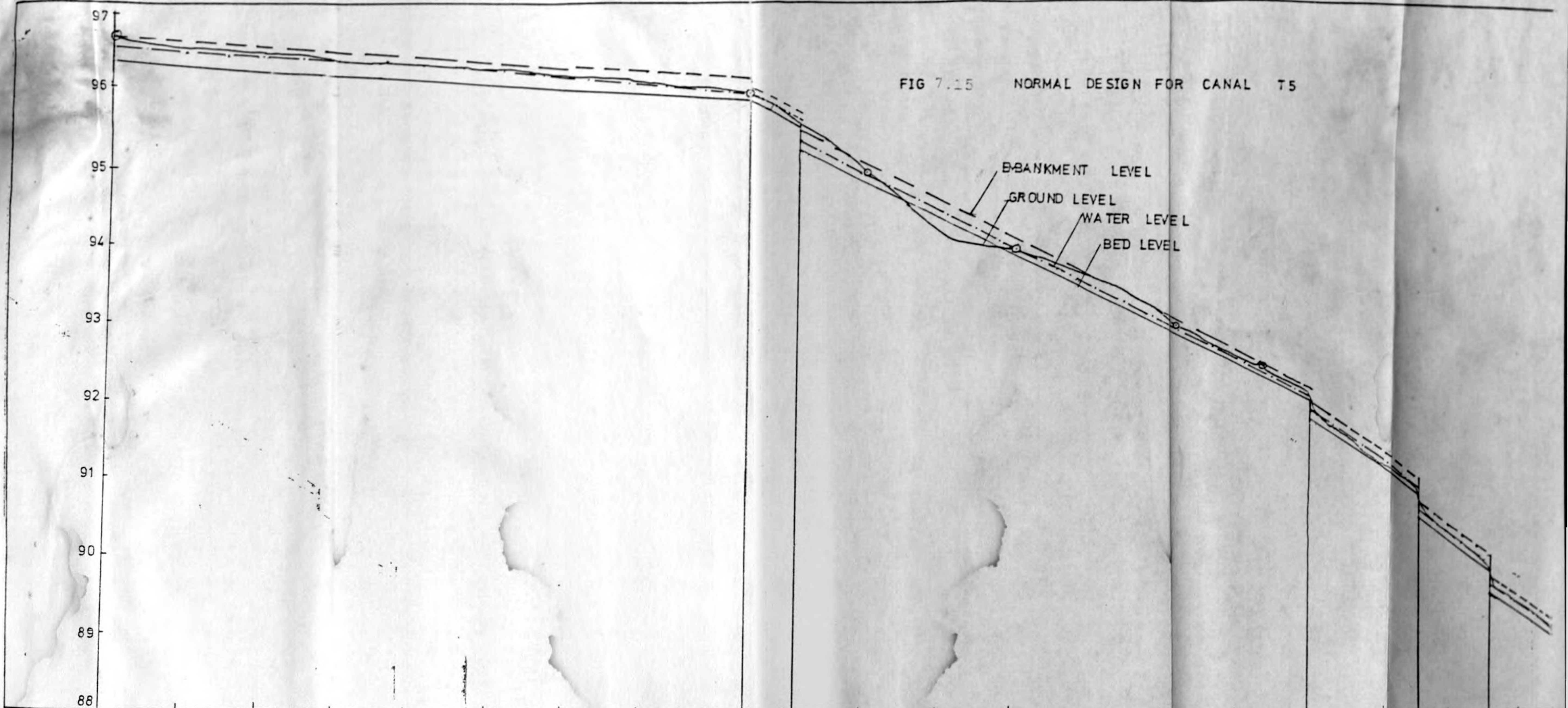


FIG 7.15 NORMAL DESIGN FOR CANAL T5

CHAINAGE (m)	BED LEVEL (m)	WATER LEVEL (m)	GROUND LEVEL (m)	EMBANKMENT LEVEL (m)
0.0	96.40	96.58	96.70	96.68
	95.90 / 95.90	96.08 / 96.01	96.00	96.18 / 96.11
540	95.60 / 95.30	95.70 / 95.40	95.60	95.80 / 95.50
960	92.05 / 91.85	92.16 / 9195	92.05 / 92.05	92.26 / 92.05
	90.85 / 9055	9095 / 90.65	90.85	91.05 / 90.75
	89.85 / 89.55	89.95 / 89.35	89.85	90.05 / 8975
1170	89.00	89.10	89.00	89.20

	0.0–(≈500)	(≈500)–960	960–(≈1050)	(≈1050)–(≈1135)	(≈1135)–1170
SLOPE (m/m)	0.001	0.007	0.01		
FLOW (l/sec)	12	12	12		12
	b = 0.3, d = 0.18, z = 1.5	b = 0.3, d = 0.11, z = 1.5	b = 0.3, z = 1.5	d = 0.10	