DESIGN OF AN IRRIGATION SYSTEM FOR AN AREA IN THE AWASH VALLEY OF EASTERN ETHIOPIA

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PREFACE

The area for which this irrigation system is designed is located 9°20'50" North Latitude and 40°10'55" East Longitude. This is within the Awash River Basin in Eastern Ethiopia. The climatological and hydrological data, the soils and topographic maps, soils and economic survey reports, and general agricultural production and development studies were obtained from the Awash Valley Authority.

The data and results are presented in the English and metric systems. The first was required for the design calculations and the latter is used in the country.

The main objective of the project was to acquaint the author, on a synthetic basis, with the approach to planning, design and layout of an irrigation system design project. The results and design presented should help any agency with the method of design but direct application should be supported by more detailed research and studies of specific areas.

The Blaney-Criddle method of estimating the consumptive use of water was employed in estimating water requirements of cotton, grain sorghum, and peanuts.

Effort was made in selecting the most common and appropriate spelling of place names since there is no standard of spelling adapted.

It would be impossible to include all the names of the many here at Oklahoma State University and at home who have in one way or another contributed to the author's understanding and completion of the study as it would be unfair to fail to mention those to whom special thanks are due.

The author wishes to express his gratitude to the Agency for International Development under whose program the author was able to pursue his studies.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

Ethiopia has a total land area of 450,000 square miles and a population of 22 million. Only 15 per cent of the potentially cultivable land is cultivated at the present time and 90 per cent of its population is engaged in agriculture and livestock. Agriculture contributes 75 per cent of the gross domestic product and 90 per cent of foreign currency trade. A wide range of soils, climate and altitudes permit the production of a diversified range of agricultural commodities. From the central highlands that receive most of the torrential rains, rivers radiate in all directions. Not only is Ethiopia endowed with a combination of a variety of climatic conditions and abundant natural resources, but is also strategically located amidst countries that are not quite that fortunate.

The low density of population, the availability of abundant natural resources and a variety of climatic factors, the dependence of the population on the basic industry of agriculture, and the geographical location of the country cannot overemphasize the importance of the immediate development of large-scale scientific agriculture. This realization, of course, has not slipped the minds of those who are interested and actively engaged in the development of the nation. The second five-year plan allocates 20.9 per cent of investment to agriculture followed by industry which commands 18.8 per cent. Although there is a trend towards industrialization, agricultural products must provide the raw materials for industry, as well as foreign exchange required to purcahse the necessary machinery and equipment.

The "big rains" generally fall within the three-month period of mid-June to mid-September providing the farmer with a period of nine months of ideal conditions for farming operations. With these, however, comes the only climatic limitation as stated by Huffnagel (10):

> The greatest climatic limitation is the amount and distribution of rainfall, which in many parts, is so low that it produces desert or semi-desert conditions. Whenever those low rainfall areas can be irrigated, as for example, in the Awash Valley, valuable agricultural land can be gained.

This, of course, is a situation inviting the introduction and use of well-planned systems of irrigation. Scientific irrigation whether on large or small scale, on a full or supplemental level, is the application of the right amount of water at the right time to the soil in order to promote and maintain optimum growth of crops for maximum production. In general, the climate of Ethiopia exhibits conditions suitable for year-round production except for

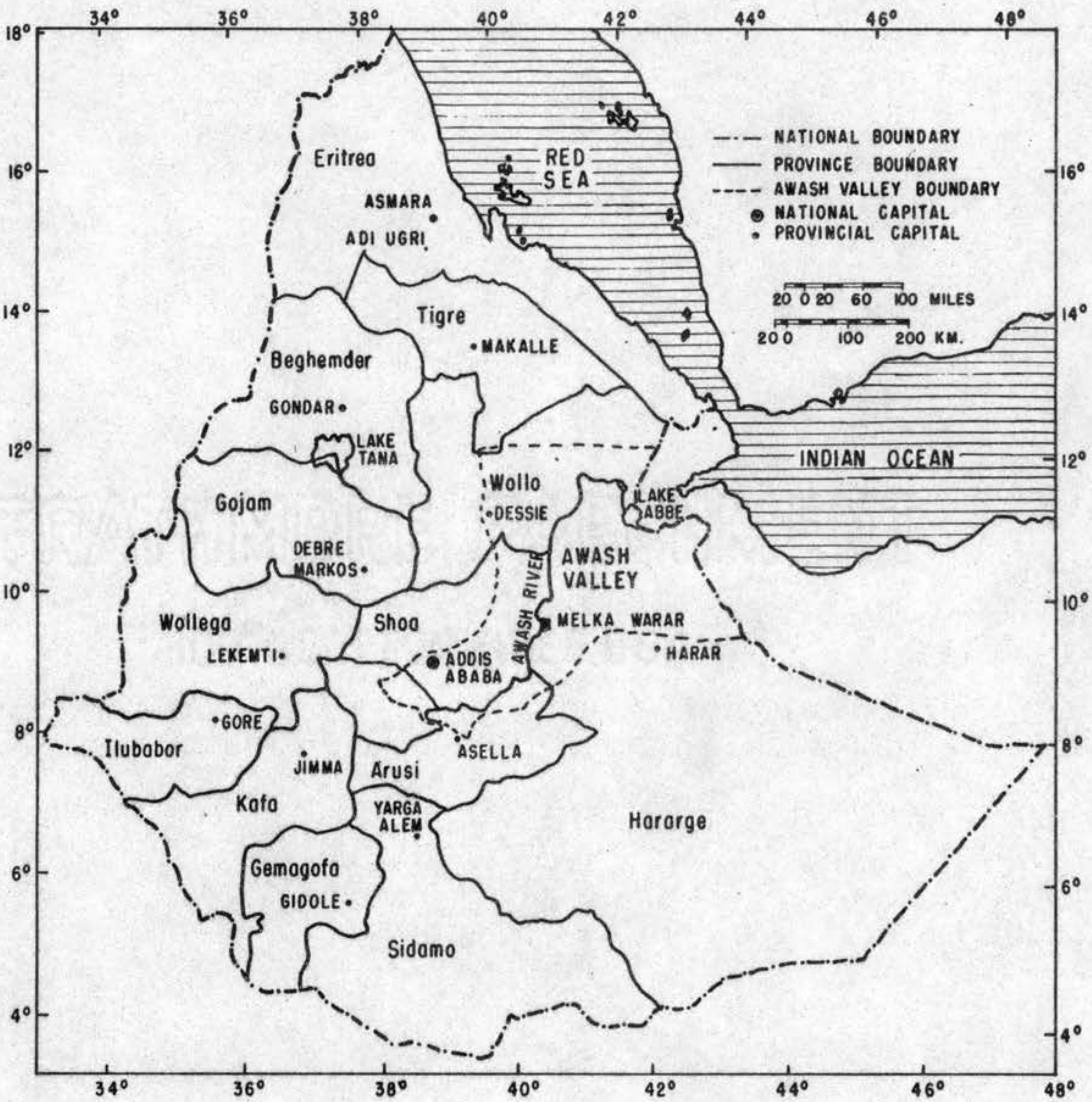

Figure 1. Ethiopia--its provinces and their capitals and the location of the Awash Valley and Melka Warar

the three rainy months which could, to some extent, limit farming operations and cause damage and spoilage of mature crops. The remainder of the year, however, has optimum conditions for crop production dimmed only by lack of water.

There then is the challenge for the irrigation engineer.

To a country like Ethiopia where development is at its infancy and where any project can upset the economy of the country, the successful implementation of any undertaking is vital to the national economy, the survival of the profession, and the continuation and inspiration of other projects. The proper planning, design, construction, and operation of an irrigation system, therefore, is essential. In order to achieve these, the basic irrigation problem of when and how much to irrigate must be solved. Irrigation studies and research results show that irrigation practices are influenced by the kind of crops grown and stage of maturity, the type of soil of that area, the amount and distribution of rainfall, temperature, and other climatic factors.

Undoubtedly, Ethiopia cannot and has not launched any major research programs on this field of study. She has neither the capital nor the personnel. Nevertheless, this should not be an excuse for inaction. It would, for instance, be wise to adopt selected results of research and actual applications following an exhaustive study, analyses, and comparisons of the variable factors of the areas involved. Empirical formulae of such findings could be modified for local conditions. These again could be adjusted after field applications. The Blaney-Criddle method of estimating the consumptive use of water is one such example.

Objectives

The objectives of the study were as follows:

1. Acquaint the author with methods and approaches of design of irrigation systems.
   a. Methods of estimating or determining water requirements by crops of given areas.
   b. Determining sizes, types, and number of canals and structures.
   c. Understanding the operation and maintenance of system.
2. Give the author background and experience in planning and operation of the system for teaching, research, and extension which he might be called upon in his home country.
3. Lend understanding of economics, management and financing, and legal aspects of irrigation enterprises.

CHAPTER II

REVIEW OF LITERATURE

The Awash Valley

The Awash Drainage Basin which is popularly known as the Awash Valley contains portions of four provinces. It includes the eastern parts of Shoa and Wello, the north-eastern part of Arusi, and the northern section of Hararge. Ato Mesfin (22) reports an estimated area of about 31 million acres (12,340,000 hectares). The size of the irrigable area is however estimated at about one million acres (400,000 hectares) by Bolten and Hennesy (22). Dushan and Iva LaLevich (17) estimate an area of 741,000 acres (150,000 hectares) in their preliminary surveys. Although there is a disagreement in the size, there is an agreement in the presence of significant land area.

This valley displays a diversity of relief. It includes the escarpments of the northwestern highlands having, in parts, an altitude of 13,132 feet (4,000 meters) and the lowlands of the Danakil Plains with as low elevation as 656 feet (200 meters). There are four distinct step-like formations: a) the northernmost part which is roughly

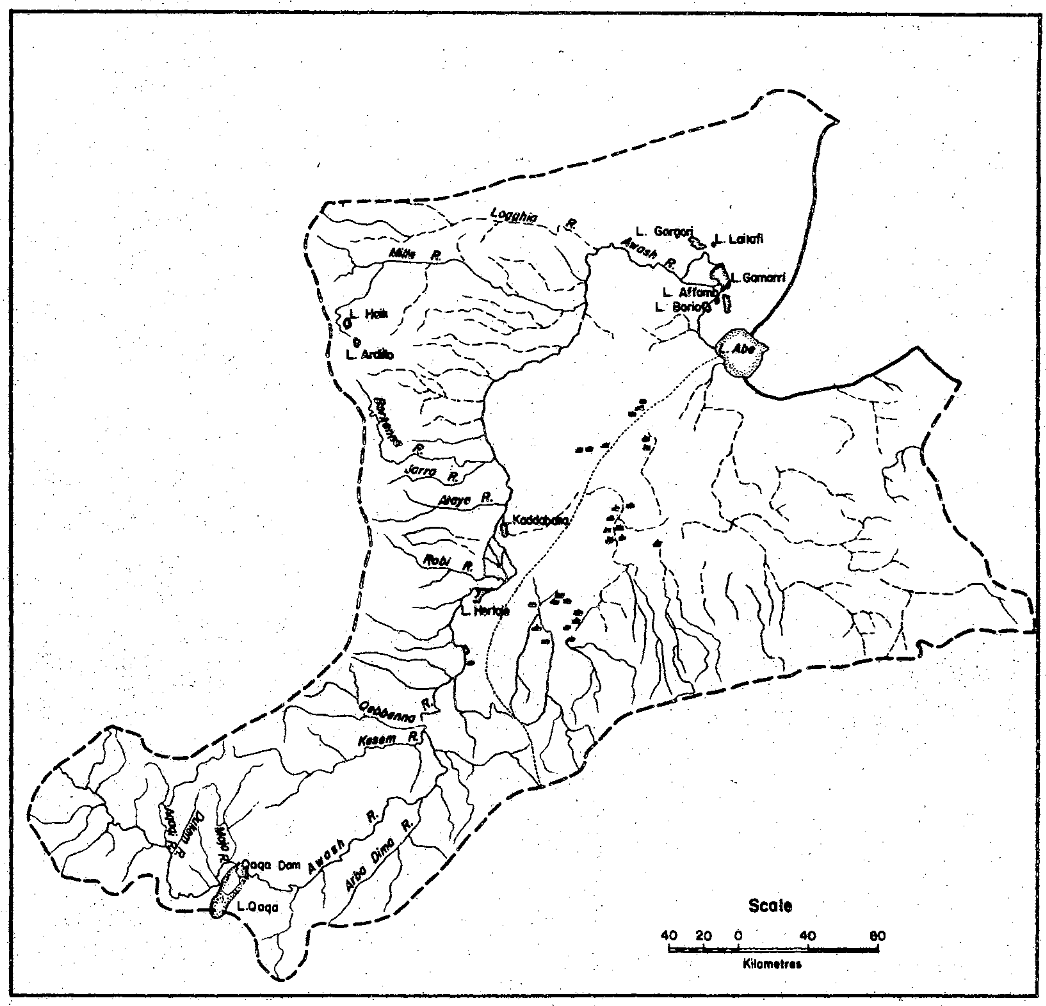

Figure 2. The Awash Drainage Basin

between 656 feet and 1640 feet (200-500 meters) above sea level, b) the central part which is between 1640 and 3280 feet (500-1000 meters), c) the edges of the escarpments that rise to an altitude of 3280 to 6560 feet (1000-2000 meters), and d) the divide which has an average elevation of 6560-9840 feet (2000-3000 meters) or even higher (22).

The lower valley borders the Read Sea coastal areas. It has extreme climatic conditions at certain times and sections. Ato Mesfin writes:

> The lower Awash Valley was a major national handicap; it was a forbidding desert barrier between the highlands of Ethiopia and the Red Sea; it was an inhospitable, malaria-infested, hot and dry despicable region; it was a region suited only to the hard and frugal existence of the few nomads that played no significant part in the national economy. The lower Awash Valley, therefore, was an asset only as an inhospitable natural defense. But economically it was a liability, since it formed an almost insurmountable barrier between the Ethiopian hinterland and the coast. The highlanders considered it absolutely unfit for settlement and development. Hence, it was one of the neglected lowlands of Ethiopia where nature reigned supreme.

By far, the greater portion of the Awash Drainage Basin is in the 1964-4920 feet (500-1500 meters) altitude area. Messrs. LaLevich confirm that the areas suitable for irrigation are within the elevation ranges of 1214-3937 feet (370-1200 meters). It is called the Central Awash Valley. It is a monotonously flat land with slightly undulating plains dotted by numerous but diminutive volcanic mountains. The area of the project is within this division of the

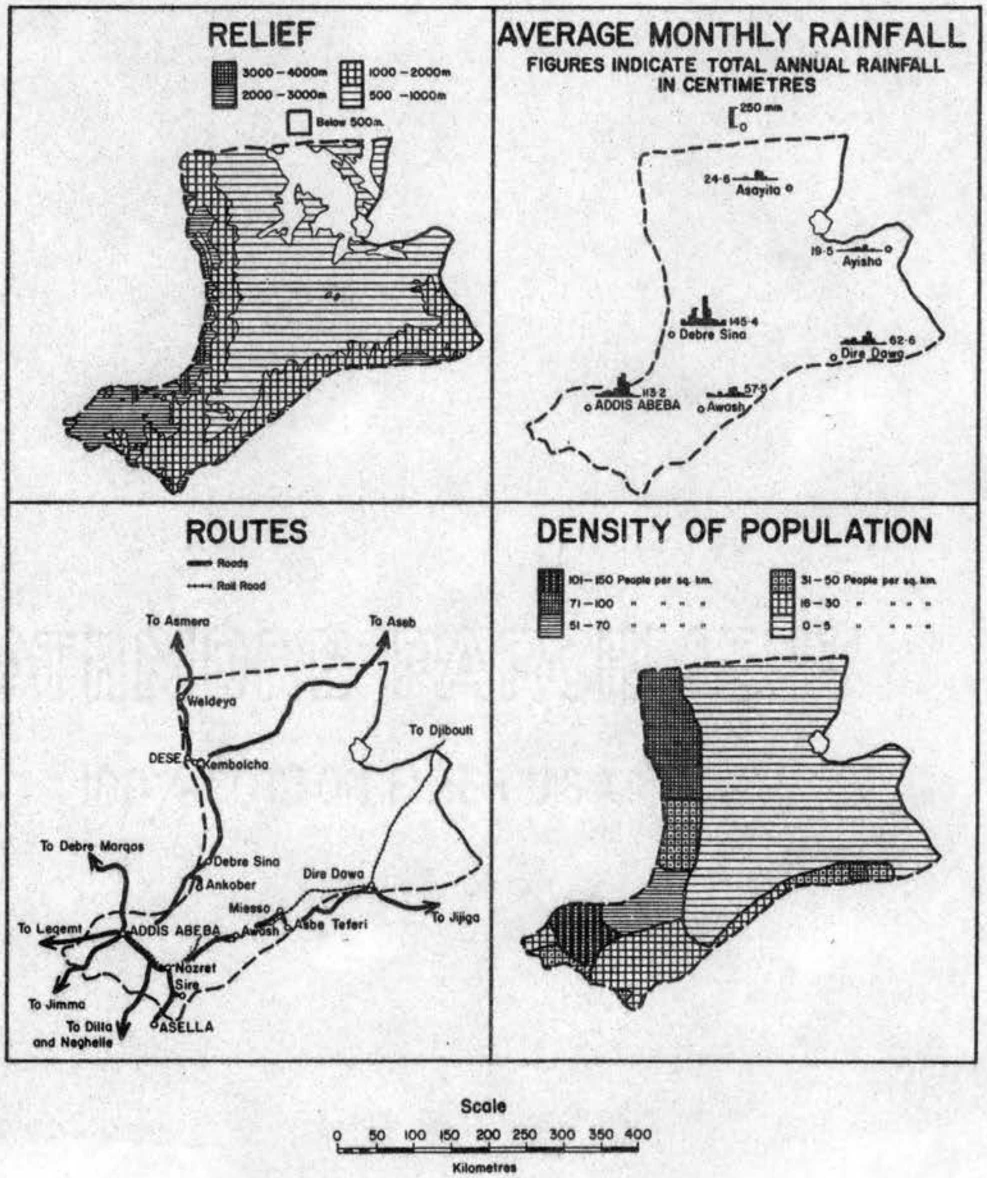

Figure 3. Relief, routes, rainfall, and population density of the Awash Valley.

region. It is considered to be one of the potentially richest agricultural regions of the country by various experts. But its agricultural development depends on the control and conservation of the waters of the Awash.

The higher altitude divisions of the valley have temperate to semi tropical climates. They constitute the most heavily populated and farmed region of the country. Their rich flat plateaus and valleys together with their climate and precipitation are ideal for wheat, barley, and teff (eragrostis abyssinica). The nation's most significant agricultural enterprise, the sugar plantation and industry is within this division.

In general, the Awash Valley is the most important single region of Ethiopia fit for large-scale modern agricultural development (1).

The Awash River

The Awash has its beginnings in the central Shoan Plateau. In its course of approximately 431 miles (690 kilometers), it is joined by smaller rivers and tributaries, the most important of which are the Akaki, Kessem, Kebbena, and Mille. The Awash is a perennial river. It makes its way from its source in a southeasterly direction to the edge of the escarpment, then assumes a north and northeasterly direction to its destination of the swamps of Lake Abbe. It is the only major river that flows to the

TABLE I

MONTHLY FLOW OF AWASH MEASURED AT THE AWASH STATION NO. 10 IN FT.^{3} AND M.^{3} RESPECTIVELY

Month	Period of Record 1961-62	1962-63	1963-64
January		2,394,865.4 67,824	3,793,480 108,000
February		2,224,918.4 63,011	4,385,570.5 127,034
March		3,666,989.4 103,853	4,276,853.1 121,123
April		5,542,257.6 156,960	3,864,538.3 109,446
May		6,754,251.4 188,424	3,863,584.9 109,419
June	4,237,200 120,000	4,003,659.7 113,386	4,708,023.5 133,334
July	4,776,850 135,000	5,357,080.6 151,744	4,277,947.7 121,154
August	5,119,950 145,000	17,227,466.5 487,892	4,514,819.1 127,868
September	5,650,553 160,027	12,030,328.9 340,706	7,003,244.2 198,336
October	3,531,000 100,000	4,103,304.9 116,208	12,798,497.9 362,461
November		2,830,096 80,150	8,704,056.2 246,504
December		2,088,375 59,414	5,618,739.1 159,126

east and does not cross the national boundary leaving the rich soils inland. It is the most important river in Ethiopia. Due to its source, the Awash has waters suitable for irrigation. Its contribution to the national development is not limited to agriculture. Its waters contribute to about 76 per cent of the hydro-electric power of the country. It is not navigable. In some areas it flows through deep rocky gorges which make it suitable for the construction of dams and reservoirs, a series of which is under plan and construction.

Description of Area

The area for which the irrigation system is designed is found in the Central Awash Valley. It is within the Amibara Irrigation Project area. The Amibara Project has a commanded irrigable area of 29,393 acres (11,900 hectares). Prior to the construction of the Koka Dam, this area used to get flooded when the Awash overflowed its shallow banks during the rainy season. The area selected for this thesis is the site of the Ministry of Agriculture Research Station. That particular sector is known as the Melka Warar. It is located at the sothern edge of the Amibara along the eastern shores of the river. It is about 20 miles (32 km.) from the railway station and town of Awash and about 15 miles (24 km.) from the electric power supply line leading to

AMIBARA – ANGELELE
IRRIGATION PROJECT
PROPOSED SCHEME FOR LAND ALLOCATION
Scale 1:100,000

	Total Commoded Area	Commanded Area According to the first Irrigation
Middle size form	3600 ha	2800 ha
Ministry of Agriculture	1100 ha	900 ha
big Concession	6900 ha	6350 ha
Big Concession or Settlement	5550 ha	4750 ha
Settlement	1950 ha	1850 ha
Total	19100 ha	16650 ha

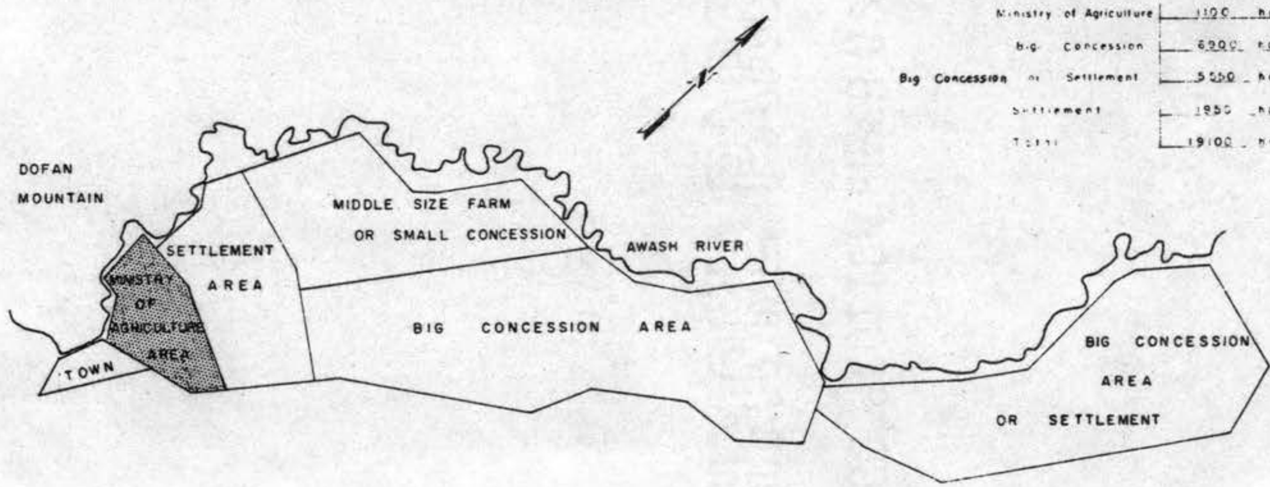

Figure 4. The Amibara and Angelele irrigation development plan.

Dire Dawa and Harar. A new dam near the town of Awash is under construction which will most likely be the source of hydro-electric supply for this area. According to plans of AVA, Melka Warar is the intake site for the Amibara Irrigation Project.

Soil maps of the Melka Warar sect of only 1000 acres (410 hectares) were available. However, soil tests for the entire area were made. It is also reported that these soil tests were representative of the Amibara Project (AVA). On this basis and also the availability of more land on the Amibara sector, an area of 3000 acres (1210 hectares) was chosen.

The great potential of this area depends on its rich virgin soils. The predominant soils of this area are alluvial soils of volcanic origin. They include soils in the range of clay loam to clay in texture. The average organic matter content is 2 per cent and the P^H values range from 7.5 to 8.5. Murphy (23) reported a P^H of 7.6 and organic matter content of 2.25 per cent and total nitrogen of 0.1316 per cent. The amount of phosphorus, potassium, and calcium present is high and that of magnesium is medium (23). The surface soils contain a high per cent of free carbonates which might affect the availability of phosphorus and potassium. The color of the surface soils varies from gray-brown to light-brown, but black soils are found.

The climate varies with altitude. Temperature as well as precipitation varies as one travels from west to east. The temperature increases from west to east and from south to north while rainfall decreases in that pattern. The reason for the reduction of precipitation is because the moisture-bearing monsoon winds moving in a northeasterly direction from the Indian Ocean are trapped by the central and eastern mountain ranges. The temperature, however, increases with a decrease in altitude and vice versa. The average annual temperature for the Central Awash Valley is between 71.6 to 77 degrees Fahrenheit (22-25°C). The average annual range is everywhere small about 41°F (5°C) while the average daily range is about 59°F (15°C). This indicates warm to hot days and cool nights, a condition that encourages plant growth. The average annual rainfall of the area is about 23.6 inches (600 mm.). The fact that the highest precipitation occurs during the hottest period and the amount of rainfall for an area that is warm or hot throughout the year is noteworthy.

The climate of the area has an obvious effect on the vegetation. The vegetation diminishes from west to east as does the precipitation. The dominant vegetation of the area is scattered acacias, thornbushes, and grass. It is not, however, uncommon to find green grass and even dense forests in spots where a body of water stood for some time after the rains. A wide variety of tropical and semi-tropical crops, fruits, and vegetation can be grown in this area. From observations of farms in the vicinity, Murphy reports cotton and peanuts along with fruits to be the major crops. The soil is suitable for cotton, oilseeds (peanuts, castor beans, sunflower, sesame), sugarcane, rice as well as for sub-tropical and tropical fruits (oranges, lemons, bananas, papaya, etc.). Tobacco, red pepper, and vegetables can also be grown (17). Most of these crops have successfully been grown on individual or cooperative farms where very little crude irrigation has been practiced. Grain sorghum is the leading crop grown without irrigation. It is mostly grown by the settled tribes along the Awash River flood plains as the water recedes.

The hydrological studies of this area began in February 1962. The objectives of these studies were to:

1. Prepare an inventory of the water resources of the entire valley.
2. Execute climatological study with particular reference to evaporation rates.
3. Study sediment flow.
4. Establish, if possible, storage dams at Kessem, Kebena, Mille, and Tendaho.

Since March 1962, a network of 26 hydrological stations, 8 complete meteorological stations, and 80 rain gages have been installed. It was, however, possible to obtain data from only one source as shown in appendices. This is the gage No. 10 at the Awash Railway Station. Incidentally, this is the site of the dam presently under construction. Before the construction of the Koka Dam, the Awash is reported to flow at the rate of 5650 cubic feet per second (160 cubic meter per second). It is expected that after the construction of this dam a constant flow of 1500 cubic feet per second (42 cubic meter per second) could be assured (10).

Present Land Use

The indigenous population of this area are the nomadic Dankalis. They graze their cattle, sheep, goats and camels on the natural grass moving up and down the plains along the Awash during the dry season and onto the high Aleydegi Plains during the wet season. Few of them practice settled agriculture at times of adequate rainfall. Their main occupation, nevertheless, remains to be nomadic pastoralists. The plains along the Awash that get flooded by the overflows provide significant pasturelands for these nomads after recession.

Some fairly large-scale farms had been initiated by some wealthy people from the cities and highlands, but due climatic conditions, shortage of labor supply, conflicts with the natives, and lack of skilled labor and mangement failed them. This is witnessed by the scattered remnants of such farms maintained by tenants and others owned by those who chose to stay.

Recently, however, farming has been encouraged and land is being granted to government agencies, concessionaires, and capable individuals for large-scale development with modern techniques. This is being carefully planned and followed by the AVA.

Economic Feasibility

Ethiopia has definite advantages over the rest of Africa. This nation is surrounded by the desert and semi-desert countries of north and east Africa and the Middle East. Her waters support the limited agriculture of Egypt and Sudan. The Red Sea brings her closer to these areas than any other potentially as rich country. She could indeed be called the "bread basket" of East Africa. Her agricultural products could simply find their way as far as India. Her grain crops could certainly contribute to the solution of the ever increasing food shortages of that part of the world.

The Awash Valley has the greatest potential to play the most significant role in this endeavor. Preliminary economic surveys by FAO experts show definite development potentialities of the basin. Estimates indicate that the annual net gains are almost double the annual costs with a benefit-cost ratio of 1.95 to 1 at 6 per cent interest rate for the irrigation phase. The irrigated cultivated land could be increased 14 times; the annual gross value

27 times; and the annual net gains 50 times. The irrigable area of 155,600 acres (63,000 hectares) could be more than doubled with the construction of dams (FAO). Although detailed pre-investment studies are necessary, these findings are believed to provide a reasonably accurate assessment of the potentialities in developing the agricultural economy of the Central Awash Valley. Irrigation system costs were based on existing systems, crop yields were conservative, and production was kept within estimated market demands.

Within a decade, the development of 16,300 acres (6,600 hectares) has made the country self sufficient in sugar and reduced the foreign currency drain by Eth. $6 million annually. This is appreciated more when one realizes that this makes up 6 per cent of total import. The same company, the Wonji Sugar Company, has been exporting sugar for the last three years.

There are other commodities to which this pattern of development might be applied. For instance, cotton could replace a large share of Eth. $40 million annual imports of cotton textiles and sisal and kenaf could also eliminate the Eth. $2 million spent on gunneybags annually. Similar products include canned fruits and vegetables, butter, cheese, soap and other oil bearing products (1).

Dushan and Iva LaLevich (17) estimated that there are roughly 741,000 (300,000 hectares) of land suitable for irrigation on which about 100 modern farms, 7,410 acres (3,000 hectares) per farm for the production of cotton and oilseed products. Following is a table prepared by the authors based on approximate calculations showing feasibility of investment.

After full development and according to this estimation, a farm 7,410 acres (3,000 hectares) in size could bring about Eth. $1/4 million per year. It stands to reason that an area 3,000 acres in size could yield approximately Eth. $100,000 per year. These estimates do not include the costs of dams.

TABLE II

FEASIBILITY ESTIMATES OF COTTON AND OILSEED FARMS

Purpose	One Farm	A Hundred Farms
Agricultural Implements and Tools	$222,684	$22,268,400
Buildings	259,550	25,955,000
Livestock	42,800	4,280,000
Digging up of Ground	150,000	15,000,000
I. Basic Means	$735,034	$73,503,400
Salaries of Permanent Staff		
Workers	$107,280	$10,728,000
Seasonal Workers' Salaries	122,000	12,200,000
Wear and Tear with Interest and Amortisations	190,240	19,024,000
II. Floating Capital	$419,520	$41,952,000
III. Value of Annual Production for the Market	675,065	67,506,500
Net Annual Income (III-II)	$255,545	$25,554,500

Prospects for Future Development

The potential of the Awash Valley has long been realized. The exploitation and development of its resources, however, require extensive surveys. The UNSF acting through FAO has already accomplished the preliminary part of this taks. For the most successful development of the entire valley, it is desirable to set up a master development plan based on the findings of UNSF/FAO and further detailed investigations. For this reason, the Awash Valley Authority was created as a chartered autonomous organization in 1962. The AVA and UNSF/FAO are now engaged in making a complete survey of the resources of the valley. Based on their plans, Ato Mesfin makes this statement:

> The Awash Valley as an integrated economic region has a very bright future, indeed. But this will largely depend on how much effective AVA's control will be on developments in the region.

Besides its natural resources and climatic conditions, this region enjoys the advantages of location. At present, it is bordered, except on the coast, by highways and a railway that connect this area to the major cities and ports. These are the centers of consumption and export of either food products or raw materials. Another highway now projected on the right banks of the river will link the town of Nazareth with Tendaho, a town located at the northern edge of the valley and on the highway leading to the main port of Assab. This is expected to cut the distance and the cost of transport by one-quarter. There is also a plan to extend the railway to the coffee-producing region of Sidamo Province (1, 22). Several schemes to increase water resources can be contemplated and some of them have been investigated in some detail by the UNSF/FAO survey. The following table prepared by the same agency summarizes the project of development of the basin.

A fact that will have a significant impact on the reclamation of the region is the density of its population and their occupation. The population distribution varies from 0-13 people per square mile (0-5 per square kilometer). These are nomadic tribes constantly moving back and forth along the banks of the Awash in the Central Valley. These tribes have very little value of land ownership. They could be concentrated into smaller areas under proper management. By common law these nomads use the state land for grazing their livestock. They have acquired this right only through centuries of use.

TABLE III

IRRIGABLE AND FLOOD CONTROL AREAS AND POWER PRODUCTION AFTER STRUCTURAL DEVELOPMENT

Project	Additional Areas Irrigable Ac. & Ha.	Total Areas Irrigable Ac. & Ha.	Flood Protection Ac. & Ha.	Power Prod. Capability (Mill. Kw. Hr.)
Current water resources with Koka Dam		155,610 63,000	172,900 70,000	110
Tendaho Reservoir Dam	121,030 49,000	276,640 112,000		80
Kessem Reservoir Dam	44,460 18,000	321,100 130,000		35
Awash Station Compensation Dam	12,350 5,000	333,450 135,000		
Meki River Diversion	37,050 15,000	370,500 150,000		12

Water Rights and Rates

By General Notice No. 299 of 1962, "The Awash Valley Authority possesses natural resources which require orderly and efficient development." At the present time, this authority has not come up with any water rights and use regulations. The problem of levying water charges, determining priorities, and distribution remains unsolved. This is a very complex task that requires full cooperation and combined efforts of agencies in many areas of government, business, agriculture, education, and social authority. It demands the mutual understanding and collaboration of the men having diverse engineering, scientific, economic, legal, and other technical skills. Expertise is necessary to devise and levy water rates and to establish a competent technical and operational service capable of dealing with the complex problems of water apportionment and its controlled distribution (1, 14, 17).

The AVA is currently drafting its water laws and rates. According to AVA officials, water rates will be based on the cost of diversion dams, canals and dykes, drainage systems, design, maintenance and depreciation.

System Design

Definition of terms. The following are terms as defined by Young (31):

Irrigation Requirement: The quantity of water, exclusive of precipitation, that is required for crop production. It includes surface evaporation and other economically unavoidable wastes. Usually expressed in depth for given time (volume per unit area for given time).

Water Requirement: The quantity of water, regardless of its source, required by a crop in a given period of time, for its normal growth under field conditions. It includes surface evaporation and other economically unavoidable wastes. Usually expressed as depth (volume per unit area) for a given time.

Consumptive Use (Evapo-transpiration): The sum of the volumes of water used by the vegetative growth of a given area in transpiration and building of plant tissue and that evaporated from adjacent soil, snow, or intercepted precipitation on the area in any specified time, divided by the given area. If the unit of time is small, such as a day or a week, the consumptive use is expressed in acre-inches per acre or depth in inches, whereas, if the unit of time is large, such as a crop-growing season or a 12-month period, the consumptive use is expressed as acre-inches per acre or depth in feet.

Irrigation Efficiency: The percentage of irrigation water delivered to the farm or field that is available in the soil for consumptive use by the crops. When measured at the farm headgate it is called farm irrigation efficiency and when measured at the field or plot it is designated as field irrigation efficiency.

Soil Moisture: The water in unsaturated soil. It is expressed as a percentage on a dry-weight basis, or in inches per foot depth of soil.

Field Capacity: The moisture percentage, on a dry-weight basis, of a soil after rapid drainage has taken place following an application of water. This moisture percentage is reached approximately two days after irrigation.

Available Moisture: The quantity of water in the soil that is available for plant use, as limited by field capacity and permanent wilting percentage. It is expressed as percentage of the dry weight of the soil or depth of water in inches per foot of depth of soil.

Moisture Percentage: The percentage of moisture in the soil based on the weight of the oven-dry material.

The profitability of an irrigation enterprise depends, to a large extent, on the soundness of the system design. By far the largest portion of the investment is allocated for the survey, analysis, planning, and design of the irrigation system. It is, therefore, important that the system be designed with the most economical consideration. An ideal system design from an engineering point of view is not necessarily profitable.

Linsley and Franzini (19) point out that the first step in planning an irrigation project is to establish the capability of the land to produce crops which provide adequate returns on the investment in irrigation works. No two irrigation projects are identical, and no absolute outline or standard of procedure for project design is feasible. The following list as outlined by Linsley and Franzini, however, summarizes in general terms the steps which are required for most projects:

1. Land classification
2. Estimation of irrgation water requirement
3. Determination of sources of available water
4. Analysis of chemical qualities of available water
5. Design of dams and spillways for storage reservoir or diversion works
7. Design of the distribution works
8. Economic analysis of the project to determine whether the estimated cost is returnable from the potential benefits, and financial analysis to establish repayment plans
9. Security of legal title to water
10. Establishment of an organization which will operate the project. In some cases this is a necessary first step, since the operating organization may also design the project.

Israelsen and Hansen (13) list the following criteria important in the design of a surface irrigation system:

1. Store the required water in the root zone of the soil. The amount of water that must be stored varies with soil, crop, and stage of plant growth. The system, therefore, should be flexible enough to meet these varying conditions.
2. Obtain reasonably uniform application of water. Here, again, the intake rate of crops and soils, size of stream, and the time vary making it practically impossible to design a system that would provide a satisfactory control under all conditions. An elaborate system of control devices, together with sound land grading, can provide a nearly uniform distribution and application. For good distribution, it is recommended that the water reaches the end of the field in about one-fourth the total irrigation time.
3. Minimize soil erosion. It is impossible to eliminate erosion as long as there is water moving. However, proper design and layout and management can minimize erosion significantly.

4. Minimize runoff of irrigation water from the field. Some ways of reducing runoff are: Reducing the amount of water entering the field, the velocity, and the slope. Reduction of these factors increases intake rate and reduces runoff considerably.
5. Provide for beneficial use of runoff water. This involves reuse of the runoff water in lower lands or by pumping it back to project area.
6. Minimize labor requirement for irrigation. Good land preparation, control, and irrigation layout can minimize labor requirement.
7. Minimize land used for ditches and other controls to distribute water. Proper layout providing for longer runs through better land grading can minimize land wasted for the construction of more ditches.
8. Fit irrigation system to field boundaries. The length of irrigation fields and the design of the system are controlled by the boundaries.
9. Adapt system to soil and topographic changes. A furrow running through different soil textures experiences uneven distribution due to differences in intake rates and water-holding

capacities of these textures. These textures require different irrigation frequencies. Therefore, the irrigation layout should be such that a minimum variation in these factors occurs in these fields.

10. Facilitate use of machinery for land preparation, cultivation, furrowing, harvesting, etc. Allow for roads capable of handling the widest machinery expected.

Water Requirements and Methods of Estimation: Crop-water requirement is the quantity of water, regardless of its source, required by a crop in a given period of time, for normal growth under field conditions. It includes surface evaporation and other economically unavoidable wastes. It is usually expressed as depth (volume per unit area) for a given time (31). Total water requirement cosists of water needed by the crop plus the losses associated with the delivery and application of water. Irrigation water requirement on the other hand, is that portion of the consumptive use which must be supplied by irrigation. It is the consumptive use less the effective precipitation. The effective precipitation is the portion of rainfall available for plant use (2).

There are several methods of estimating the consumptive use of water which is the basis for estimating the water requirement by crops, but there is no known method of determining this quantity. As a matter of fact, water requirement is influenced by several variable factors. The actual amount can vary within the same locality. Dissimilarity in soil, climate, or geology of the area greatly changes or affects total water requirement. In the process of estimating water requirement, the consumptive use of water by crops of interest is estimated. This value is then adjusted according to known or assumed efficiencies of delivery and application and other coefficients or correction factors. Consumptive use may be estimated by direct measurements and climatic observations and studies of which the Blaney-Criddle method is one. Israelsen and Hansen list the tank and lysimeter experiments, field experimental plots, soil moisture studies, integration method, and the inflow-outflow methods as direct methods of measuring consumptive use. They also include the Penman, Thornthwaite, Lowry-Johnson and the Blaney-Criddle methods as climatic indices for estimating consumptive use (13).

The Blaney-Criddle method: In estimating the water requirement by crops, the Blaney-Criddle method is popular for the arid and semi-arid regions. This method has been found effective in estimating consumptive use of water with only the climatological data and the per cent of daylight hours available. The latter is obtained from tables. The empirical formula for this method was developed for the western United States. It is, however, used for estimating the consumptive use by a particular crop in a given area if the consumptive use by the same crop in a different area is known, the temperature data is available, and the coefficients are determined or estimated.

The mathematical expression of the formula is:

$$U = K\Sigma tp = KF$$

Where the following quantities must be determined for the same period:

U = Consumptive use of water: Inches for a given time period.

F = Sum of the consumptive use factors for the period (sum of the products of mean temperature and per cent of monthly daytime hours or (t x p)/100).

K = Empirical coefficient (annual, irrigation season, or growing season).

t = Mean monthly temperature in degrees fahrenheit.

p = Percentage of daytime hours of the year, occurring during the period.

For monthly calculations small letters are used for clarity:

f = Monthly consumptive use factors, $(t \times p)/100$

k = Monthly coefficient, $\frac{u}{f}$

$u = kf$ = Monthly consumptive use, inches (2, 13).

<u>Design of canals</u>: The design of canals and conveyance structures involves considerations of and limitations by various factors. There are two types of irrigation canals, lined and unlined. The most common irrigation conveyance chanels are ditches excavated in the natural material. Without artificial lining of channel beds and sides, these are called earth canals (13). Earth canals have the advantage of economy and simplicity of construction. There is, however, danger of failure unless their design and construction is accompanied by skill and experience. Where the water value is high due to its duty and scarcity, canals are lined in order to reduce or prevent seepage, allow higher velocity, insure stability and endurance, prevent growth of weeds, and minimize or eliminate maintenance expenditures. The benefits accruing from the saving of irrigation water as a result of lining can offset the savings by not lining the canals in localities where lining materials are readily available, cost of lining is low, and where skilled labor and machinery are available.

Irrigation canals can have various shapes and sizes of cross sections. The trapezoidal shape is common for earth canals.

According to Etcheverry (6) the design of canal cross sections involves:

1. Determination of bed width and depth or selection of a fixed depth and the determination of the corresponding bottom width required to give a desired fixed velocity.
2. Selection of side slopes for the water cross section and for the outside of the bank.
3. The consideration of berms and spoil banks.
4. Selection of height of top of bank and the freeboard.
5. Selection of top width of the crown of bank.

The dimensions of depth and width can vary with type of material through which the canals are excavated. These in turn govern the velocity permissible and the slope allowable. Etcheverry and Israelsen and Hansen present an empirical formula:

$$b = 2d \tan \frac{\theta}{2}$$

for determining the bottom width. Here b is the bottom width, d is the depth of the cross section and θ is the angle between the side slope and the horizontal (6, 8, 13). Simons and Albertson found the width and depth to vary with the wetted perimeter and hydraulic radius respectively. These quantities vary also with variation in volume of water flowing through and with the kind of bed materials of the alluvial soils. The empirical formulas of:

$$d = 1.25R = C_1Q^n$$

$$b = 0.68P = C_2Q^n$$

have been used in estimating the depth and width of canals in alluvial lands. The values of the constants of C_1 and C_2 depend upon the parent material of the soil (26).

Depth and width could also be estimated or determined from the basic continuity equation relating flow to cross sectional area and velocity.

$$Q = VA$$

Where A = Cross sectional area in square feet

V = Velocity in feet per second

Chezy found that $V = C\sqrt{RS}$

Where R = Hydraulic radius (area divided by wetted perimeter)

S = Slope of the energy grade line or the piezometric head line

The Chezy coefficient is mostly expressed by:

$$C = \frac{1.49}{n} R^{1/6}$$

Combining these equations results what is commonly called the Manning Equation of:

$$V = \frac{1.49}{n} R^{2/3} S^{1/2}$$

which is applicable when channel slope is less than about 10 per cent. The continuity equation for earth channels then becomes

$$Q = \frac{1.49}{n} R^{2/3} S^{1/2} A$$

In design work the value of n recommended for uniform, straight earth canals is 0.0225. The slope can be measured (3, 13). Linsley and Franzini recommend an n value of 0.025. From this equation the values of b and d could be determined by trial and error.

The canal cross section displaying the most advantageous hydraulic elements is when the hydraulic radius is equal to one-half the depth (19).

The side slopes of trapezoidal earth canals vary from 1/4:1 for hardpan and rock formations to 3:1 for cuts in very sandy soils. Side slopes of 1 1/2:1 for small canals and laterals and 2:1 for larger canals have been found adequate in canals constructed by the Bureau of Reclamation. Considerable change in dimensions is noticed in fills after the natural processes of weathering and compaction take place (6, 8, 19, 26). The stability and nature of bank material also affects these ratios.

Adequate freeboard above the design water level must be provided as a precaution against accumulation of sediment in canals, reduction in hydraulic efficiency by plant growth, wave action, settlement of the banks, and flow in excess of design quantities during storms. The freeboard recommended by the Bureau of Reclamation for trapezoidal earth canals is approximately one-fourth the water depth plus one foot with a maximum of 6 feet (26).

$$\text{Freebaord} = \frac{d}{4} + 1$$

Etcheverry states that the freeboard varies from one foot for small canals to a maximum of three feet for large canals. Within these limitations a safe rule given is to make the freeboard above the maximum water level equal to one-third of the water depth.

Velocities for earth canals usually range from 1 1/2 feet per second for small laterals to 3 feet per second for larger canals according to Rippon. Linsley and Franzini recommend a maximum velocity of 2 feet per second for silt loams. The permissible velocity to be used should be based on a careful study of the materials through which the canal or lateral will be constructed and the slope of the canal.

The top width of banks is determined by their use. The width of these banks used for the operation of maintenance machinery is determined by the size of the machinery. These widths also depend upon the top width of the water surface, the nature and condition of the bank materials, and the method of construction. Without these limitations, the width generally used ranges from a minimum of about 2 feet to a maximum of 10 feet for large canals (6, 19).

Rippon states that the width considered necessary to accomodate modern rubber-tired equipment ranges from a minimum of 12 feet for small canals to a maximum of 24 feet for canals with a capacity of 5000 cfs. or larger.

Many canal failures occur as a result of foundation difficulties rather than failure of banks. It is important, therefore, that thorough study be made of the foundation conditions during design and construction (26). Special treatments such as extending compacted embankment to an impervious layer if it lies within a reasonable distance may be necessary. Another weak point in canal construction is the contact plane between the embankments and ground surface. This could be minimized by clearing all brush and foreign material and contact could be improved by plowing to depths up to 6 inches or more.

Drainage: Drainage is defined as the removal and disposal of excess water and salt from agricultural lands. There are two types of drainage: Surface and subsurface or underground drainage. The latter is considered a land maintenance operation because it helps keep the physical and chemical conditions of the soil in the optimum situations. The basic necessity of subsurface drainage is to lower the shallow water table. A quotation from Maierhofer (20) reflects the importance of sound drainage:

> With good drainage even the poor farmer cannot ruin the land but with poor drainage even the good farmer cannot succeed. Sooner or later salts or ground water, or both, will rise to the root zone soil. This may take 2 years, or 20--sometimes longer.

The benefits from drainage are that it improves the soil structure and increases and perpetuates the productivity of soil. Some of the agricultural benefits as pointed out by Israelsen and Hansen are that it (13): (1) Facilitates early plowing and planting, (2) Lengthens crop-growing season, (3) Provides more soil moisture and nutrients, (4) Increases aeration, (5) Promotes bacterial growth, (6) Leaches down excess salts from the soil, and (7) Assures higher temperatures which are essential for crop growth and development.

Permeability is the major soil property of concern in a drainage study. It is also the dominant variable influencing the feasibility and cost of drainage. In planning the drainage system, consideration must be given to the height to which ground water can be allowed to rise and saturate the soil and the removal of the excess ground water. This is controlled by storage capacity of the soil as measured by its specific yield characteristic. This is the amount of non-capillary pore space in the soil that will hold water and allow it to drain by gravity.

The selection of surface drainage facilities for individual field areas depends largely on the topography, soil characteristics, crops, and availability of suitable outlets.

The first step in the selection of storm-drainage works is the determination of the quantities of water which must be accommodated. In most cases, only an estimate of the peak flow is required, but where storage of water is proposed the volume of flow must also be known, explains Maierhofer (20). Twenty to thirty per cent of the irrigated lands in aird regions need drainage to continue their productivity according to Israelsen and Hansen. In these regions, drainage follows irrigation whereas in wet or swampy areas drainage precedes other operations.

Steps in design of drainage system as outlined by Linsley and Franzini (19) are summarized as follows:

1. Prepare a detailed contour map of the area. A contour interval of one foot is commonly necessary.
2. Select the location of system outlet. If several outlets are possible, an economic study of the alternatives may be advantageous.
3. Determine the drainage modulus for underdrains, and estimate the amount of water the ditches will intercept.

4. Layout a system of ditches of adequate size to carry the expected flows.
5. Determine the proper depth for tile drains and plan the tile drain layout.
6. The first trial layout of mains may require revision after the plan for underdrains is completed. The entire system should be planned for minimum cost by use of shortest possible routes for pipes and ditches.
7. Estimate project costs and proceed with legal steps necessary to undertake the project.

The trapezoidal cross section is most common for drainage ditches, with side slopes not steeper than 2/3:1. Slopes of 2:1 or 3:1 are required in sandy or clay soils with little cohesion as stated by Linsley and Franzini (19). The slope, alignment, and spacing of ditches are determined mainly by local topography. Lateral ditches are usually 1/2 mile apart but on level land a spacing of 1/4 mile may be necessary. With favorable land slopes a ditch spacing of one mile may be feasible. The ditch system must follow the natural depressions especially on shallow soil, but where possible, the ditches are run along property lines, Schwab, et al., Israelsen, etc. (8, 13, 19, 20).

Ditches are usually between 6 and 12 feet deep. Where the lateral joins the main, their depth must be the same so as to minimize scouring. It should also enter the drain at an angle of about 30 degrees in the direction of drain as reported by Maierhofer (20).

CHAPTER III

PROCEDURE AND DESIGN

Location and Description of Project Area

The design project is undertaken for the Melka Warar area of the region for which topographic and soils maps, soil and water analysis results, economic feasibility and agricultural development possibilities reports were available. It is found in the middle or central Awash Valley and its geographic location is 9°20'50" North Latitude and 40°10'55" East Longitude. It is currently under development by the Ministry of Agriculture for the establishment of an agricultural research station. The size of this area is about 2,700 acres (1,100 hectares). However, an area of 3,000 acres (1,210 hectares) was used in calculations due to the abundance of vast area of similar soil and physical characteristics on the northern boundary. Topographic maps with 0.50 meter (1.64 feet) contour intervals prepared in 1964 by Nor-Consultants, Addis Ababa, were obtained from AVA. Melka Warar is within the Amibara Development Area (Fig. 4) It is a relatively flat land on the eastern sides of the Awash. Before the construction of Koka Dam and the control of the Awash River flow during the wet season, this area used to get flooded. It is about 22 miles (35 km.) north of the town of Awash and about the same distance from the all-weather highway and the railway. With the completion of the compensation dam which is under construction, a constant supply of water and possibly electric power is expected. It is confirmed by the AVA that there is sufficient irrigation water for more than twice the area of the development plan.

Soils

The results of the pedological studies were also obtained from the AVA. The analytical work was done at the soil laboratory of the Haile Sellassie 1 University Forestry Institute. The field survey was carried out by AVA staff. Sixty-two profiles were examined and 25 of these were trenches. The samples were taken from each profile at average depths of 0-0.10, 0.40-0.50, 0.80-1.50 meters (0-0.33, 1.31-1.64, 2.62-4.92 feet respectively.

Soil classification of the area was based on water saturation percentage factor. There were three main classes with the following saturation percentage values:

I.	Soil classes 11 and 12	More than 50%
II.	Soil class 2	Between 40 and 50%
III.	Soil class 3	Less 40%

Soil class 11 contained the impermeable, deep black soils with high water saturation percentage and very low lime content. Water saturation decreased with depth. These soils have high field capacity but lower moisture availability

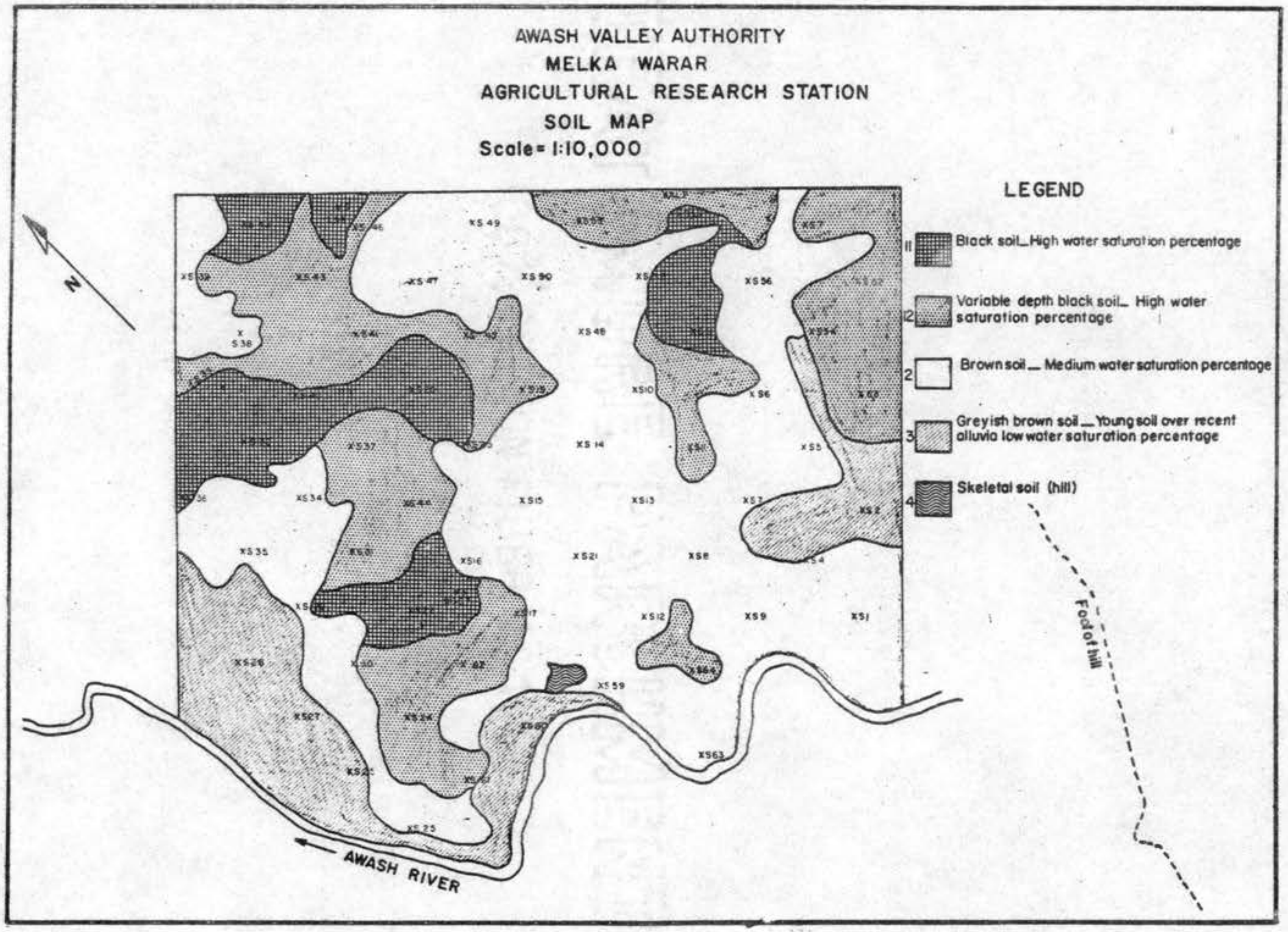

Figure 5. Melka Warar soils map.

TABLE IV

AVERAGE CHARACTERISTICS OF SOILS OF MELKA WARAR

Characteristic	Class I1	Class I2	Class 2	Class 3
p^H range	7.5-8.0	7.5-8.0	8.0-8.5	8.0-8.5
Cation exchange capactiy	> 65 Meq./100 gm.	60 Meq./100 gm.	60 Meq./100 gm.	60 Meq./100 gm.
Exchange complex saturation	97%	97%	97%	97%
Exchangeable calcium	70%	75%	69%	70%
Exchangeable sodium	< 5%	< 5%	< 5%	< 5%
Salinity	< 0.5 MMHO./CM	< 2.2 MMHO./CM	> 2 MMHO./CM	4 MMHO./CM
Organic matter content	1.5%	2%	> 2%	2%

because of high moisture percentage at wilting point and difficulty of root penetration which follows drying.

Class 12 also has high water saturation percentage soils with variable depth of black soils over alluvia containing little lime with variable depth. They are generally shallow: 0.20-0.80 meters (0.65-2.62 feet). The subsoil is brown loam or clay loam. Water saturation percentage decreases with depth here too and often reaches 40% at depths of 0.80 meters. The top soils of this class are impermeable but are better drained and easier to work than the black soils of Class 11.

The medium saturation percentage soils are relatively young soils over alluvia or brown soils containing very little lime. The top layers have saturation percentages between 40 and 50 per cent but less than 40 per cent at lower depths. They have medium permeability and are well drained. The average moisture is relatively high with a penetrable structure for root development.

The low saturation percentage soils are also young soils with little lime. Their color is grayish or brown and they have coarser texture. Water saturation percentage is homogeneous for the profile and is less than 40 per cent. A summary of the average characteristics obtained from AVA reports is tabulated in Table IV.

In the irrigability classification, Class II was divided into three types. These are indicated and described

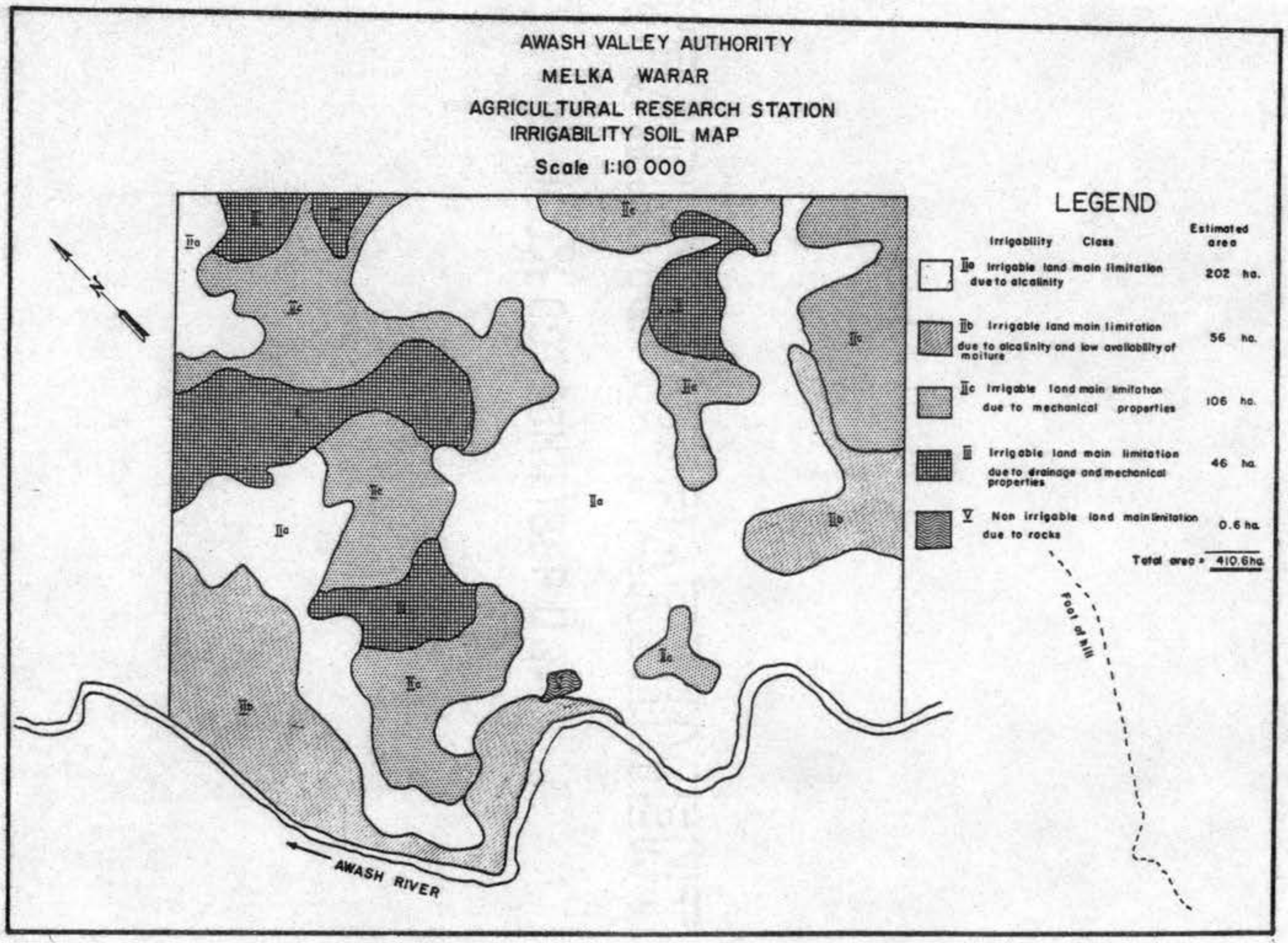

Figure 6. Melka Warar irrigability soil map.

in Fig. 6. The chemical analyses revealed that the P^H values for the surveyed soils ranged from 7.5-8.5. The soils of this area are rich and suitable for irrigation excluding the black soils which are limited to shallow-rooted crops without treatments. These black soils are very hard to work when dry and cause a rapid wear of implements and heavy pre-planting irrigation is necessary. These make up about 11 per cent of the surveyed area. The texture of area included gravel in a few spots. The organic matter content is relatively high but phosphorus and nitrogen fertilizer applications could give good results, as indicated from soils reports, especially in alkaline classes. In the first use cycle, soil moisture equilibrium rather than soil fertility could be the production limiting factor.

Crops

The crops selected for the project are cotton, grain sorghum, and peanuts. These crops are well adapted to the area. Grain sorghum is grown in large quantities by the natives. The adaptability of cotton and peanuts is indicated by the returns of the little acreages grown. Cotton has been highly recommended for the area by AVA and FAO experts to relieve the heavy import of cotton lint from abroad. The selection, therefore, is based on the importance, adaptability, rotation requirement, and market demands.

Water Requirements

In estimating the consumptive use (evapo-transpiration) of water by cotton, grain sorghum, and peanuts for the Melka Warar area, the Blaney-Criddle method was used. The per cent of daylight hours was obtained from tables and adjusted for project area. The consumptive use coefficients used were estimated in a previous research project for the region. Only a year's rainfall data were available for Melka Warar. Therefore, irrigation water requirements for other surrounding localities whose weather data was available was worked out to see the deviation in results. Average data for the years 1952-59 for Awash Station were also available and the the diversion water requirement based on these data was the lowest and consequently showed the largest deviation.

In estimating the volume of water that must be diverted to supply the water requirement, peak irrigation water requirements were used. A conveyance and delivery efficiency of 56 per cent was assumed. The potential water requirements for the various crops was estimated on a rotation basis. Double cropping was also assumed possible for grain sorghum and peanuts. Irrigation water requirement, estimated potential consumptive use values, and volume of diversion water for the different crops, areas and months are shown in Tables IX through XII.

System Design

In the design of the system, stable channels in alluvial materials were considered. Stable channels as defined by Lane(18) are unlined earth canals carrying water, the sides and banks of which are not scoured by the moving water, and in which objectionable deposits of sediment do not occur. The design project area has alluvial soils and design techniques of alluvial channels were carefully followd. There are two theories concerned with the design of channels in alluvial materials. These are the regime theory and the tractive-force theory. The tractive-force theory was initiated in India by Kennedy and developed by Lindley, Lacey, Bose, Blench and others. Three American engineers, C. R. Pettis, L. B. Leopold, and T. Maddock, Jr., investigated the applicability of the regime theory to American rivers. Recent work on the subject has been presented by D. B. Simons and M. L. Albertson whose empirical formulas for determining the channel characteristics have been used.

In determining the channel characteristics, five classes of bed and bank materials were considered. These are classed as:

A. Sand bed and banks

B. Sand bed and cohesive banks

C. Cohesive bed and banks

TABLE V

DESIGN EQUATIONS FOR ALLUVIAL SOILS

Unknown	A	B	C	D	E
P = wetted perimeter	$3.25Q^{.512}$	$2.46Q^{.512}$	$2.10Q^{.512}$	$1.66Q^{.512}$	$1.63Q^{.512}$
R = hydraulic radius	$.500Q^{.361}$	$.431Q^{.361}$	$.357Q^{.361}$	$.251Q^{.361}$	$.325Q^{.361}$
A = area = RP	$1.625Q^{.863}$	$1.06Q^{.873}$	$.75Q^{.973}$	$.417Q^{.973}$	$.527Q^{.873}$
V = velocity = $\frac{Q}{A}$	$.615Q^{.127}$	$.944Q^{.127}$	$1.33Q^{.127}$	$2.40Q^{.127}$	$1.90Q^{.127}$
d = water depth = 1.25R	$.625Q^{.316}$	$.539Q^{.361}$	$.446Q^{.361}$	$.314Q^{.361}$	$.406Q^{.361}$
$\overline{w}$ = average depth = .8P	$2.6Q^{.512}$	$1.968Q^{.512}$	$1.68Q^{.512}$	$1.328Q^{.512}$	$1.304Q^{.512}$
W_T = top width = $1.15\overline{w}$	$2.99Q^{.512}$	$2.263Q^{.512}$	$1.932Q^{.512}$	$1.527Q^{.512}$	$1.5Q^{.512}$
b = bed = .68P	$2.21Q^{.512}$	$1.673Q^{.512}$	$1.428Q^{.512}$	$1.129Q^{.512}$	$1.108Q^{.512}$

A = Sand bed and banks

B = Sand bed and cohesive banks

C = Cohesive bed and banks

D = Coarse non-cohesive material

E = Imperial data like B (large sediment loads)

TABLE VI

DESIGN OF THE IRRIGATION CHANNELS FOR THE VARIOUS BANK AND BED MATERIALS - Q_D = 46.7 CFS

Unknown - Feet	A	B	C	D	E
P = wetted perimeter	23.22	17.6	15.03	16.0	15.22
R = hydraulic radius	2.0	1.724	1.427	1.35	1.40
A = cross-sectional area	46.6	30.4	21.5	21.65	21.29
V = velocity	1.002	1.538	2.166	2.16	2.19
d = water depth	2.50	2.156	1.784	1.65	1.75
$\bar{w}$ = average width	18.576	14.08	12.01	13.1	12.165
W_T = top width	21.39	16.20	13.81	14.2	13.33
b = bed width	15.80	11.96	10.2	12.0	11.0
s = channel slope	.000188	.000295	.000392	.000396	.000606
F_R = Froude number	0.112	0.185	0.284	0.296	0.292

D. Coarse non-cohesive materials

E. Imperial data like B with large sediment loads

The results of calculations to determine the channel characteristics for this project are found in Table VI. These results have been compared with the results obtained by use of other empirical equations.

The Froude number $\left(\frac{v}{\sqrt{gd}}\right)$ for the different materials was determined. It is recommended that the value of the Froude number be less than 0.3 in order to prevent eroision of the banks due to wave action. The Froude number for classes A, B, and C as determined by using the regime flow formulas were less than 0.3. However, classes D and E resulted Froude numbers of 0.616 and 0.412 respectively. Therefore, the channel dimensions for these two classes were modified to yield velocities such that the Froude number was less than 0.3 as indicated in Table VI.

Main Canals and Laterals

Two branches of main canals leading from the pumping station were designed encircling the project area. Although bed and bank materials of class C were assumed predominant in the area, design is included for all the classes so that change could be made whenever the canal passes thorugh the different classes of soil.

The sizes of the various hydraulic characteristics for all classes are found in Table VI. The velocity, slope and Froude number increased from soil class A to class E while

TABLE VII

DESIGN OF A LATERAL FOR BED AND BANK MATERIAL OF CLASS C FOR DIFFERENT FLOWS

Unknown - Feet	200 acres 3.1 cfs	320 acres 5.0 cfs	550 acres 6.84 cfs	550 acres 8.55 cfs
P = wetted perimeter	3.75	4.78	5.62	6.3
R = hydraulic radius	0.538	0.638	0.715	0.775
A = cross-sectional area	2.03	3.05	4.02	4.915
V = velocity	1.535	1.631	1.70	1.75
d = water depth	0.812	0.958	1.059	1.16
$\overline{w}$ = average width	3.00	3.83	4.50	5.04
W_T = top width	3.45	4.41	5.17	5.80
b = bottom width	2.55	3.25	3.83	4.28
s = channel slope	0.001225	0.001105	0.00103	0.000981
F_R = Froude number	0.298	0.294	0.291	0.287
F_B = freeboard	0.237	0.319	0.353	0.390
D = total depth	1.049	1.377	1.412	1.55
S = side slopes	0.52:1	0.60:1	0.63:1	0.65:1

the rest of the dimensions declined in that direction indicating a higher degree of stability of these channels from A to E.

All canals will be trapezoidal earth channels with side slopes of about 1/2:1. The main canals have been designed to handle the required flow of 46.7 cfs. The size of the laterals varies with the area they supply. Cross-sectional views of four parts of a lateral supplying the largest sector in the project have been included. A graphical illustration of the effect of irrigated area or flow on the dimensions of the channels and the rate of flow indicates a uniform variation. The channel slope is affected by the discharge and the type of soil. Table VII shows a slope of 0.001225 for the discharge of 3.1 cfs and 0.000981 for the discharge of 8.56 cfs. The slope of the main supply canal for bed and bank materials of class C was 0.000392.

These earth canals are susceptible to defects due to weed growth, sediment accumulation, and compaction. These lower the efficiency of the channels in that the capacity of the canal gets reduced, the value of Manning's coefficient of roughness increases, and the velocity is lessened. These could be solved to a large extent by the addition of extra height to the banks. The freeboard is therefore designed to compensate for these possible defects and

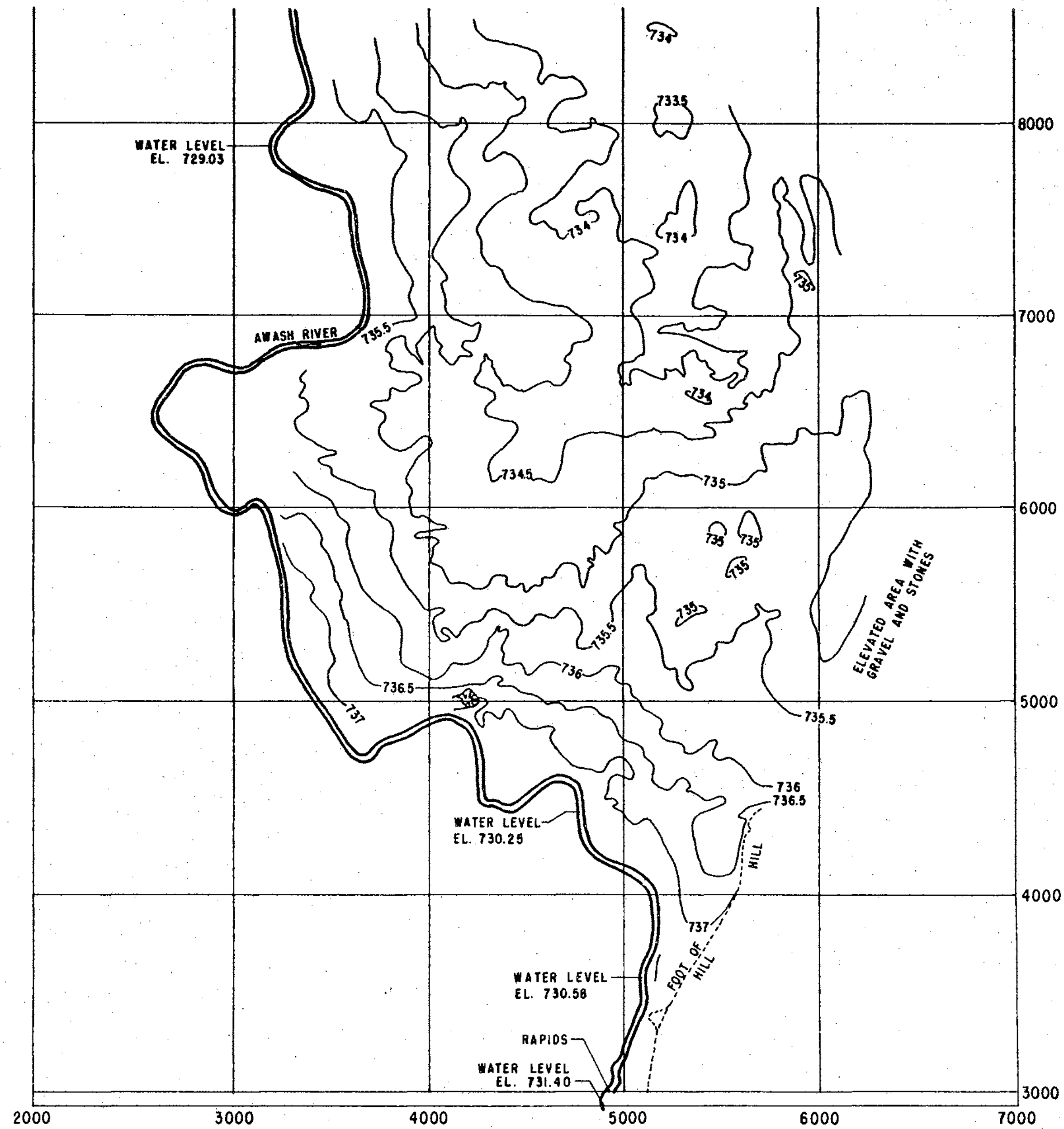

Figure 7. Topographic map of Melka Warar.

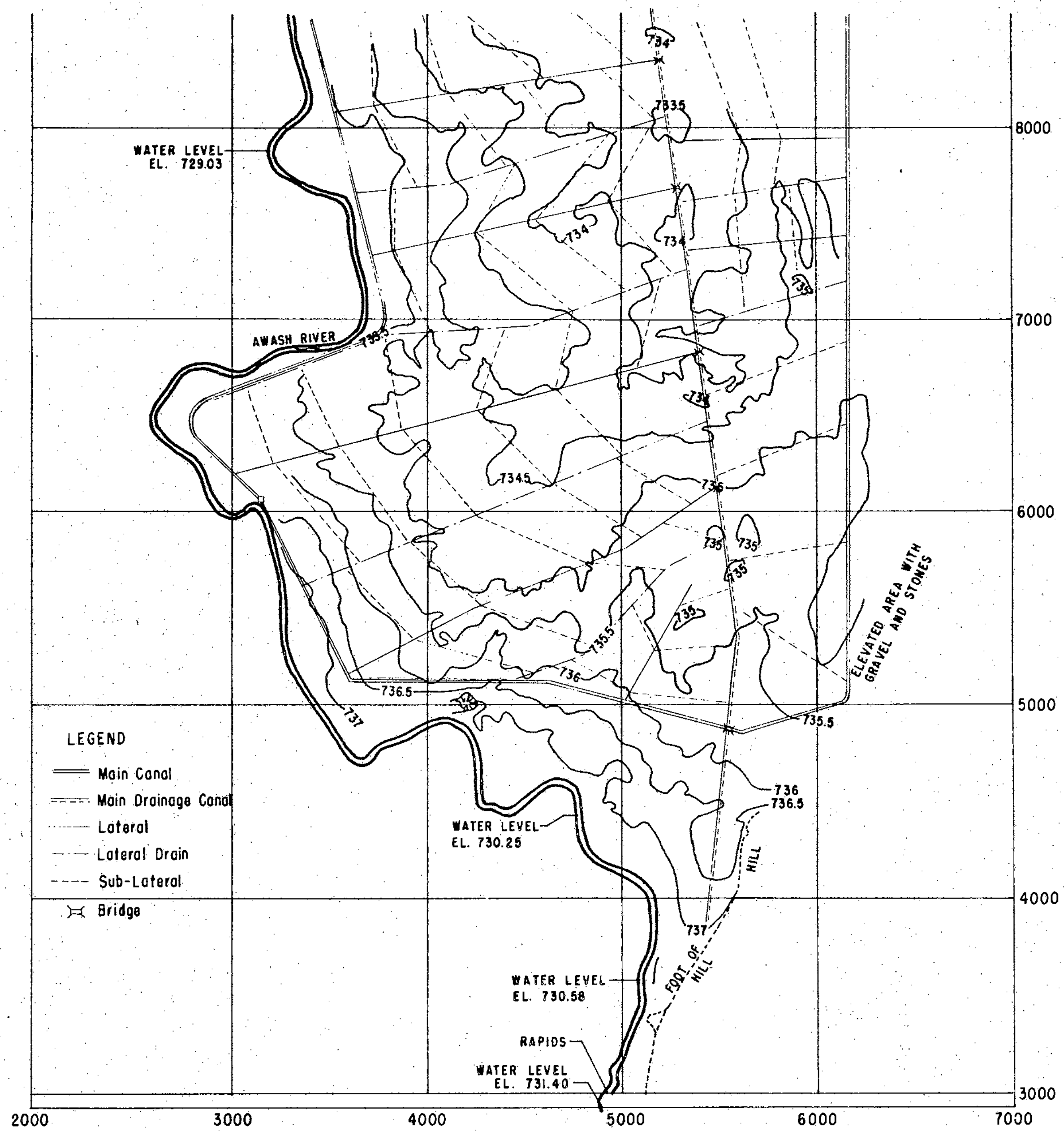

Figure 8. Irrigation and drainage systems of project.

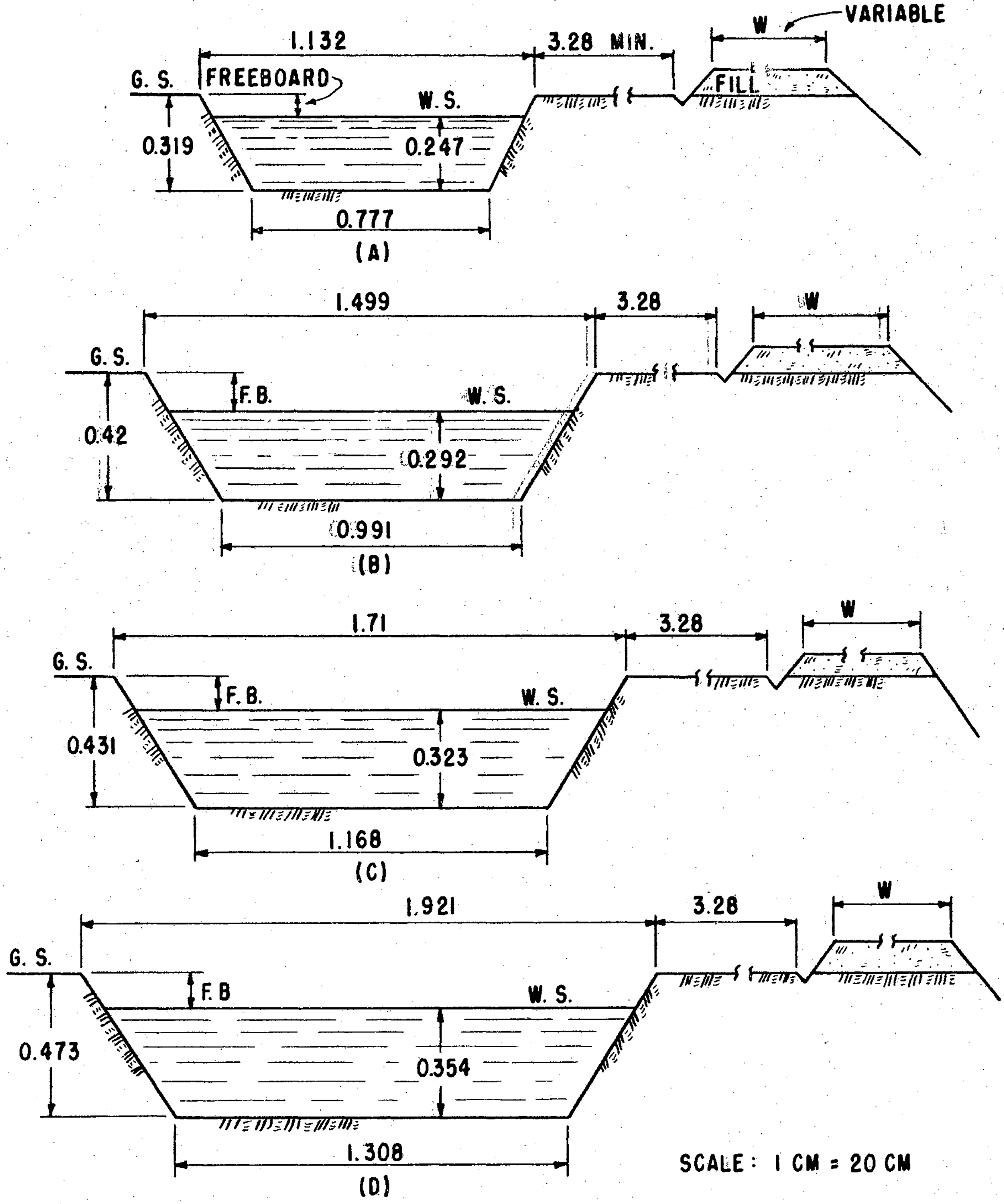

Figure 9. Typical cross-sections of four divisions of a lateral.

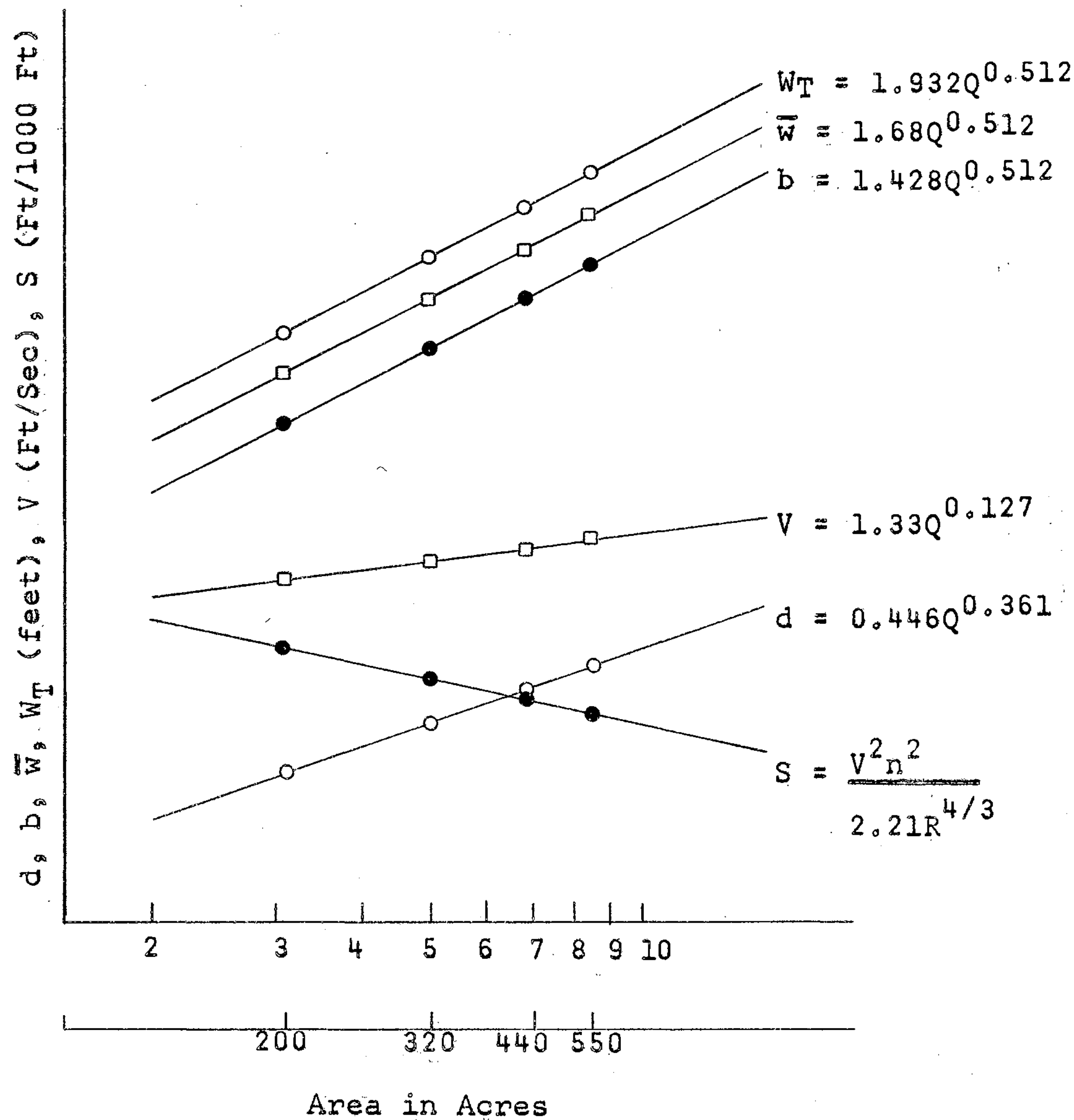

Figure 10. Variation of depth, width, velocity, and slope with discharge or area.

enable the canal to accommodate the flow for which it was intended. In addition to this, it should provide a factor of safety against overflows and bank failures.

An estimated freeboard of about one-third the channel depth as recommended by Etcheverry (6) has been used. Schwab, et al., recommended a freeboard of about 20 per cent of the total depth which was found to agree with the values determined.

Drainage:

Drainage is the removal of excess water and salts from agricultural lands. The specific yield and permeability of the soil must be determined during investigations for design. These values have not been determined by the author nor have they been availabe. However, it is clear that the drainage hazard in this area would occur due to the intense precipitation during the rainy season rather than due to irrigation. There is, however, the possibility of the need for a drainage system because of possible poor operation and maintenance.

In order to avoid the risk of drainage problems and consequent failure of enterprise, a drainage system has been included. The lateral drains can collect the excess irrigation or runoff water from adjacent fields to the main drainage ditch. The main drainage ditch has been located so that it can drain the low spots of the area, the runoff from the hill, and the excess irrigation water. It has been assumed that the area does not get flooded from the Awash during the wet season.

In arid regions, irrigation agriculture requires a good control of the water table. In drainage investigations, the source of the water table causing the problem must be determined so that the proper protective measures can be undertaken.

Drainage problems can remain undetected until their damage prohibits continued agriculture. It is important, therefore, that frequent investigations of the situation of the water table with relation to irrigation, precipitation, or seepage be performed so as to be able to diagnose the cause.

The widest spacing between lateral drains was about 3,000 feet which is well within the acceptable limit for the conditions, soils, and features of the area. However, more detailed surveys with smaller intervals are necessary and could relocate these ditches.

The outlet of the drainage ditch has been located at the lower ends of the area. Upon further development of the area north of Melka Warar, the outlet could be carried on back to the river.

The slope of the main drainage ditch is about 1/2 foot per 1,000 feet which approximates natural land slope.

Side slopes of ditches of 1 1/2:1 could be assumed safe. The depth of the main ditch can be determined if either the peak runoff or the depth and situation of the water table is known.

Proper maintenance of drainage should include the removal of soil and vegetation from drains, repair or fill of breaks and holes, and chemical extinction of roots and weeds.

CHAPTER IV

RESULTS AND RECOMMENDATIONS

Operation and Maintenance

The operation and maintenance of a system involve the proper and timely farm operations, scheduling of irrigations, general management and maintenance of the farm, farm equipment and utilities, and personnel. The staff should include a manager, an agricultural engineer or irrigation specialist, an agronomist, a mechanic, and servicement.

The operation of the farm should include timely land preparations, planting, irrigating, harvesting and processing, and marketing. It is very important that the frequency and amount of irrigation be closely estimated or determined. These depend upon several factors. Mainly, however, 1) the water need of a crop, 2) availability of irrigation water, 3) the capacity of the root-zone soil to store water determine when and how much to irrigate. The type of crop as well as its stage of growth and the kind of soil influence these requirements. Sandy soils with shallow water tables planted to shallow rooted crops

TABLE VIII

RESULTS OF WATER ANALYSIS

Station	Lab No.	Date	Height		PH	Concentration	Cond.
			Feet	Meters		GRM/Liter	mmhos
Awash Station	1062	2/24/65	3.84	1.17	8.2	0.1	0.038
No. 10	1080	9/3064	4.56	1.39	7.4	T	0.0057
	90	10/7/64	5.84	1.78	7.4	T	0.0059
	49	5/13/64	4.13	1.26		8.6	
Near Melka	50		4.53	1.38		T	
Warar	51		3.54	1.08		0.8	
	52		4.82	1.47		0.6	
	53		4.82	1.47		0.5	

TABLE IX

WATER REQUIREMENT BY CROPS SELECTED BASED ON ACTUAL PRECIPITATION ON AREA

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Cotton												
Consumptive use				2.15	4.05	4.58	7.36	7.67	4.92	3.19		
Precipitation				5.04	-0-	-0-	1.49	3.68	2.28	.49		
Irr. water requirement				-0-	4.05	4.58	5.87	3.99	2.64	2.70		
Grain Sorghum												
	4.39	5.73	7.46	3.90	2.48	5.32	7.72	8.01	3.84			1.97
	.37	1.20	1.34	5.04	-0-	-0-	1.50	3.68	2.28			1.04
	4.02	4.53	6.12	-0-	2.48	5.32	6.22	4.33	1.56			0.93
Peanuts												
	4.46	5.72	3.76			3.28	5.52	7.31	3.80			2.61
	.37	1.20	1.34			-0-	1.50	3.68	2.28			1.04
	4.09	4.52	2.42			3.28	4.02	3.63	1.52			1.57
						4.58	5.87	3.99	2.64			
	4.02	4.53	6.12		4.05	5.32	6.22	4.33	1.56			.93
	4.09	4.52	2.42		2.48	3.28	4.02	3.63	1.52			1.57
	8.11	9.05	8.54		4.53	13.18	16.11	11.95	5.72			2.50
Average =	4.055	4.525	4.27		2.265	4.39	5.37	3.98	1.907			1.25
Ave. Ac-In/Month	12165	13575	12810			13170	16110	11940	5721			3750
Ft^3/Sec	17.0	19.0	17.98			18.4	22.58	16.75	8.03			

TABLE IX (Continued)

Peak Q for the averages = 22.58 cfs based on average precipitation

$$Q_D = \frac{22.58}{.56}$$

$$= \underline{\underline{40.3}} \text{ cfs}$$

Peak Q for July with U = 6.22 inches

$$Q = 26.1$$

$$Q_D = \frac{26.1}{.56}$$

$$= \underline{\underline{46.7}} \text{ cfs}$$

TABLE X

WATER REQUIREMENT BY CROPS SELECTED BASED ON AWORA MELKA
PRECIPITATION DATA

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Cotton												
Consumptive Use				2.15	4.05	4.58	7.36	7.67	4.92	3.19		
Precipitation				2.24	1.08	.94	3.68	5.16	2.06	.42		
Irr. Water Requirement				-0-	2.97	3.64	3.68	2.51	2.86	2.77		
Grain Sorghum												
	4.39	5.73	7.46	3.80	2.48	5.32	7.72	8.01	3.84			1.97
	.69	.83	1.46	2.24	1.08	.94	3.68	5.16	2.06			.24
	3.70	4.90	6.00	1.66	1.40	4.38	4.04	2.85	1.78			1.73
Peanuts												
	4.46	5.72	3.76			3.28	5.52	7.31	3.80			2.61
	.69	.83	1.46			.94	3.68	5.16	2.06			.24
	3.77	4.89	2.30			2.34	1.84	2.15	1.74			2.37
						3.64	3.68	2.51	2.86			
	3.70	4.90	6.00		2.97	4.38	4.04	2.85	1.78			1.73
	3.77	4.89	2.30		1.40	2.34	1.84	2.15	1.74			2.37
	7.47	9.79	8.30	1.66	5.37	10.36	9.56	7.51	6.38	2.77		4.10
Average =	3.735	4.895	4.15	1.66	2.48	3.45	3.19	2.50	2.13	2.77		2.05
Average Ac-In.Mon. =	11205	14685	12450	4800	7455	10350	9570	7500	6390	8310		6150
Ft^3/Sec	15.71	20.54	17.45	6.72	10.42	14.50	13.4	10.5	8.95	11.62		8.6

TABLE X (Continued)

Peak Q for averages = 20.65 cfs based on Awora Melka precipitation

$$Q_D = \frac{20.54}{.56}$$

$$= 37.61 \text{ cfs}$$

Peak Q for March with u = 6.00 inches

$$Q = 25.2$$

$$Q_D = \frac{25.2}{.56}$$

$$= \underline{45} \text{ cfs}$$

TABLE XI

WATER REQUIREMENTS BY THE DIRE DAWA AREA
BASED ON ACTUAL PRECIPITATION

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
1961												
Cotton				2.15	4.05	4.58	7.36	7.67	4.92	3.19		
Precipitation				2.50	3.09	-0-	6.06	9.45	4.17	-0-		
				-0-	0.96	4.58	1.30	-0-	0.75	3.19		
Grain Sorghum	4.39	5.73	7.46	3.90	2.48	5.32	7.72	8.01	3.84			1.97
	-0-	-0-	.22	2.50	3.09	-0-	6.06	9.45	4.17			-0-
	4.39	5.73	7.24	1.40	-0-	5.32	1.66	-0-	-0-			1.97
Peanuts	4.46	5.72	3.76			3.28	5.52	7.31	3.80			2.61
	-0-	-0-	.22			-0-	6.06	9.45	4.17			-0-
	4.46	5.72	3.54			3.28	-0-	-0-	-0-			2.61
1962												
Cotton				2.15	4.05	4.58	7.36	7.67	4.92	3.19		
				1.17	-0-	.30	4.06	4.76	2.11	1.62		
				0.98	4.05	4.28	3.30	2.91	2.81	1.57		
Grain Sorghum	4.39	5.73	7.46	3.90	2.48	5.32	7.72	8.01	3.84			1.97
	-0-	-0-	-0-	1.17	-0-	.30	4.06	4.76	2.11			.08
	4.39	5.73	7.46	2.73	2.48	5.02	3.66	3.25	1.73			1.89
Peanuts	4.46	5.72	3.76			3.28	5.52	7.31	3.80			2.61
	-0-	-0-	-0-			.30	4.06	4.76	2.11			.08
	4.46	5.72	3.76			2.98	1.46	2.55	1.69			1.53

TABLE XI (Continued)

1963											
Cotton				2.15	4.05	4.58	7.36	7.67	4.92	3.19	
				2.68	5.98	1.38	1.05	6.52	2.22	-0-	
				-0-	-0-	3.20	6.31	1.15	2.70	3.19	
Grain Sorghum	4.39	5.73	7.46	3.90	2.48	5.32	7.72	8.01	3.84		1.97
	-0-	.16	.63	2.68	5.98	1.38	1.05	6.52	2.22		.33
	4.39	5.57	6.83	1.22	-0-	3.94	6.67	1.49	1.62		1.64
Peanuts	4.46	5.72	3.76			3.28	5.52	7.31	3.80		2.61
	-0-	.16	.63			1.38	1.05	6.52	2.22		.33
	4.46	5.56	3.13			1.90	4.47	0.79	1.58		2.28
1964											
Cotton				2.15	4.05	4.58	7.36	7.67	4.92	3.19	
				2.91	2.46	.67	1.15	8.02	3.74	-0-	
				-0-	1.59	3.91	6.21	-0-	1.18	3.19	
Grain Sorghum	4.39	5.73	7.46	3.80	2.48	5.32	7.72	8.01	3.84		1.97
	.02	-0-	2.07	2.91	2.46	.67	1.15	8.02	3.74		1.32
	4.37	5.73	5.39	0.99	0.02	4.65	6.57	-0-	0.10		0.65
Peanuts	4.46	5.72	3.76			3.28	5.52	7.31	3.80		2.61
	.02	-0-	2.07			.67	1.15	8.02	3.74		1.32
	4.44	5.72	1.69			2.61	4.37	-0-	0.06		1.29

TABLE XI (Continued)

Peak u for	1961	=	7.24 in.	=	21720 Ac-In/Mo.	
	1962	=	7.46 in.	=	22380 Ac-In/Mo.	
	1963	=	6.83 in.	=	20490 Ac-In/Mo.	
	1964	=	6.57 in.	=	19710 Ac-In/Mo.	
Q for	1961	=	30.4 cfs			$Q = 56\%$ of Q_D
	1962	=	31.3 cfs			
	1963	=	28.7 cfs			
	1964	=	27.6 cfs			
Q_D for	1961	=	54.3 cfs			
	1962	=	55.8 cfs			
	1963	=	51.3 cfs			
	1964	=	49.3 cfs			

TABLE XII

WATER REQUIREMENTS FOR THE WANJI SUGAR ESTATE BASED ON ACTUAL PRECIPITATION DATA

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
1962												
Cotton				2.15	4.05	4.58	7.36	7.67	4.92	3.19		
				.98	.51	1.30	7.56	3.58	3.38	2.05		
				1.17	3.54	3.28	-0-	4.09	1.54	1.14		
Grain Sorghum	4.39	5.73	7.46	3.80	2.48	5.32	7.72	8.01	3.84			1.97
	-0-	-0-	3.03	.98	.51	1.30	7.56	3.58	3.38			.25
	4.39	5.73	4.43	2.92	1.97	4.02	0.16	4.43	0.46			1.72
Peanuts	4.46	5.72	3.76			3.28	5.52	7.31	3.80			2.61
	-0-	-0-	3.03			1.30	7.56	3.58	3.38			.25
	4.46	5.72	0.63			1.98	-0-	3.73	0.42			2.36
1963												
Cotton				2.15	4.05	4.58	7.36	7.67	4.92	3.19		
				5.50	5.27	2.12	10.90	13.65	3.42	-0-		
				-0-	-0-	2.46	-0-	-0-	1.50	3.19		
Grain Sorghum	4.39	5.73	7.46	3.90	2.48	5.32	7.72	8.01	3.84			1.97
	0.04	-0-	0.63	5.50	5.27	2.12	10.90	13.65	3.42			1.58
	4.35	5.73	5.83	-0-	-0-	3.20	-0-	-0-	0.38			1.03
Peanuts	4.46	5.72	3.76			3.28	5.52	7.31	3.80			2.61
	0.04	-0-	0.63			2.12	10.90	13.65	3.42			1.58
	4.42	5.72	3.13			1.16	-0-	-0-	0.38			1.03

TABLE XII (Continued)

1964												
Cotton				2.15	4.05	4.58	7.36	7.67	4.92	3.19		
				4.09	4.09	4.06	6.57	7.00	5.56	.87		
				-0-	-0-	.52	0.79	0.67	-0-	2.32		
Grain Sorghum	4.39	5.73	7.46	3.90	2.48	5.32	7.72	8.01	3.84			1.97
	.43	-0-	1.06	4.09	4.09	4.06	6.57	7.00	5.56			.50
	3.96	5.73	6.40	-0-	-0-	1.26	1.15	1.01	-0-			1.47
Peanuts	4.46	5.72	3.76			3.28	5.52	7.31	3.80			2.61
	.43	-0-	1.06			4.06	6.57	7.00	5.56			.50
	4.03	5.72	2.70			-0-	-0-	0.31	-0-			2.11

Peak U for 1962 = 5.73 in. = 17190 Ac-In/Mo.
1963 = 5.72 in. = 17160 Ac-In/Mo.
1964 = 6.40 in. = 19200 Ac-In/Mo.

Q for 1962 = 24.1 cfs
1963 = 24.0 cfs
1964 = 26.9 cfs

Q_D for 1962 = 43 cfs
1963 = 43 cfs
1964 = 48 cfs

Values of Q_D based on Peak U

Dire Dawa	= 49.3 cfs
Wanji S. E.	= 48 cfs
Melka Warar	= 46.7 cfs
Awarar Melka	= 45 cfs
Awash Station	= 36.4 cfs*
Average Q_D	= 45.08 cfs

*This value was calculated on the basis of average precipitation for the period 1952-59 of the town of Awash.

TABLE XIII

SEDIMENT LOAD OF AWASH MEASURED AT THE AWASH
STATION NO. 10 IN 1000 METRIC TONS

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Total
1961-62									116.20	112.35			288.15
1962-63	6.78	6.30	10.39	778.68	963.11	17.06	57.05	607.41	97.57	34.86	16.03	5.94	2601.8
1963-64	24.23	10.95	10.94	13.33	12.12	19.53	300.91	949.68	123.25	47.74	21.60	25.41	1559.69

TABLE XIV

EVAPORATION DATA IN INCHES AND MILLIMETERS

Station	Elevation Ft. & M.	Method	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Awora Melka	2641 805	Normal Sunken Pan. Evp.	10.04 255	11.73 298	13.15 334	12.32 312	12.83 326	12.32 312	10.04 255	9.21 234	11.18 284	11.18 284	10.04 255	10.04 255
Awora	2641 805	Normal Large	7.72 196	8.54 217	10.24 260	10.79 274	10.94 278	11.81 300	9.76 248	9.76 248	10.39 264	8.27 210	6.81 173	7.36 197

TABLE XV

TOTAL MONTHLY SOLAR RADIATION
AWORA MELKA-CAL/CM^2/DAY

T.M.S. Radiation	Year	Station Gage Height	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Mean	1962	2641												
Monthly		805										633	605	598
Intensity	1963	2641												
of T.S.R.		805	576	598	620	633	644	644	605	587	616	598	552	562
	1964	2641												
		805	576	616	652	609	620	598	556	544	587	601		
Normal	1962-64	2641												
Monthly		805	580	610	635	620	630	620	580	565	600	600	580	560
Intensity														
of T.S.R.														

require more frequent irrigation but lesser amounts. On the other hand, deep clay soils with deep water tables planted to deep-rooted crops require less frequent but heavier applications.

For Melka Warar the irrigation frequency was found to range from once every fifteen days during the crop emergence and dry fruiting period to once every seven days during the flowering and wet fruiting stages of the crops. Higher values of factors affecting irrigation requirements were considered in arriving at these frequencies since the area is located in an arid region.

The depth of water per application varied from 5.3 inches for cotton to 2.7 inches for peanuts. Grain sorghum required an addition of 4.5 inches per application. Here again, higher values were assigned the variables which seemed reasonable for local conditions and compared favorably with similar regions of the United States.

Proper maintenance of pumping plant, conveyance and distribution canals and drainage ditches, farm roads, machinery, and buildings cannot be overemphasized. It includes the repair and service of pumps and farm machines and implements, and the repair and cleaning of the canals. This is especially important because of the fact that spare parts are not readily available and a delay in securing them could mean the loss of the entire crop. It is, therefore recommended that a number of pumps be installed. Five pumps with a discharge capacity of about 10 cfs each can be installed minimizing the chance of failure of the pumping system. It is still necessary, however, to keep a good supply of spare parts of the factory-repairable parts of a pump.

Operation and maintenance roads must be built along the main canal, laterals, and drainage system. Minor operation and maintenance ways should also be provided along the sub-laterals. The size of these roads is to be determined by the size of the largest machinery driven over them.

The canal running along the hill on the southern and eastern borders may require lining with clay from other sections of the area. Therefore, a critical investigation on the permeability of the soils on that area should be made.

The southern section of the land has been kept aside for buildings and workers' quarters. However, a small-scale sprinkler irrigation system could be used to develop a fruit and vegetable garden or pasture areas if needed.

In case of excessive sediment flow, sediment excluders should be included in the system. These are tubes inbedded at about 30° across the channel bed. With the top arch removed, the top edge of the cut-off tubes should be even with the channel bed. These tubes can remove the sediment rolling along the channel bed and reduce the sediment bed load considerably.

Financing

One method of financing that has worked successfully in Ethiopia is the participation of foreign investment. The foreign companies provide the technical know-how as well as part of the capital while the country supplies the land and the labor force. Even though Ethiopia is especially short of the technical side, the involvement of foreign capital definitely encourages local investors to take part. Major development projects have previously been financed by the government. Recently, however, private enterprises have been inspired with government loans and bond issues. People have been rather reluctant of government involvement and obviously foreign investment gives them a sense of confidence and security. This should, therefore, continue until local enterprises realize and understand the principles and operations of such undertakings and until they are able to continue on their own. Hopefully, this could mean short-term investment.

The area of the project, however, is owned by the Ministry of Agriculture and government funds will be used in its development. But an agricultural development of this size could be undertaken by individual investors or cooperatives with limited technical aid. A trend of large-scale development by concessionaires with about 1/3 to 1/2 foreign investment could certainly bring about fast development of the region. The government should and would, after determining priorities of regional development, finance major constructions such as dams and reservoirs. Returns from land sales, taxes, and water charges could pay the expenses.

Staff Training

The successful development of this area depends upon the ability and dedication of the administrative and technical personnel. Well-trained personnel competent to analyze, plan, and implement such development programs are required. The selection and training of such personnel, therefore, has top priorities. Upon them rests the sucessful development of the region and the country as a whole.

These pioneers should be given expert training and experience. They should also be given a responsibility backed by the government agencies. The highest degree of cooperation and teamwork is necessary in this endeavor.

CHAPTER V

SUMMARY AND CONCLUSIONS

Water requirements for four locations in the different sectors of the Awash Valley were estimated. The water requirement of Melka Warar was about average. The soil and water analyses confirmed the suitability of the area for agricultural development. The economic feasibility studies also indicated profit.

The results of this project are neither detailed, complete, nor conclusive in all respects of design. In fact, there is even doubt as to the accuracy and dependability of the data received. However, every effort was made to make the design as applicable to the area as possible with the extent of available literature and time. It should, therefore, be borne in mind that application of these values should be complemented by actual, detailed investigations, research, and designs.

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APPENDICES

APPENDIX 1A

CLIMATOLOGICAL DATA OF THE AWASH VALLEY
AVERAGE PRECIPITATION IN INCHES
AND MILLIMETERS

Location, Altitude and Period Covered	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Yearly Total
Addis Ababa Alt. 8661 Feet 2640 M. 1902-36 [35 Years]	.63 16	1.594 41	2.518 64	3.346 85	3.779 96	5.236 133	10.984 279	11.722 298	7.756 197	.827 21	.591 15	.276 7	49.651 1252
Moggio Alt. 6037 Feet 1840 M. 1931-37 [7 Years]	.341 9	.985 25	1.772 45	1.81 46	1.652 42	5.98 152	6.49 165	7.51 191	4.13 105	.236 6	.197 5	0 0	31.3 791
Adamitullu Alt. 5709 Feet 1740 M. 1914-36 [23 Years]	.473 12	.985 25	1.378 35	2.36 60	2.638 67	2.21 56	4.28 109	3.84 95	3.27 83	.668 17	.394 10	.511 13	23.9 582
Miesso Alt. 4200 Feet 1280 M. 1931-37 [7 Years]	.511 13	2.638 67	3.27 83	2.678 68	2.59 66	1.73 44	4.33 110	5.62 143	3.54 90	.128 3	.985 25	.433 11	28.42 723
Harar Alt. 4232 Feet 1290 M. 1914-18, 1922-34 [18 Years]	.433 11	1.30 33	2.164 55	4.33 110	4.96 126	4.09 104	5.67 144	5.43 138	3.82 97	1.89 48	.95 24	.511 13	35.54 903.0
Dire Dawa Alt. 4200 Feet 1280 M. 1927-34 [8 Years]	.866 22	.787 20	3.382 86	3.07 78	2.85 72	1.535 39	4.28 109	3.78 96	2.52 64	.473 12	.354 9	.63 16	24.5 623
Awash Alt. 1952-59 [7 Years]	2.59 65.8	1.06 26.9	2.62 66.2	1.77 44.9	.582 14.8	1.93 49.2	5.33 135.3	6.72 170.9	2.06 52.3	.58 12.9	.071 1.80	.185 4.7	25.4 645.7

APPENDIX 2A

WEATHER DATA OF DIRE DAWA
PRECIPITATION IN INCHES
AND MILLIMETERS

Year	Units	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
1961	Inches	0	0	.220	2.50	3.09	0	6.06	9.45	4.17	0	4.33	0
	Mm.	0	0	5.6	63.4	78.6	0	154.5	340.8	106.8	0	110.7	0
1962	Inches	0	0	0	1.165	0	.295	4.06	4.75	2.108	1.615	1.38	.0786
	Mm.	0	0	0	29.6	0	7.5	103.2	121.0	53.5	41.5	35.0	0.2
1963	Inches	0	.1575	.63	2.68	5.98	1.38	1.045	6.52	2.22	0	1.067	.33
	Mm.	0	0.4	16.0	68.0	152.8	35.0	26.5	166.5	56.4	0	27.1	7.7
1964	Inches	.024	0	2.07	2.91	2.46	.673	1.15	8.02	3.74	0	0	1.32
	Mm.	0.6	0	52.6	73.8	62.5	17.1	29.2	204.1	95.2	0	0	33.6
Average	Inches	.00797	.003937	.708	2.31	2.82	.586	3.09	7.10	3.07	.41	1.70	.41
	Mm.	0.2	0.1	18.6	58.7	74.3	14.9	78.5	180.6	78.0	10.4	43.2	10.4

APPENDIX 3A

WEATHER DATA OF DIRE DAWA-TEMPERATURE IN °FAHRENHEIT AND °CENTIGRADE

Year	Units	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
1961	Degrees Fahrenheit	73.04	75.92	71.78	79.34	82.40	84.74	77.90	76.20	73.58	79.52	71.42	71.96
	Centigrade	22.8	24.4	22.1	26.3	28.0	29.3	25.5	24.0	23.1	26.4	21.9	22.2
1962	°F	71.66	73.94	72.50	82.22	77.00	78.08	81.32	77.90	71.06	77.72	73.94	72.50
	°C	22.0	23.3	22.5	27.9	25.0	25.6	27.4	25.5	21.7	25.4	23.3	22.5
1963	°F	72.14	75.56	80.42	77.00	80.06	82.22	81.14	79.34	79.52	81.68	76.46	72.86
	°C	22.3	24.2	26.9	25.0	26.7	27.9	27.3	26.3	26.4	27.6	24.7	22.7
1964	°F	73.94	74.30	80.24	77.36	82.22	83.30	78.8	77.18	78.08	78.08	74.12	69.08
	°C	23.3	23.5	26.8	25.2	27.9	28.5	25.6	25.1	25.6	25.6	23.4	20.6
Average	°F	72.68	75.02	76.64	79.70	80.42	82.	79.70	77.36	75.56	79.34	75.92	71.60
	°C	22.6	24.9	24.8	26.5	26.9	27.8	26.5	26.5	24.2	26.3	24.4	22.0

APPENDIX 4A

WEATHER DATA FOR WANJI SUGAR ESTATE
TEMPERATURE IN °FAHRENHEIT
AND °CENTIGRADE

Year	Temperature	Units	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
	Minimum	°F	50.54	52.52	59.18	59.36	62.42	65.30	62.24	61.70	59.90	49.74	54.86	54.60
		°C	10.3	11.4	15.1	15.2	16.9	18.5	16.8	16.5	15.5	9.3	12.7	12.0
1962	Maximum	°F	77.72	81.86	83.04	86.18	86.90	86.18	78.98	77.54	77.90	78.80	78.44	78.80
		°C	25.4	37.6	37.8	30.1	30.5	30.1	26.1	25.3	25.5	26.0	25.8	26.0
	Average	°F	64.22	67.10	70.70	73.86	74.66	75.74	70.70	69.62	68.90	63.86	66.74	66.20
		°C	17.9	19.5	31.5	33.7	34.7	34.3	31.5	30.9	30.5	17.7	19.3	19.0
	Minimum	°C	11.8	15.0	14.2	16.3	15.8	16.6	16.3	15.6	15.3	10.0	13.4	14.0
		°F	53.24	59.0	57.56	61.34	60.44	61.88	61.34	60.08	59.54	50.0	56.12	57.20
1963	Maximum	°C	24.9	28.1	29.4	27.3	27.3	28.4	25.2	23.8	25.9	27.2	25.6	24.8
		°F	76.8	82.6	84.9	81.2	81.0	83.2	77.4	74.8	78.7	81.0	78.1	76.6
	Average	°C	18.4	21.6	21.8	21.5	21.5	22.5	20.8	19.7	20.6	18.6	19.5	19.4
		°F	65.1	70.9	71.3	71.3	70.7	72.5	69.5	67.5	69.1	65.5	67.1	66.9
	Minimum	°C	14.1	16.1	14.7	13.4	14.6	16.4	16.0	15.2	15.3	11.8	8.6	11.3
		°F	57.4	61.0	58.4	56.1	58.3	61.5	60.8	59.4	59.6	53.6	47.5	52.3
1964	Maximum	°C	25.7	27.9	31.1	37.9	29.0	27.9	24.7	24.7	25.2	25.5	26.0	23.7
		°F	78.3	82.2	88.0	82.2	84.2	82.2	76.5	76.5	77.4	77.8	78.7	74.7
	Average	°C	19.9	22.0	22.9	20.7	21.8	22.2	20.4	20.0	20.3	18.6	17.2	18.3
		°F	67.8	71.6	73.7	69.3	71.2	72.0	68.7	68.0	68.6	65.5	63.1	64.9

APPENDIX 5A

CLIMATOLOGICAL DATA FOR AWORA MELKA

Awash Station Height	Units	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Yearly Total
2641'	P In	.692	.834	1.462	2.24	1.078	.938	3.68	5.16	2.06	4.17	.50	.241	19.3
805M	MM	17.6	21.2	37.2	56.8	27.4	34.6	93.5	131.0	52.3	10.6	12.7	6.1	490.0
	T °F	75.7	79.8	82.2	81.6	83.8	86.0	82.2	79.8	82.7	80.2	78.4	76.2	
	°C	24.4	26.6	27.9	27.6	28.8	30.0	27.9	26.6	28.2	26.8	25.8	24.6	
	RH<50%		45	45		44	40				40	43	48	

APPENDIX B

ABBREVIATIONS AND CONVERSION FACTORS USED

AVA = Awash Valley Authority

UNSF = United Nations Special Fund

FAO = Food and Agriculture Organization

Eth. = Ethiopia

U.S.D.A. = United States Department of Agriculture

1 U.S. $ = 2.50 Eth. $

L Hectare = 2.47 acres

1 Square Mile = 2.59 square kilometers

1 Millimeter = 0.03937 inches

1 Cubic Meter = 35.31 cubic feet

1 Mile = 1.6093 kilometers

1 Meter = 3.2808 feet

1 Acre = 4047 square miles

OSU = Oklahoma State University

TCA = Technical Cooperation Administration

VITA

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