# A STUDY OF

# WADI MEGENIN FLOODS

Division of
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A STUDY OF WADI MEGENIN FLOODS

## PREFACE

This is a study of the floods of the Med Wadi (The Megenin), past, present, and future. It contemplates both cause and effect, in the confidence that an understanding of both of these, and a recognition of the trend of these floods as well, are essential in devising a sound approach toward the problem, and in the development of specific plans for a profitable solution - a solution that will not only be permanent in nature but will also provide the near-maximum in efficiency, in the ratio of benefits to costs.

The USOM Division of Agriculture and Water Resources has been requested by several Government of Libya Agencies and by the Libyan-American Reconstruction Commission to participate in the study of this problem , and in the analysis, evaluation, and development of proposals and project plans. Specifically, this monograph has been prepared in response to a directive from Mr. Floyd D. Larson, Chief of the Division, dated 16 May, 1956.

There is in preparation in this office a plan and proposal for a complete program of land management and stabilization on the whole Wadi Megenin watershed. The present study, however, is concerned primarly with the flood-at-Tripoli situation; for this it offers a plan for modest flood-protection improvements in the flood zone, based upon the assumption that the full-scale watershed program will progressively, at a satisfactory rate, harness these floods.

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SUMMARY


## The Problem

There have been floods on the Wadi Megenin for a long time. Until very recent times, these floods were beneficial to the orchards and vineyards on the southern outskirts of Tripoli, because the floods came gently; throughout the flood zone they provided a welcome irrigation, left a fertile blanket of clay and organic material over the land, and caused much water to percolate down into the underground reservoir which supplies Tripoli's wells.

But great changes have taken place in the watershed, changes that have altered greatly the character of the floods. The floods have become more violent, and now they leave behind, in some portions of the flood zone, thick deposits of sand that do much damage to crops, vines, and trees. A chain of events, set in motion less than one-third of a century ago, has progressively increased the population of both humans and animals in the watershed, and their intensified pressure on the land has brought about a progressive reduction in the density of trees, bushes, forage grasses, and esparto grass. Storm runoff has greatly increased, erosion has multiplied, and the result is acceleration of flood damages, principally from deposits of sand.

## The Approach to the Problem

How can a flood problem be solved? There is the "downstream" or "fight the flood where it is" approach. This involves large engineering structures whose aim is to bottle up the flood (detention reservoirs), or push it aside (dikes, diversions, and canals). There is another approach, the "upstream" or "prevent the flood at its source" approach. This method contemplates the widespread application of land management measures, procedures, and practices, in man's utilization of farmland, rangeland, and forest, that will cause a maximum infiltration of rain into the soil, and that will present an unending series of barriers - blades of grass, shrubs and trees, contour dikes, terraces, and small reservoirs - to impede the overland flow of water.

Under unusual and extemely favorable conditions - hard soils, favorable topography, low sediment yield rate, and others - the downstream, structural approach may offer a bargain-priced though impermanent solution. More often than not, the all-around best solution is one which employs a proper balance of upstream and downstream measures. At the other end of the scale, where nearly all the physiographic factors are unfavorable for downstream structures - sandy, easily erodible soils, steep rugged topography, a very high sediment yield rate, an excessively high flood peak discharge rate - and especially when the violence of the floods is still in a rising trend - the upstream, or watershed stabilization (through good land management) concept is the only


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feasible approach toward the reduction of flood damages. This does not mean the immediate and complete abandonment of existing partial-control structures, for indeed it may often be profitable to keep these works in operation for some time yet. But this does preclude the feasibility of undertaking large new projects in or near the flood zone. In these circumstances, virtually all efforts and resources must be applied over widespread areas of the upland watershed, in the direction of the permanent solution of curing the trouble at its source - where the raindrop falls.

Such is the situation in the watershed of the Wadi Megenin. The extremely high runoff rate, the excessive erosion and consequent sediment yield rate, the structureless character of the gefara and the flood plain soils, all add up to class this watershed very, very far down toward the end of the scale, that practically prohibit the feasibility of downstream structures and accentuate the necessity for concentrating on complete watershed stabilization measures almost to the exclusion of downstream damming or diking or diverting-and-channelling-off works.

Elements of the Plan Proposed Here

A project proposal for a comprehensive watershed stabilization and management plan and program is now being developed by the Division of Agriculture and Water Resources and it may here be briefly stated that this program is believed to be justifiable economically by the results that can be achieved in 1) checking the progressing destruction by erosion of the watershed's resources, 2) the increase in production that can be attained by good land management, and 3) the project's value as the first full-scale demonstration of the principles and practices of land management, a demonstration that can point the way toward the revolution in land use and land tenure that must take place before there can come about any marked increase in production, on a sustained yield basis, from the "open" land of Libya. A basic premise of this study, then, is that such a watershed program will be put into effect.

The downstream works herein proposed are very simple and limited in scope. This plan, referred to as Proposal 2 in this study, contemplates the expenditure of some £L 20,000 for minor improvements to the existing drainage channel through the flood zone, limited elevating of certain section of "sunken" roads that are buried by sand after each flood that now occurs, and a provision for maintenance of these facilities. With the watershed program in operation, this study submits that it is more economical to do only these things in the flood zone, accepting the damages to agricultural developments

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and private property on a diminishing scale for some time yet, in confidence that within a reasonable period of time the watershed program will have reduced these damages to a small fraction of their present proportions.

It should here be noted that even should net losses and damages to private interests, contemplated in Proposal 2, be compensated by direct payments from the public purse, the validity of the economic analysis would not be affected. Such direct and complete compensation would be unwarranted in the present instance; instead, private-interest financial aspects of this situation, and the responsibility of the public to assist the injured individual properly fall into the same category as that which relates to private losses from all such natural causes - flood, fire, lightning, or tornado.

Economic Analysis of the Diversion-to-the-Sea Plan (Proposal 1) and the Existing Channel Improvements Plan (Proposal 2)

In order to analyse the physical factors and the economics of these two proposals, and to consider the probable consequences of one and of the other in related matters such as groundwater recharge, a detailed analysis and projection into the future of some of the elements of costs, damages and benefits that pertain to each of these plans, has been made. This analysis shows that the only profitable solution to the flood problem is the complete watershed stabilization program, with only minor works in the flood zone - that no large downstream engineering project such as the diversion-to-the-sea scheme can hope to be worth its cost and its consequences. The facts supporting these findings are set forth in Section III of this study, supplemented by an Appendix of graphs and charts which break down the cost analysis into their component parts, with final conclusions reached from a summation of these component parts, and their projection into the future.

STUDY OF WADI MEGENIN FLOODS

SECTION I

STUDY OF FLOOD DAMAGES AND BENEFITS

INTRODUCTION

The purpose of Section I of this study is to evaluate the effects of periodic flooding of the Wadi Megenin in the southern outskirts of Tripoli, with a special study of the medium-small flood of March 1956. The effects of those recurring floods are both damaging and beneficial.

In order to analyze the effects of the floods it is expedient to consider the various aspects of benefits and damages in a number of more or less separate categories, even though each one is interrelated with and interdependent upon one or more of the others. The most significant of those are:

DAMAGES:

(1) Agriculture (private property)
  (a) To growing crops (cereals, vegetables, vines, trees)
  (b) To the land (deposits of unbeneficial sediment)
  (c) To farm buildings, irrigation systems, etc.
(2) Public Property
  (a) To roads
  (b) To buildings
  (c) To the artificial channel.

In another respect, the damages can be separated into two distinct categories.

(1) Damages caused by water, per se.
(2) Damages caused by unbeneficial sediment deposits.

BENEFITS:

(a) Irrigation of growing crops (cereals, vegetables, vines, trees)
(b) Deposits of beneficial, fertile sediment.
(c) Recharge of ground water reservoir at Tripoli.

/ ..... The Trend

THE TREND - The Changing Character of the Floods

That there are manifold and significant benefits of these floods, there can be no doubt. The damages are readily observable and make an immediate impact upon private property owners or the public weal, and so are quite readily evaluated; the benefits, however, are of a more subtle nature, and do not make their effects felt immediately. For this reason they are not so readily observable, especially on these areas where damages are of considerable intensity. The benefits - such as a "free" irrigation of olive trees or grape vines or even half-grown cereals, or of eucalyptus trees in the Government forest preserve - will not be reaped (and even then probably not identified by the beneficiary) until harvest time. The benefits of the suspended sediment in the floodwater - the dissolved clay particles, mineral plant nutrients leached from the upper watershed soils, and organic matter - are manifested not only in the next harvest but in permanent improvement of the soil upon which these sediments are laid down. The benefits from the floodwater which percolates downward through the soil to supplement the annual recharge of the groundwater reservoir (the source of Tripoli's municipal and irrigation water supply) is not limited to wells in the flood zone but extends to a considerable area surrounding the flood zone. This groundwater benefit may be small comfort to the farmer whose crops have just been damaged or to the public treasury which must bear the expense of removing sediment from flooded streets and highways; this benefit is not subject to precise measurement; nevertheless, the considerable value of this floodwater in maintaining the level of the groundwater reservoir and sustaining its yield to meet the ever-increasing withdrawal demands made upon this subterranean reservoir is readily demonstrable by a qualified groundwater geologist.

To determine that these benefits are of considerable significance, one need only take a brief look into the recent history of the floods and the flood zone. There have been floods in the delta of the Megenin on the southern outskirts of Tripoli for a long time. But the consensus is that, taken as a whole, the floods up until the largest-until-then event of December 1945, were considered to be an unmitigated blessing; the slight damages were greatly outweighed by the benefits in the form of irrigation and deposition of a layer of fertile and therefore valuable clay-organic sediment which covered the entire flooded zone. And the portion of the floodwaters which did not evaporate directly into the air or subsequently by transpiration of

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vegetation, went down to recharge the groundwater reservoir. For at that time there was no channel to the sea and therefore none of the water flowed over-land into the sea.

But beginning with the flood of 1945, and for every medium and large flood since that time the damages have progressively increased and the benefits- even the readily identifiable surface benefits - have become almost forgotten, because in most of the flood zone near the points of break-out from the channel, where the depositions of sand are deepest, the damages now overwhelm the benefits. It is almost forgotten that even at the present time, the lower portion of the flood zone, where the area receives a gentle irrigation and a layer of fertile clay - organic sediment, still receives a considerable net benefit from the average flood, after the minor damages have been subtracted from the gross benefits. It appears incontrovertible that in recent years, the entire character of the floods have changed; not only has the gross volume and the peak discharge rate of the floods increased considerably, but even the composition of the floods has changed. Now, when these enlarged floods, racing down the deepened channel through the gefara, are slowed and spread out over the flood plain at Tripoli, several times the quantity of sterile unwanted sand is deposited on the farms and on the streets and highways of the flooded zone by each cubic meter of floodwater as compared to that laid down by the floods before 1945.

What has caused this change in the character of the floods? And will these influences continue to move even further in the direction that will cause the floods to grow progressively larger, bringing down increasing loads of sterile sand, until some time when the watershed has reached its maximum possible "efficiency" in shedding rainwater and sand? The answers to these questions appear to be clear and equally incontrovertible; the reduction of vegetative density and consequent compacting of the surface of the land in the gebel area of the watershed, progressively accelerated during the past quarter of a century, have progressively increased the water-shedding "efficiency" of the watershed; the faster-rushing, enlarged flood flows are more "efficient" producers and carriers of sediment, so that each cubic meter of water now delivers several times as much sand upon Tripoli as before.(1 And even a cursory examination of the watershed strongly indicates that these trends have not yet reached their

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(1 See Dr. Magazzini's estimate - Rainfall Data - Table I, Appendix
Dr. Magazzini is Chief, Meteorological Section, Ministry of Communications
Government of Libya.

climax, that the maximum limits of "efficiency" in the water shedding characteristic of the watershed have not yet been attained. A recognition of this trend is of some import in weighing the relative merits of an "upstream" or watershed stabilization approach to the solution of the problem and the "downstream" or flood-diversion-at-Tripoli approach.

FLOODS OF THE PAST TEN YEARS:

The flood of December 1945 is believed to have been the largest that has occured. Several others have caused considerable damage, including one in 1951. In April 1955 came the largest since the 1945 event. A somewhat smaller one occurred in December. The probable quantity of rain that fell on the watershed in the gebel during the 4-day rainy period in December exceeded by a considerable margin the total that fell during the 4-day rain of April. The hour-to-hour intensities during these rains are not known, and the (2 intensities are as important as total quantity of rainfall in determining the amount of runoff, since rate of runoff is the rate at which intensity of rainfall exceeds the infiltration rate of the surface of the watershed. However, it is known that when the December flood occurred, a very considerable amount of water was diverted from the Megenin into the Amiot and Sidi Gilani canals, and that most of this water during the first 6-8 hours of the flood period was dissipated in the flood irrigation zones served by these canals. This was accomplished, however, at the cost of very severe damages to these works, which would cost an estimated £L 75,000 to restore.

During the latter hours of the flow, the two canal systems had deteriorated to the point that water was no longer spreading over a wide area, but was flowing essentially confined in a new channel that had not existed a few hours before. The new channel was cut from the upper (Amiot) diversion down across country, into and at a right angle across the main Sidi Gilani canal (where 25,000 cubic meters of sediment was deposited) and straight on down the slope until it rejoined the watercourse at the Megenin itself. Therefore, during the latter half of the flood period, nearly all the water diverted from the Megenin by the two projects, returned to the Megenin. However, the infiltration during the first half of the flood probably disposed of 2,000,000 cubic meters of floodwater. But for this, the December flood at Tripoli might very probably have exceeded the April event in peak and volume.

(2 Rainfall Data - Table I - Appendix

THE FLOOD EVENT OF MARCH 1956:

The medium sized flood of March 1956 broke out of the channel in the flood zone for a period of some 12 hours. Based on Dr. Magazzini's estimates of hour- to-hour discharge rate, a hydrograph of the flow has been developed (Appendix Plate 1) The total flood volume that teached the Tripoli area is found to be on the order of some 3,000,000 cubic meters, of which approximately one half is estimated to have left the channel and spread out over the flood zone. The area flooded was approximately 280 hectars. This area is shown on the map of the flooded zone that accompanies this report. ( Appendix - Plate 2).

THE EFFECTS OF THE FLOOD ON MARCH 1956:

A detailed tract-by-tract study of the effects of the flood was made over the entire flooded area. All types of gross damages to agricultural lands and developments were studied and evaluated, in terms of physical units and monetary value, and as set forth on the Table of Flood Effects included in the Appendix. (Table 2)

The same procedure was followed in evaluating the several categories of gross benefits, as far as irrigation and deposition of valuable suspended sediment is concerned, but excluding for the present, any estimate of the monetary value of deep percolation as a factor in ground water recharge (this is discussed in a separate paper prepared by Dr. Cederstrom, Ground Water Geologist, to be found in the Appendix to this report).

The survey found that gross damages to agriculture and related developments totalled approximately £L 24,000, while gross benefits came to some £L 9,000. From this, a reasonable overall picture is that net agricultural and other private property damages amounted to approximately £L 15,000. The monetary value of ground water recharge (some 1,000,000 cubic meters) which would be a credit against this net damage figure, can logically be assessed in the realm of at least a thousand Libyan pounds, but since a specific monetary value of this factor is difficult to establish, no deduction from the damage figure will be made - it remains at £L 15,000.

As concerns damage to public property, limited almost entirely to minor breaks in the masonry retaining wall at Km 4 and to deposition of sand on streets and highways and in the channel itself, only a rough estimate will be made here. The volume of sand deposited in the streets and highways was probably about 20,000, certainly not more than 25,000 cubic meters. The amount left in the channel (exclusive of channel areas at road intersections) was somewhat greater, but not more than 50,000.

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The total volume probably did not exceed 60,000, but to allow a reasonable margin for error, the figure of 75,000 will be used here.

With modern earthmoving equipment, material of the nature of this sediment can be picked up and moved a proper distance away from the channel, or even up to 100 meters distance, for a cost of 6 to 8 piasters per cubic meter. But even if the cost were to be as high as 10 piasters, and 75,000 cubic meters were to be excavated, the cost would be only £L 7,500 . If a small extra allowance of £L 500 is made for repair of canal retaining walls, damage to highway surfacing at Km 4 and other minor items of public damage, then an overall figure for the total net damages for the flood of March can be established at about £L 23,000.

SIGNIFICANT OBSERVATIONS CONCERNING FLOOD DAMAGES:

In making this survey of effects of the flood several facts became strikingly apparent. The several aspects of the flood were discussed at length with a considerable number of the owners or operators of farms that were subjected to the flood.

All parties who were affected by this and previous floods are of the opinion that before 1945 the floods of the Megenin did no appreciable damage, but resulted in considerable net benefit, because the water did not carry sand. Nearly all believe that there would be less damage if the floodwaters were permitted to spread over a larger area, that is, if no retaining walls or dikes had been built to attempt to protect certain installations or areas. They have observed the failure of efforts to date (the artificial channel, dikes, walls etc.) to keep flood waters off the land; the manner in which this channel becomes clogged at several points during each flood event makes them skeptical that any such scheme will be completely successful in conveying the sand to the sea. They are all concerned over the increasing violence of the floods, but particularly in regard to the great increase in the volume of sand that is deposited wherever the floodwater, after it breaks out from the channel, is slowed down a bit. And they are nearly united in their belief that the best approach toward the solution of the problem is to restore conditions in the watershed to the way they were before the floods began to do damage. They realize that this will take time, and feel that in the meantime the existing channel should be maintained and improved to a limited extent.

But the most significant observation made during the study is that the floodwaters flowing over the land actually do relatvely little damage per se. The floodwater does its principal damage as a vehicle for transporting heavy, undissolved sediment - the sand - onto the land.

The water, whether by its velocity or by standing impounded for a period

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of time, does only minor damage, confined almost exclusively to low-growing annual crops in the early stages of their growth. The important damages are caused, almost without exception whether to trees, vines, or irrigation systems, by the depositions of sand. And the study brought out an estimate that this small flood left behind, in the flood zone, something on the order of a half-million tons of sand. Thus, while the channel succeeded in wasting into the sea about one-half of the valuable water and suspended sediment, something like 90 percent of the bedload sediment - the sand - was left behind, in the farm fields, in the streets and highways, and in the flood zone section of the channel itself. Obviously, the reason that water moves on to the sea, but sand does not, is that the velocity of the flood is reduced as it travels through the flood zone, and its ability to transport the heavy bed-load is correspondingly reduced.

This at once leads to the conclusion that any scheme for channeling the floodwater through the flood zone, or over any route of lesser gradient than that of the wadi in its approach to the flood zone, will be of little benefit. If such a channel is wide enough, it may succeed for a brief period of time, in conveying most, perhaps all of the floodwater ( if no flood greater than the 1945 event occurs) to the sea, but it can hardly be expected to succeed in sweeping into the sea nearly all of the bed-load sand that the wadi moves down. It then becomes only a question of time, if the sand is not removed from the channel between floods, until the accumulation of sediment will so reduce the channel capacity that the channel will no longer accommodate a large flood flow and some of the flood will leave the channel, headed in whatever direction offers the greatest inducment of gradient.

STUDY OF THE WADI MEGENIN FLOODS

SECTION II

A PLAN FOR MINOR IMPROVEMENTS IN THE FLOOD ZONE

INTRODUCTION

This plan for minor improvements in the Tripoli flood zone is based on the promise that there will be put into effect, an intensive, comprehensive land management program on the watershed, which will progressively reduce the quantity and intensity of floods of water and sediment that periodically descend upon the Tripoli flood zone. Until this project has been in operation for several years - long enough to have brought about some reduction in peak flood discharge rate and considerable reduction in the percentage of sediment in the floodwater - it is believed that any large engineering works in the lower reaches of the Megenin water course are economically unsound. The present artificial channel through the flood zone, while wasting valuable water into the sea, does prevent a portion of the floodwater from flowing out over the land and this function seems to justify its continuing existence. In the March 1956 flood this channel carried approximately one-half of the floodwater to the sea. This plan for minor improvemtns, then, is exceedingly simple. It aims toward maintenance of the existing channel at approximately its present discharge capacity and suggests a plan for raising certain sections of roadbed to reduce the cost of sand removal at those points.

At the present time, the only mechanical improvements are the masonry and concrete walls on both sides of the channel on a reach of some 150 - 200 meters on the approach to the right-angle turn at Km 4, and the 50 meters length of masonry wall on the outside of a sharp left curve some one-and-a quarter kilometers downstream from Km 4.

It appears to be desirable that the walls on the outside of these two curves be maintained, but not raised. Since the lower reaches of the channel will carry essentially no greater discharge than now passes Km 4, there is no advantage in making any great improvement here, but it is believed to be worthwhile to make a small increase in the radius of curvature of the inside of this and the next sharp bend - perhaps up to a 50 meter radius. This could involve the public acquisition of about 0.2 hectars of land. No wall should be built on the inside of these curves. At no other places are the curves of especial significance, because the last point of major "breakout" is only a few hundred meters below the second of

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these curves where water runs down the main street leading NNE to Porta Benito. For this reason it is recommended that no other changes in alignment be made.

The next item of this plan is the raising by approximately one meter of the roadbed of the Castel Benito highway from about Km 5 to the first small rise north of Km 4 so that when the floodwater pours across at Km 4 (as it will and properly should continue to do until the watershed stabilization program becomes fully effective) the depth of sand which remains on the roadbed after the flood will be considerably lessened, with a corresponding reduction in the volume that must then be removed. Exactly the same treatment is recommended for the reach of main NW-SE road which parallels the wadi in the vicinity of the Azizia highway crossing. Some channel excavation in approximately the first 1000-meter reach below this crossing should be made, to increase the gradient by approximately one-third, but this excavation need be no more than 10 meters wide on the bottom, and would involve removal of only an estimated 5,000 cubic meters of material. This item is, however, the least essential on the whole plan, since there have never been any damaging breakouts below the Azizia crossing.

The one remaining item of this plan is that the channel below Km 4 be maintained on approximately its present gradient, following each flood, and that sand be excavated from the roads and highways, by the employment of efficient earthmoving equipment.

A good combination of equipment for this purpose would be one tractor-dozer scraper unit and one small (approximately ½ cubic meter capacity) truck-mounted dragline unit. There should be a roadway on the right side of the canal from Km 4 to the bridge near the sea, along which the dragline and trucks could operate. (Right of way for this road should logically be donated by the property owners involved, as their participation in this program for amelioration of damages from small and medium floods). The dragline is especially valuable for loading sand into dump or other trucks when it is desired to make a roadbed fill, such as just previously discussed, or when contractors or others desiring to acquire "free" fill material are found to be willing to haul away sand without charge if it is loaded into their trucks by the dragline, without charge.

With the forgoing minor improvements, and with the employment of the maintenance equipment as described, there would be essentially no need to employ hand labor for sand removal as is done at present; and following

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the line of discussion on this point in Section I of this report, it is estimated that the total annual cost for necessary public maintenance work would not exceed £L 15,000, gradually diminishing as the watershed control program becomes more and more effective.

The initial development cost of these minor improvements would be no more than a proper portion of that necessary for raising (and re-surfacing) the sections of roadbed as discussed previously. The whole cost of raising the roads cannot properly be charged as a cost of this plan, for it is obvious that within a few years these roadbeds will have to be raised in any case - whether or not there is a new channel to take three-fourths of the wadi flow to the sea. Even if a new channel were built, the one-fourth of the wadi flow that would continue down the present channel would continue to put considerable sand in some reaches of these roads. Already the level of the land in the area surrounding the roads, especially in the vicinity of Km 4, is so much higher than the roadbed, and the banks of waste sand thrown to the sides of the road are so much higher than even the average area level, that there is truly "no more place to put the dirt", and the situation strongly indicates the necessity for raising the road. Again, practically the same discussion applies to the reach of road paralleling the wadi at the Azizia crossing. Since both these sections of road are close by and parallel to the wadi, the cost of placing the material to make these fills, if it were planned as a part of the channel excavation (maintenance) operation, would be at a very nominal figure - hardly more than the cost of excavating the material and depositing it as waste at the most convenient dumping ground. As an overall estimate, it is believed that not more than £L 20,000 should be spent as an initial development cost (this is separate from the first year's £L 15,000 maintenance cost) in implementing this plan.

STUDY OF WADI MEGENIN FLOODS

SECTION III

ECONOMIC ANALYSIS OF FLOOD CONTROL PROPOSALS

THE TWO PROPOSALS

Two proposals are compared in this analysis.

Proposal I - Diversion-to-the-Sea Scheme - Re-routing the lower 11 Kilometers of the wadi into a new channel to the west of Tripoli.

Proposal II - Maintaining and improving to a limited extent the present artificial channel through the flood zone (based on the assumption that there will be inaugurated without undue delay an intensive, comprehensive watershed stabilization program).

THE PREMISES

The discussions to follow are based upon several premises. One is that fresh water is of such significance in the economy of the Tripoli Oasis that no appreciable amount of money can justifiably be spent to cause any appreciable amount of water, even floodwater, to be wasted, unused into the sea. A second premise is that flood and sediment producing characteristics of this watershed and the extreme erodibility of the gefara soils are such that the only feasible approach to flood control is to so alter the watershed characteristics that much less rainfall runs off the watershed. A third is that the watershed stabilization program is economically justified on its own account - the results and benefits within the watershed, and the program's significance as the first comprehensive demonstration of land management principles ( land resources utilization and conservation principles necessary for sustained and increased agricultural production), are ample justification for the cost of this program.

Therefore the downstream benefits of the watershed project, such as reduction of streambank erosion now eating into fertile farmlands bordering the watercourse, lessening of damages at the Tarhuna road bridge, and progressive reduction of flood damages at Tripoli, are bonus benefits, against which no part of the watershed project costs need be charged.

BASIS OF COMPARISON OF THE TWO PROPOSALS

In making this comparison, it is necessary to assess the various effects of the floods, now and projected into the future, for the two plans, first, in physical units, then converted into their monetary equivalents. Thus, development works, damages, benefits, maintenance operations, and other factors involved in the comparison can be added up in compatible terms. It is never possible to measure the flood effects, especially those concerning such factors as

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groundwater recharge, with incontrovertible precision. Similarly, it is never possible to convert a number of diverse factors into monetary units, to the complete satisfaction of all interests concerned; nevertheless, this is the only satisfactory basis for making a summation of all the factors. Finally, when all costs are stated on an annual basis, and year-to-year variations are reduced to an average annual figure, direct comparisons of one plan against the other can then be made.

ANALYSIS OF COST FACTORS, AND PROJECTION OF TRENDS

Progressing from the discussions in Sections I and II, the average annual value of the several factors involved in each proposal, for the present and for the future, must be established.

A first item in the comparison of Proposal 1 and Proposal 2 is the initial development cost. For Proposal 1, the diversion-to-the-sea scheme, this cost is estimated at £L 175,000; for Proposal 2, the plan for minor improvement of the existing channel and roads and streets, the estimate is £L 20,000.

It was stated previously that the net damages from the March 1956 flood were determined to be on the order of £L 15,000 to private property and £L8,000 to public property. About the only method of converting these figures to an average annual basis is to add up all the flood experiences from about 1945 to the present time and divide by the number of years. The average annual damage figures probably would not exceed, by an appreciable percentage, those for the one flood of March, 1956, as there have not been more than ten such floods in the past ten years. But allowing for the fact that the trend of the magnitude and frequency of the floods is an increasing one, it seems reasonable and proper to estimate that, currently, average annual damages, or losses, are somewhat greater than that for the March flood. While it seems unlikely that current annual damages could be as great as twice the March flood figure, nevertheless in order to be certain that an ample allowance is made, a figure essentially double the March damages will be used henceforth in this analysis. Therefore, current annual costs and damages are set at:

£L 30,000 average annual damages to agriculture and private property

£L 15,000 average annual damages, essentially maintenance costs, to public property (on the basis of use of efficient earthmoving equipment for sand removal instead of hand-shovel labor.

Here it must be repeated that the minor improvements to the existing channel

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and the raising of previously inundated sections of roads (Proposal 1), which can be completely accomplished in one summer season at a cost of £L 20,000 would make an immediate small reduction in damages to agriculture since channel capacity would be slightly increased, and a rather considerable reduction of public expenses since with roadbeds raised there would be much less sand to be removed following each flood. However, no credit or reduction in either private or public flood damages will be assumed as a result of these improvements, in projecting damage costs into the future as portrayed on Plate 3 (Appendix). Instead, the downward trend of these costs is computed solely as a result of the flood-diminishing accomplishment of the watershed stabilization program. Here again, this procedure makes doubly certain that the allowance for future damages is ample.

The influence of the watershed program on the size, shape, and composition of the floods, as shown on Plate 1a and as discussed previously, will have a corresponding influence on all damages in the Tripoli area, presented graphically on Plate 3. Here, the "curve" connecting the total annual costs takes the familiar "bell-shaped" conformation. The rate of change would be slow at first in consonance with the time lag required for the watershed program to reverse the present upward trend of the floods, but within a very few years the several mutually-supporting changes in the watershed would be accelerating the downward trend of the floods and the damages in the Tripoli delta (the cost "curve" would tilt more steeply as each year passed by), until by 1965 the decrease in damages would be on the order of some £L 4,000 per year. Eventually, following achievement of a near-maximum degree of stability (or equilibrium) in the watershed, visualized as attainable about 1975, the curve would become less steep, but by then the average annual damages would be down to a very low figure - something on the order of perhaps £L 6,000 per year, or even less. Actually, this is believed to be a modestly conservative projection of the results that might be brought about as a result of the watershed program. Certainly by this time the density of vegetation on the watershed should be equal to, probably greater than that which existed in the period 1920 - 1930, gullies and streambanks should be well stabilized, and altogether the flood and sediment producing characteristics of the watershed should be correspondingly comparable to what they were during this early period, when, it should be borne in mind, the floods were definitely beneficial, on net balance, to the lands of the delta flood zone. Therefore it is even possible that the annual cost curve (Plate 3) would go all the way down to zero before 1975.

An analysis of the initial situation and a projection of future costs

./... attendant

attendant to Proposal 1, the diversion-to-the-sea, can be made in a similar manner, and is shown on Plate 4. First, it is estimated that to carry out the proposal as outlined in the published preliminary plan for "Improvement of the Lower Megenin" including the "necessary improvements to the existing channel" and the bridge on the Azizia highway, an initial investment of about £L 175,000 would be required. It is assumed that construction operations could not be completed between two consecutive rainy seasons, and that the first season's work (spring-summer 1957) could not be expected to divert the floods of the following rainy period, which means that the first year's flood damage costs would be the same as for Proposal 1 - £L 45,000. During the second year (spring-summer 1958) construction operations could be completed, and for future floods 75 percent of the flow of water and sediment would be diverted along Trace 1 to the sea. At the moment of completion of the project works, some time prior to the onset of the rainy season in the fall of 1958, the total charges against the project would at that time be the £L 175,000 development cost, plus the £L 45,000 damages from the previous season's floods, for a total of £L 220,000 (every loss or damage that occurs after the inception of work on either Proposal 1 or Proposal 2 must be charged against that plan in order to make the comparison valid). But as soon as the first flood begins to move down the new diversion channel, maintenance costs would commence here, and other losses resulting from the waste of water would begin to accumulate as a charge against this project. These losses will be discussed later on in this Section.

With 25 percent of the flow of the floods continuing to go down the existing, or old channel, there will continue to be heavy depositions of sand at all constrictions - at Km 4 and the other sharp bends, and at the road crossings 1) north of the Roman Church, 2) at Azizia Barracks, 3) at the international highway near the sea. Since this sand must then be removed for the same reasons that it has been removed following floods of the past, there will still be considerable expense attendant to this maintenance requirement. Actually, the annual volume of sand deposited here might amount to more than one-half the current quantity, but for purposes of this analysis, and in order to avoid the possibility of "favoring" Proposal 2 in this respect, a figure of only one-third the current amount will be used. One-third of the current annual cost of this item, as explained previously in the discussion of Proposal 2, is £L 5,000, and it should be recalled that the figure can be this low only if the sand removal is performed with efficient earthmoving equipment.

This item is labelled as "Maintenance of Old Channel and Roads", on plate 4. Initially it amounts to £L 5,000 annually. But more important than the

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initial situation is the trend of future events. Without the watershed program, the trend of the floods of water and sediment will be increasing, ever more rapidly (as has been observed during the past 25 years) for some years into the future. This has been discussed in Section I, and is shown graphically on Plate 1a. Therefore it is only reasonable to project that the cost of this maintenance item would increase progressively so that by 1975 it would attain an annual figure of £L 10,000, double the initial amount.

The next item, or segment of annual costs attendant to Proposal 1, is the loss of the beneficial effects of water spreading out over the flood plain - prevention of this flooding of private land is stated in the Plan for Improvement of the Lower Megenin (Proposal 1) as being the major justification for the project in the first instance.

If there is to be no more spreading of water over the flood plain, all the traditional benefits of irrigation and deposits of the fertile suspended portion of the sediment, which even now enriches the lower, more distant boundary areas of the flood zone, beyond the reach of sand, will be lost. This loss, though undesirable, will be an inescapable corollary of prevention of the floods. But without doubt a loss of equal or greater consequence will be the reduction in the recharge of the groundwater reservoir that supplies Tripoli's wells. Each cubic meter carried by any channel to the sea instead of spread out over the delta flood zone means, except for the relatively small evaporation loss, one less cubic meter either used by vegetation or added to the groundwater reservoir. This subject has been discussed in Section I and in the special statement by Dr. Cederstrom, USOM Groundwater Geologist (Appendix). The value of this loss item - irrigation, beneficial suspended sediment, and groundwater recharge - is conservatively set at £L 5,000 per year, initially. But here again, the future will certainly bring an increase in the importance of the groundwater factor. With no more flooding of the delta zone, the drop in the average groundwater level, in an area much larger than the area formerly flooded, would undoubtedly become progressive with the passage of years, which means that all water lifts and, consequently, pumping costs, would become progressively greater. Concurrently there would also occur a gradual decline in yield rate of the shallower or poorly constructed wells. Obviously, when these wells deteriorate to the point that they fail, by a certain margin, to meet the established demands previously satisified, their owners will find it necessary to make additional investments for enlargement or deepening of these wells, and even, eventually, for drilling new ones.

And then, as the lowering of the water table proceeds farther and farther, there is the ominous threat of saltwater intrusion, into these wells where the

/..... water surface

water surface is consistently pulled down below the level of the sea. Therefore it is believed that the irrigation-and-groundwater loss, initially £L 5,000 could become a factor of considerable proportions; but for the purpose of holding to strict conservatism in this analysis, this factor will be estimated to have increased to only £L 10,000 annually by 1975.

The final item of annual cost of the Proposal 1 project is the maintenance requirement for the new works - the "barrage" in the Megenin, the eleven-plus kilometers of channel, and the six "waterfalls" (mechanical structures designed to drop the flow 3 meters or more at each of the six sites.) The maintenance requirement would commence with the first flood upon which the barrage performs its intended diversion. If the scope of the damages caused by the December 1955 flood in the unlined main and auxiliary canals of the Amiot-Viale and the Sidi Gilani diversion projects are any indication of what might happen to the unlined diversion-to-the-sea canal, much of which would also be in soft, erodible sand, it can be seen at once that annual damages to the latter canal could be of considerable proportions. Since the gradient and hydraulic radius of the new canal (both proposed to be less than in the watercourse of the Megonin itself) would reduce the velocity of flow in the canal as compared to the velocity of approach in the watercourse upstream from the barrage, the canal would be unable to carry the full load of sediment being delivered into it, and therefore a considerable percentage of the sediment would be deposited in the canal. Unless all this deposition were to be removed, following each flood, it would continue to accumulate until the restricted channel would overflow. Windblown sand would make frequent contributions to the constriction of the channel. Wherever the channel extended through reaches of sandy formations, floodwaters would cause the banks to erode rapidly, causing the channel to become wider and shallower, and therefore less efficient in discharging floodwater. When the inevitable overflows shall have occurred, floodwaters that had escaped the channel would, unless herded back by long, strong dikes, by-pass the "waterfalls", with serious wash-outs at the steep breaks in gradient in the vicinity of, or immediately adjacent to the abutments of the "waterfall" structures. This would leave the structure standing high and dry, performing no useful function, until the rather expensive maintenance work is performed. In short, to maintain the entire system in the same shape - the actual physical dimensions - of its original design and construction, the annual maintenance requirement would unquestionably be rather heavy. Obviously, the proposal must have contemplated maintaining the canal in its original shape and gradient; otherwise, there would be no purpose served by the construction of the waterfalls. Though it is possible that annual maintenance costs could average as much as one-fourth the initial development cost, the figure to be used in this analysis, in order to allow all possible credit to the proposal, is here set at a considerably lower figure

/.... of £L 20,000

of £L 20,000.

Total annual costs, following completion of the project, shown graphically on Plate 4, begin at £L 30,000; but they would increase in accordance with the current trend (Plate 1a) so that by 1975 the annual costs would be on the order of £L 50,000.

Finally, the last step in the economic analysis of the two plans is a comparison of the cumulative costs, developed by a simple accumulation of the annual costs shown on Plates 3 and 4. Cumulative costs for the two plans are set forth on Plate 5. There are two curves for each of the proposals, the lower one of each pair of curves showing partial costs to be assessed against that proposal. The lower curve for Proposal 2, the plan for minor improvements to the existing channel, portrays costs-damages to agricultural developments and private property. By 1975 the watershed stabilization program will have become so effective in controlling the floods of water and sediment at Tripoli that this curve will have become nearly level, as annual net damages approach the very low figure shown on Plate 3. The upper curve of this pair sums up all costs, including the initial development cost and public costs as well as private costs.

This curve also becomes essentially level by 1975.

The cumulative cost curves for Proposal 1, the diversion-to-the-sea scheme, however, present quite a different story. Here, the comparatively large initial development cost puts the investment, or cost, at a high level to begin with. Then, the several annual costs, commencing at a figure of £L 301000 (Plate 4), will be rising in an ever-increasing trend, in consonance with the ever-increasing violence of the floods, since, as has been previously stated, it is presumed that with this scheme in effect there would be no effective watershed stabilization program. (Note once more: engineering works alone - rock dikes, et cetera - without control of grazing, of cultivation, of esparto pulling, can not possibly bring about effective stabilization of the watershed.)

The lower of the pair of curves for the diversion scheme sums up initial costs plus maintenance cost for the diversion and its appurtenances - the canal and the waterfalls - only. The upper, or, "total costs" curve includes these costs and all other that pertain to this scheme:

1) First year's flood damage in the flood zone since the diversion would not yet be in operation (£L 45,000)
2) Maintenance of the existing channel and roads.
3) Increased irrigation development and operation costs due to lowering of the average groundwater level.
4) "Lost" flood-irrigation benefits (consolidated with item 3 on Plates 4 and 5).

/..... A glance

A glance at the upper curve pertaining to each proposal shows that there is at all times a considerable spread between the two - the cumulative total of costs to be charged against the diversion scheme will exceed that for the existing channel improvement plan by at least £L 100,000 at any time in the future. By 1970, the cumulative advantage in favor of this plan will increase to almost £L 200,000, while by 1975 this advantage will reach the proportions of at least £L 300,000.

CONCLUSION

The questions may be asked - should not both the watershed stabilization program and the diversion-to-the-sea scheme be carried out? Would not the cost of the diversion scheme be justified by the reduction in flood damages which it would bring about? The answer to these questions lies partly in the premise stated in the beginning of this analysis - that fresh water is of such significance in the economy of the Tripoli Oasis that no appreciable amount of money can justifiably be spent to cause any appreciable amount of water, even floodwater, to be wasted, unused, into the sea.

The Tripoli Oasis is quite obviously the focal point of the economy of Tripolitania, and to some extent, for all of Libya. If Tripolitania's economy is to move steadily forward towards that sought-for goal of viability, Tripoli must grow, and the agricultural and industrial production of the Tripoli area must grow. And each of these directions of growth will require ever-increasing quantities of water. The increase in 1) population, 2) light industrial activity and the service industries, and 3) irrigated agriculture, that have taken place in the past ten to twelve years, are some indication of what may be expected in the next decade or two. But this growth cannot take place unless the production of water supplies can keep pace with the growing demand. Not only must the population of the area grow, but an increased consumption per capita is an inescapable necessity for an expanding economy.

Therefore it is of supreme importance that the community not be committed to the operation and maintenance of a diversion project which would cause some 6,000,000 to 8,000,000 cubic meters of water to be wasted annually. Should the diversion project prove to be a "success", to the extent that the maintenance requirement should be tolerable to the public purse and the project thus kept in full operation as planned, the waste of water would obviously continue indefinitely, since private land owners in the delta zone previously subject to flood damage would be most likely to contest hotly any future proposal for abandonment of works which had eliminated such flood damages to their land. This would probably be their attitude even if there were a watershed program that had been in existence long enough to have reduced annual flood and sediment discharges by a fair margin, for those land owners could still hardly be expected to vote for abandonment of a diversion works which had been "successful" in keeping a number of floods off their land. And they would always be fearful of the

Big Flood that might come down upon them without the protection of the diversion works, even though the watershed program had tamed the recent floods.

On the other hand, should the diversion works prove to be a "failure" which would properly describe it should the maintenance requirement become intolerable and the project actually abandoned, it would then be only a matter of a few years until the channel a short distance below the barrage would, because of its extremely flat gradient, become constricted to the point that it would no longer accomodate a medium-sized flood, and then the next one would break out and turn back toward the natural watercourse, returning to it probably within a kilometer or two from the point of diversion. Should this occur, restoration of the system would then become highly improbable, and any value of the entire project would cease to exist.

Considering these alternatives, it appears improbable that with or without the watershed stabilization program, the diversion-to-the-sea project can hardly be expected to provide benefits that would be worth its cost, for the short term or for the long term. This is predictable with considerable certainty for the short term (first five years) and for the intermediate term (up to 1968 - 1970), due to the large initial cost of the diversion scheme, including the improvements to the existing channel stated in the proposal to be essential and necessary, and the obvious fact that maintenance of the new channel and its appurtenances, plus maintenance of the existing channel and of the roads and streets, will be a sizeable factor.

There is still another consideration of some significance. It hinges around the prospect that, with growing effectiveness of the watershed stabilization program in reducing the flood peak discharge rate and in reducing the average sediment content in the floodwaters, some type of engineering works would actually come into being. Perhaps the "improvement" in the flood flow by 1965 or thereabouts would be such that limited operation of the Amiot-Viale and the Sidi Gilani canals would become feasible (which is believed not to be the case at present)). Then, perhaps the diversion-to-the-east at Bir es Salalma might appear to be sufficiently feasible that this project might come into being. Then with these projects all draining off a fraction of the flood flow, a downstream low-dam detention storage reservoir - a very long dam creating a very wide, shallow lake - would very likely become feasible. Should these water-utilizing projects be placed in operation, the net flood damage at Tripoli would drop to zero immediately, as then whatever minor flooding might still occur would bring benefits to excess of gross damages, as was the case for the thousand of years before 1945. Note, however, that these engineering works can become feasible only after the watershed stabilization program has brought about some reduction in flood peaks and a considerable reduction in sediment load. Note also that these works are not assumed in the analysis presented on Plates 3, 4, and 5.

The point here is that should the community make the investments in the

diversion-to-the sea, and become committed to the rather considerable expense of keeping the scheme in operation, it seems less likely that a full-fledged watershed stabilization program would ever be put into effect, since the interests in the Tripoli flood zone, both private and public, would not then be looking to the watershed program for amelioration of the flood damage. But even if this conjecture were not correct, and the whole watershed program is put into effect, the commitment to the diversion-to-the sea would militate strongly against the undertaking of such floodwater utilization developments (engineering works on the gefara) as those just discussed which would render the diversion-to-the sea unnecessary, and, in fact, completely useless.

What is the value of a cubic meter of water? To a desert nomad who may have to carry it, 20 litres at a load, on his back, several kilometers from the well to his tent, the consumption of one cubic meter may mean as much as two hundred hours of hard labor. To put this on a commercial basis, the desert nomad, since he must do work other than carrying water, could not possibly be hired to carry the cubic meter of water for less than £L 2.000 (wages: 1 piaster per hour). This is only to say that human beings will pay, in labor or in cash whatever they must pay for the minimum amount of water necessary to sustain life. Additional uses of water merely add to the comfort of living and to the over-all economic level, the rate of this additional consumption being determined by what the economy of an individual or group can afford.

In the economy of people living in the Tripoli Oasis, a reasonable estimate of the average total cost of producing a cubic meter of water (all of which comes from the groundwater reservoir) at the ground surface level, before it is conveyed to the point of use , is about 2 or 3 piasters. The cost of distribution from ground level at the well-head, to the point of use, is an additional factor. But for comparison, the cost of delivering a cubic meter of fresh water, trucked from Ain Mrassis to a distribution point in Tobruk is probably ten times as great, 20 to 30 piasters. This one condition a lone, as long as it holds, places iron-bound restrictions upon the growth of Tobruk or the expansion of its economy.

The point here is that the over-all economy of the Tripoli Oasis, limited as it will forever be by both the quantity that can be obtained from the underground storage reservoir, and also by the cost of obtaining it, can better tolerate a damage cost for a few years yet, of one or one-and-a-half piasters (the current rate) from each cubic meter of water that floods over the delta flood zone, in order to get the cubic meter of water into the underground reservoir, than it can tolerate the expenditure of one or more piasters to avoid the flood damage by wasting the water into the sea. The day is certainly not far in the future when the enlarged and intensified demand will accept a higher cost for water than prevails at present, but there is no economic justification for hastening that day by expensive works whose function is to decrease the supply of available water.

The whole watershed, with its resources of land and water, not just one small portion of it (the Tripoli Oasis), is important to Libya. The growing floods, and their sediment load, are an undeniable measure of the accelerating destruction of the watershed's resources by erosion.

They are a clear symptom of the malady that has beset the watershed - the malady of abuse, overuse and exploitation - the removal of vegetation faster than nature has been permitted to produce it.

Only time and vegetation, not engineering works, can correct this trouble. Any sudden action aimed at obtaining quick results can be nothing more than a shot in the arm, a temporary amelioration of a malady that will certainly kill the patient, unless the malady is cured at its source. The real cure, for the patient, or for the Megenin watershed, will take somewhat longer, but will cost less and produce greater benefits in the long run. But the overall watershed program is the subject of another report.

= As for the proposals for flood control at Tripoli, the question is merely a choice of:

1) Obtaining quick relief from private flood damage and a partial reduction of p ublic maintenance costs in the present channel area, at the expense of large investment and maintenance costs in a new area, attended by the loss of all the traditional benefits of the floods, or:
2) Accepting a certain amount of flood damage in the present zone, for some time yet but on a diminishing scale: meanwhile, concentrating all possible efforts on the overall watershed program - the only permanent solution for the flood problem and the only way to prevent the destruction of the watershed's resources as well.

The question is merely one of obtaining illusory short-term benefits at the expense of the future, or of gaining greater and more lasting benefits, at less overall cost though at some specific sacrifice for the short term.

- END -

Table 1 -- Rainfall of [illegible]

Recent Events That Resulted in Floods

Millimeters Rainfall During Stated Periods

| | December 1938 | December 1945 | 26-29 April 1955 | 26-29 December 1955 | 13-14 March 1956 |
|---|---|---|---|---|---|
| Tripoli | 210 mm<br>7 days | 180 mm<br>13 days | 17 mm<br>28-29 Apr | 25 mm<br>26-29 Dec | 13 mm<br>13-14 mm |
| Castel Benito | 150 mm<br>8 days | 85 mm<br>8 days | | 33 mm<br>26-29 Dec | 17 mm<br>13-14 Mar |
| Azizia | 100 mm<br>6 days | 63 mm<br>7 days | 14 mm<br>28 Apr | 44 mm<br>26-29 Dec | 15 mm<br>13-14 Mar |
| Bu Argub | | | 14 mm<br>26-29 Apr | 54 mm<br>26-29 Dec | 13 mm<br>13-14 Mar |
| Garian | 81 mm<br>10 days | 100 mm<br>6 days | 41 mm<br>26-29 Apr | 90 mm<br>26-29 Dec | 33 mm<br>13-14 Mar |
| Tigrinna | 81 mm<br>19 days | 83 mm<br>10 days | 35 mm<br>26-29 Apr | 100 mm<br>26-29 Dec | 44 mm<br>13-14 Mar |
| Bu Gheilan | 90 mm<br>6 days | 80 mm<br>5 days | 26 mm<br>28-29 Apr | 74 mm<br>26-29 Dec | 35 mm<br>13 Mar |
| Dir Feggeg (Center Gebel) | | | 75 mm<br>26-29 | 85 mm<br>26-29 Dec | |
| Tazzoli | | | | 72 mm<br>26-29 Dec | 24 mm<br>13 Mar |
| Abiar Miggi | 90 mm<br>6 days | 49 mm<br>8 days | | 88 mm<br>26-29 Dec | 27 mm<br>13-14 Mar |
| Tarhuna | 90 mm<br>7 days | 60 mm<br>8 days | 55 mm<br>26-29 Apr | 93 mm<br>26-29 Apr | 30 mm<br>13 Mar |
| Gebel Average | 88 mm<br>8 days | 74 mm<br>6 days | 52 mm<br>4 days | 86 mm<br>4 days | 35 mm<br>2 days |

Weather stations in the Gebel

A Measure of the Change in the Flood Characteristics of the Watershed

Dr. Magazzini, GOL Meteorologist, estimates that if:

1) A 100-mm rain had fallen in a single storm (considered to be approximately the 25-year frequency event), prior to 1920, runoff would have been on the order of 7 to 8 mm (5,000,000 cubic meters.).

2) A 100-mm rain should fall in the same space of time in 1956, the runoff would be at least 15 mm producing a volume, from the 650 square-kilometer gebel drainage area, of not less than 10,000,000 cubic meters.

Since a larger flood produces a higher maximum (and average) velocity of flow, and since the sediment transporting power of flowing water is proportional to about the fourth mathematical power of velocity, it is probable that each cubic meter of water in recent floods carried 4 to 6 times as much sand, on average, as did a cubic meter of floodwater in the pre-1920 period.

TABLE 2 - EFFECTS OF FLOOD OF MARCH 1956 - DAMAGES AND BENEFITS TO PRIVATE PROPERTY.

| Lot No. | Culture Description | DAMAGES Unit | Quantity | Unit Value £ | Total Value £ | BENEFITS Unit | Quantity | Unit Value £ | Total Value £ | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|
| ~~105~~ ONORATO (owner) | Potatoes, Cabbages, alfalfa - | Ha. | 17.5 | 200 | 3500 | Ha.* | 5* | 60 | 300 | * Olives in NW part of farm receives irrigation, good clay sediment, little sand. Grain planted here received irrigation, yield probably increased by the flood. Approx. 10 Ha. on Lot 104 was very slightly damaged, received irrigation of olives and other trees and crops, and on part of the area even annual crop were benefitted. |
| | Beans - 50% lost | Ha. | 2 | 75 | 150 | | | | | |
| | Irrigation canals | Lin.Mtr. | 1000 | 0.15 | 150 | | | | | |
| 104 | Oranges, plums, nespoli | Ha. | 4 | 333 | 1300 | | | | | |
| 105 | Oranges & olives | Ha. | 4 | 250 | 1000 | | | | | |
| | Citrus - (less damages) | Ha. | 2 | 100 | 200 | | | | | |
| | Citrus & plums | Ha. | 2 | 150 | 300 | | | | | |
| | Olives | | | | | Ea. | 700 | 2 | 1400 | Several hectares received almost no sand, but a layer of clay-organic sediment, and received considerable net benefit. |
| | Irrig. canals, pipes, etc. | | | | 250 | | | | | |
| | Misc. annual crops. | Ha. | 4 | | 400 | | | | | |
| 101 | Olives & grapes | | | | | Ha. | 10 | 100 | 1000 | No sand. Beneficial clay sediment. Excellent irrigation of trees and vines, harvest increased. |
| 100 a | Misc. annual crops | Ha. | 3 | | 300 | | | | | |
| 100 | Misc. annual crops | Ha. | 1 | | 100 | Ha. | 2 | 50 | 100 | Gross benefits equal to gross damages. |
| 23 | Grapes | Ha. | 3.5 | 250 | 875 | Ea. | 2000 | 0.03 | 60 | Grapes and olives in west portion of farm received good irrigation, layer of clay sediment, little or no sand. East portion heavily sanded. |
| | Olive trees | | | | | | 200 | 2 | 400 | |
| | Almonds | Each | 100 | 3 | 300 | | | | | |
| | Potatoes | Ha. | 2 | 200 | 400 | | | | | |
| | Other annual crops | Ha. | 2 | 100 | 200 | | | | | |
| | Irrigation canals | | | | 100 | | | | | |
| 132 a | Potatoes | Ha. | 1 | 200 | 200 | | | | | |
| | Almonds | Each | 100 | 4 | 400 | | | | | |
| 131 | Annual crops | Ha. | 3 | 50 | 150 | | | | | |
| | Oranges & Almonds | Ha. | 4 | 100 | 400 | | | | | |
| 132 | Oranges, lemons, lime | Ha. | 3 | 500 | 1500 | | | | | |
| | Grapes | Ha. | 2 | 200 | 400 | | | | | |
| | Potatoes | Ha. | 2 | 200 | 400 | | | | | |
| | Pear trees in nursery | | | | 50 | | | | | |
| | Irrigation canals | Lin.Mtr. | 800 | 0.25 | 200 | | | | | |
| 132 b | Grapes - damaged or destroyed | Ha. | 0.75 | 200 | 150 | | | | | |
| | New alfalfa, potatoes, cabbages | Ha. | 2 | 175 | 350 | | | | | |
| | Irrigation canals | Lin.Mtr. | 200 | 0.20 | 40 | | | | | |
| | Olives | | | | | Ea. | 100 | 2 | 200 | Good irrigation of olives and grapes. Good clay layer deposited, little sand. |
| | Grapes | | | | | Ha. | 4 | 50 | 200 | |
| 54 a | Gov't forest reserve (South of outer loop road) | | | | | Ha. | 16 | 50 | 800 | (1956 tree growth increased 200-300%. Clay layer. |
| | Gov't forest reserve (North of outer loop road) | | | | | Ha. | 20 | 50 | 1000 | Large quantity of water to groundwater reservoir.) |
| 18 | Annual crops | Ha. | 4 | 50 | 200 | | | | | |
| 18 a | Potatoes and cabbages | Ha. | 2 | 100 | 200 | | | | | The erosion on this farm occurred in the same old channel, previously refilled by the sediment removed by the gov't from the highway. After this washout, it was not refilled, but crops were planted on the bottom of the wash, where ancient top soil lays. |
| | Beans | Ha. | 0.5 | 100 | 50 | | | | | |
| | Alfalfa - year-old | Ha. | 0.5 | 300 | 150 | | | | | |
| | Young trees - fruits & olives | Ea. | 75 | 1 | 75 | | | | | |
| | Barley - some damage | Ha. | 1 | 30 | 30 | | | | | |
| | Irrigation pipes | | | | 200 | | | | | |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 33 | Potatoes | Ha. | 3 | 150 | 450 | | | | | Sig. Palladino's farm, including that portion sold to Ess. Sorrag. Most of farm covered by heavy deposition of sand, but 4 - 5 hectares received very little, and here the crops and trees received a net benefit, since value of irrigation and fertile clay sediment more than offset the minor damages. |
| | Grain (Olives in part area) | Ha. | 8 | 50 | 400 | | | | | |
| | Alfalfa (young) | Ha. | 1 | 200 | 200 | | | | | |
| | Misc. annual crops | Ha. | 1 | 120 | 120 | | | | | |
| | Young orange trees | E a. | 5000 | .05 | 250 | | | | | |
| | Irrigation systems | Lin.Mtr. | 1200 | 0.10 | 120 | | | | | |
| | Olive trees | | | | | Ea. | 100 | 2 | 200 | |
| 37 | Irrigation canal (pipes) | Lin.Mtr. | 330 | 0.50 | 165 | | | | | The survey on this farm was made by FAOO Horticulturist Marzotti aand USOM Horticultur Boidas. On the 1.5 hectares of flowers, only 25% destroyed, and only minor damage on 25% with moderate damage on 50%. |
| | Annual crops | Ha. | 7 | 40 | 280 | | | | | |
| | Flowers - destroyed & damages, 1 crop lost | Ha. | 1.5 | 1200 | 1800 | | | | | |
| | Grap crop damage | Ha. | 1 | 150 | 150 | | | | | |
| | 3-year olive crop loss | Year | 3 | 60 | 180 | | | | | |
| | Citrus tree damage | | | | 500 | | | | | |
| | Almond crop loss | | | | 75 | | | | | |
| | Sand removal | | | | 280 | | | | | |
| 16 & 8 | Misc. annual crops | | | | 50 | | | | | |
| | Fruit trees | | | | 100 | | | | | |
| | Almonds | Ea. | 100 | 4 | 400 | | | | | |
| 22 | Olive trees | | | | | Ha. | 8 | 100 | 800 | No damages - no sand - valuable irrigation - fertile clay sediment. |
| 10 | Olive trees | | | | | Ha. | 6 | 100 | 600 | |
| 26 & 3 | Grapes | | | | | Ea. | 7000 | .03 | 200 | No sand - only clay sediment - valuable irrigation. |
| | Olives | | | | | Ha. | 18 | 100 | 1800 | |
| 71 | Barracks and school | | | | 25 | | | | | |
| 71 & 75 | Roseplants | Ea. | 2000 | 0.10 | 200 | | | | | Good irrigation on trees. Very little sand reached this farm. Good clay sediment over entire flooded area. On some 5-6 hectares, there was very minor net damage, and net bene on several hectares. |
| | Carnation crop | Ha. | 2 | 400 | 800 | | | | | |
| | Gladiolas | Ea. | 10000 | 0.03 | 300 | | | | | |
| | Olive trees | | | | | Ha. | 3 | 100 | 300 | |
| 19 | Oil and tile factory | | | | 2000 | Ha. (crops) | 3 | 50 | 150 | This factory is gradually closing out its oli oil and soap business because of demand for its products. Clay is "mined" from pits for making bricks and tile, and each flood deposits a new layer of clay in th pits. If the floods are stopped, this plant will exhaust its reserve of clay in a few years. |
| | Olive residue damages | | | | | Ha. (clay pits) | 3 | 50 | 150 | |
| | Machinery damages | | | | | | | | | |
| 40 & 43 | Olive trees. | | | | | | | | 500 | Benefits only here - irrigation & clay sedime |
| 106 | Citrus and olive trees | Ha. | 10 | Very slight | damage | Ha. | 10 | 20 | 200 | About 10 Ha. of citrus and olive trees, with small amount of annual crops. Dikes around this farm, though admitting floodwater from the south, were very effective in diminishing its velocity; therefore, no sand came in with the floodwaters, only the layer of clay sediment. Gross damages were exceptionally slight for this section of the flood zone, while benefits from flood irrigation and fertile sediment were considerable. In this instance no value is assigned to either gross damages of gross benefits - only net benefits are stated. |
| Ess. Haj Braim Gannai (owner) | Annual crops | Ha. | 3.5 | 100 | 350 | | | | | This damage figure is an exact quote of the damage estimate made by the farm owne himself. Essayed Gannai estimate his losses to annual crops and damages to his irrigation system, at £L 300. After the flood, he built a dike on the S and W sides of his farm (capable of withstanding pressure of a flood depth of perhaps 0.25 meters) at a cost of £L 50. This expense is included in the damage figure. |
| | | TOTAL GROSS DAMAGES | | | £L 23,865 | TOTAL GROSS BENEFITS | | | £L 10,360 | |
| | | For the purposes of the economic analysis, this figure is adjusted to: | | | | For the purposes of the economic analysis, this figure is adjusted to: | | | £L 9,000 | |
| | | TOTAL GROSS DAMAGES | | | £L 24,000 | | | | | |

Recapitulation:

Area of Net benefit - 103 Ha.
Area of minor damage- 59 Ha.
Area of heavy damage- 120 Ha.
Total flooded area - 282 Ha.

STATEMENT CONCERNING THE GROUNDWATER

RECHARGE ASPECT OF WADI MEGENIN FLOODS

By Dr. Cederstrom, Groundwater Geologist

In consideration of the over-all flood area problem, I think something along the following line should be included:

From the point of view of groundwater hydrology, it is simply fantastic that efforts are made to divert flood water of the Wadi Megenin, or of any wadi, directly to the sea. Libya is a country whose economy is entirely dependent upon, and will progress only to the extent of its available water supply. The water supply is essentially limited and the waste of any water falling on the ground is, by definition, extremely bad. Any plan dealing with water falling upon the ground in Libya must provide for the retention of that water upon the land and its use one way or another. Intelligent thinking does not permit any alternative plan.

The March, 1956 flood was in the nature of 3 million cubic meters of which about one-half was discharged to the sea and irretrievably lost. One-half of this water reached the flood area and of this amount a very little was lost by evaporation and transpiration; the remainder was directly added to the groundwater reservoir. Considering the open texture of the fine sand soil, in which there is a low proportion of clay, I would estimate that about two-thirds of the water that flowed onto the land percolated downward to the point of saturation and became available to wells.

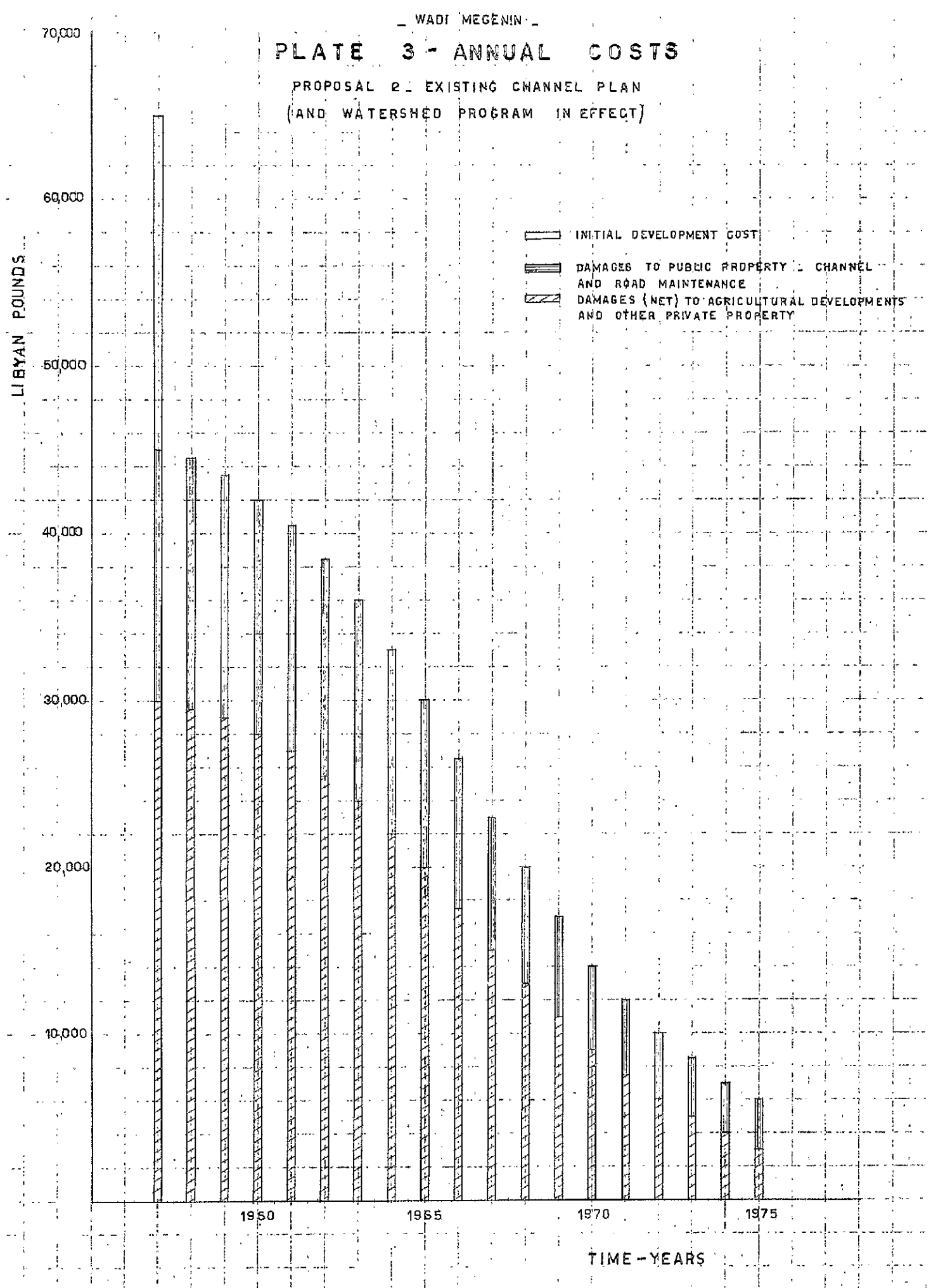
The total flow of the March flood, which was not a large one as floods here go, was about 3 million cubic meters or 790 million gallons. This amount of water is sufficient to support the demands of a modern city of 20,000 inhabitants for one year. Not more than one-third of the total flow may have reached the groundwater reservoir and it is to be deplored that all the flow was not given the opportunity to sink into the ground.

The demands for groundwater immediately to the south of Tripoli are large and consistent. The city of Tripoli obtains its water supply from wells and in the flood area there are litoally thousands of privately owned shallow wells drawing greater or lesser amounts of water throughout the year. It requires no stretch of the imagination to visualize a shortage of water as evidenced by increasing lifts to the surfacem nor is the possibility of salt water intrusion due to insufficient inflow from the south a remote danger.

./... We live

We live not only for the present but must make plans for the future. The present water supply system is not a stable situation that is going to last forever. Needs are constantly increasing and, since the amount of water added to the ground each year is limited, the demands for water can grow only up to that amount, considering the long-range point of view. Therefore, it is imperative that every reasonable and even unreasonable effort be made to save every drop of water that falls upon the ground, whether it be from the Wadi Megenin or elsewhere.

LEGEND
PLATE NO. 2
REVISION
AGRICULTURE & WATER RESOURCES DIV.
WADI MESENIN
FLOOD ZONE


_ WADI MEGENIN _
PLATE 3 - ANNUAL COSTS
PROPOSAL 2 _ EXISTING CHANNEL PLAN
(AND WATERSHED PROGRAM IN EFFECT)
INITIAL DEVELOPMENT COST
DAMAGES TO PUBLIC PROPERTY _ CHANNEL AND ROAD MAINTENANCE
DAMAGES (NET) TO AGRICULTURAL DEVELOPMENTS AND OTHER PRIVATE PROPERTY
LIBYAN POUNDS
70,000
60,000
50,000
40,000
30,000
20,000
10,000
1960
1965
1970
1975
TIME - YEARS

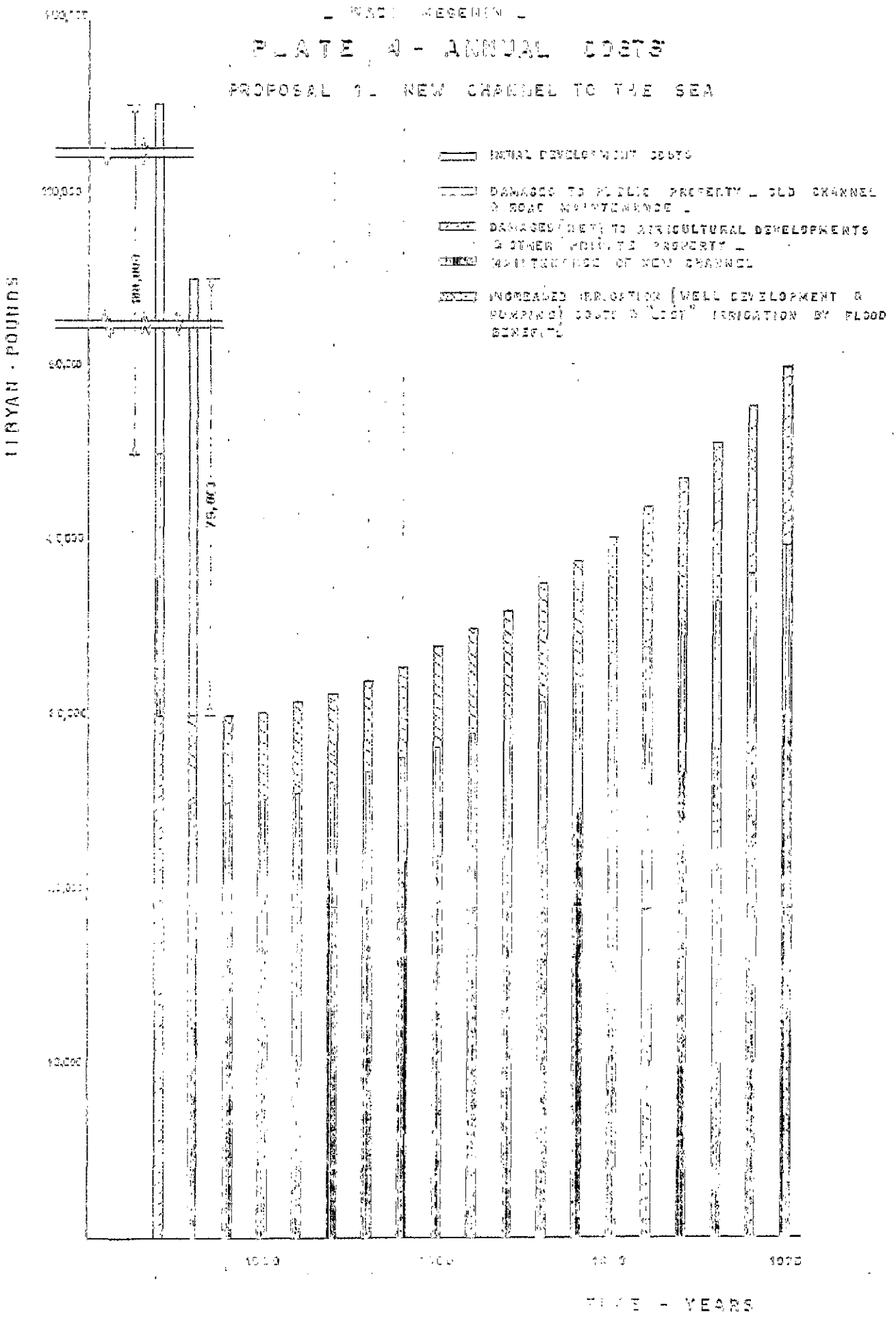
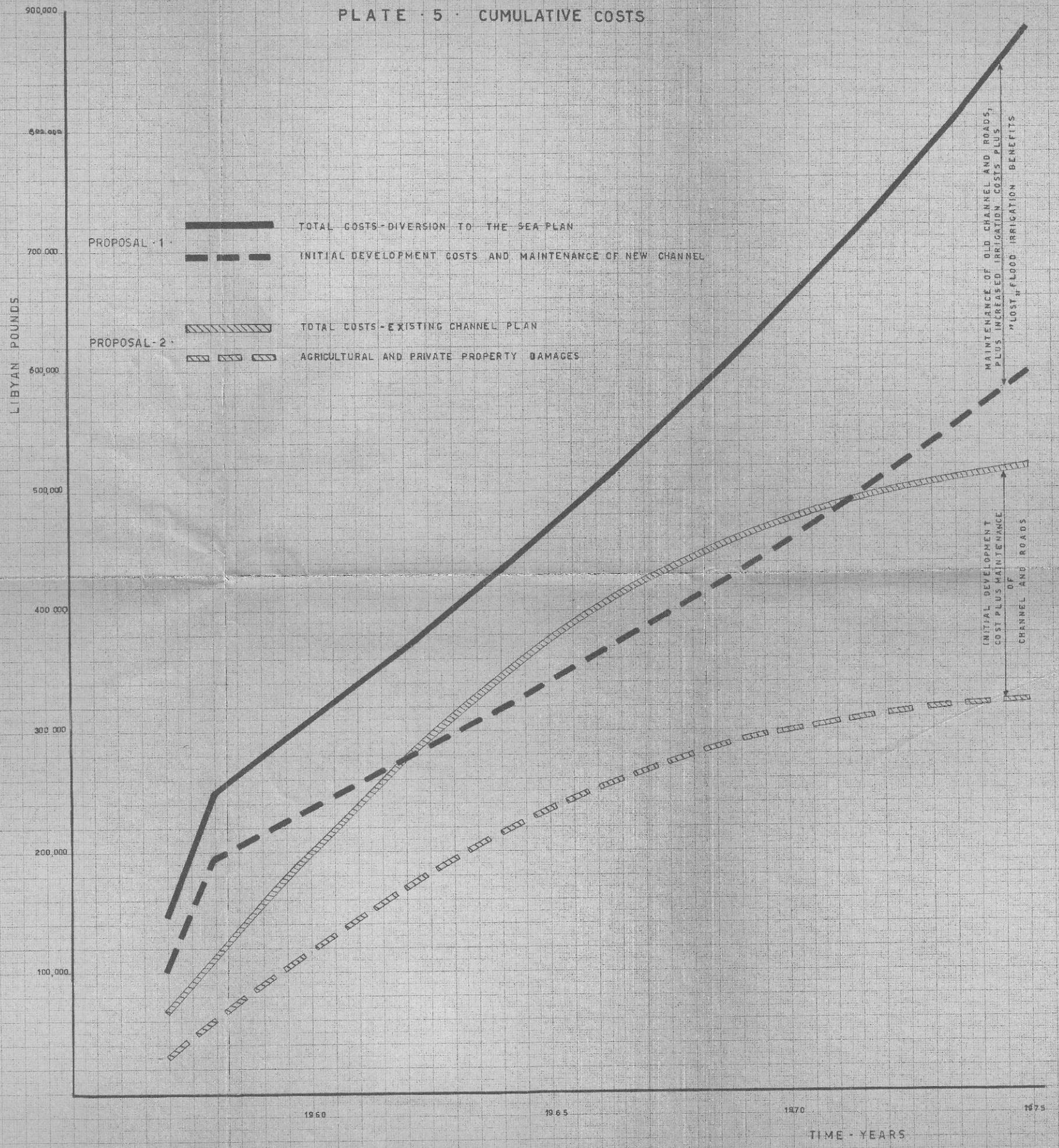


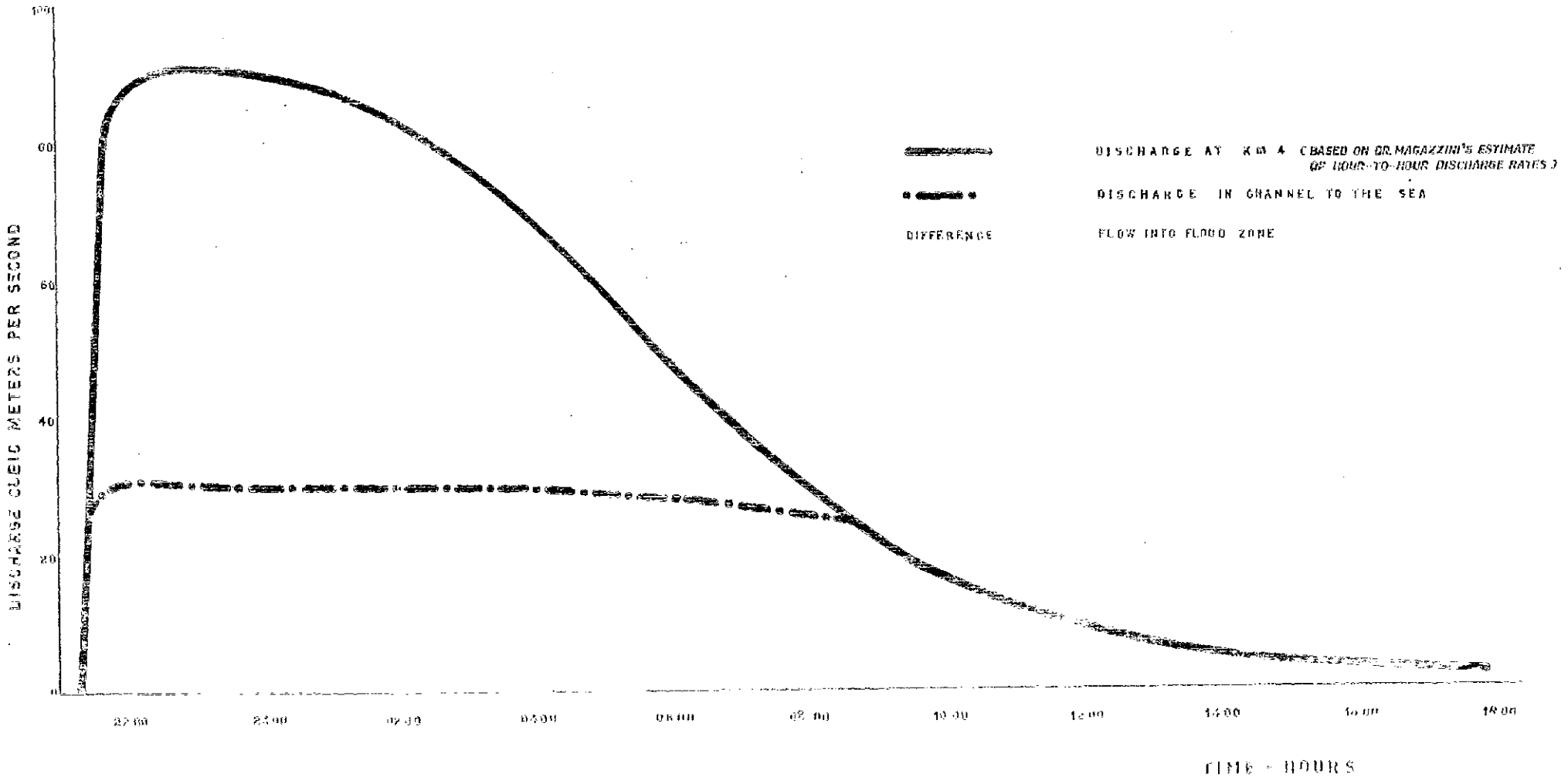
PLATE 4 - ANNUAL COSTS
PROPOSAL 1 - NEW CHANNEL TO THE SEA
INITIAL DEVELOPMENT COSTS
DAMAGES TO PUBLIC PROPERTY - OLD CHANNEL & ROAD MAINTENANCE -
DAMAGES (NET) TO AGRICULTURAL DEVELOPMENTS & OTHER PRIVATE PROPERTY -
MAINTENANCE OF NEW CHANNEL
INCREASED IRRIGATION (WELL DEVELOPMENT & PUMPING) COSTS & "LOST" IRRIGATION BY FLOOD BENEFITS
LIBYAN - POUNDS
100,000
80,000
40,000
10,000
TIME - YEARS

WADI MEGENIN

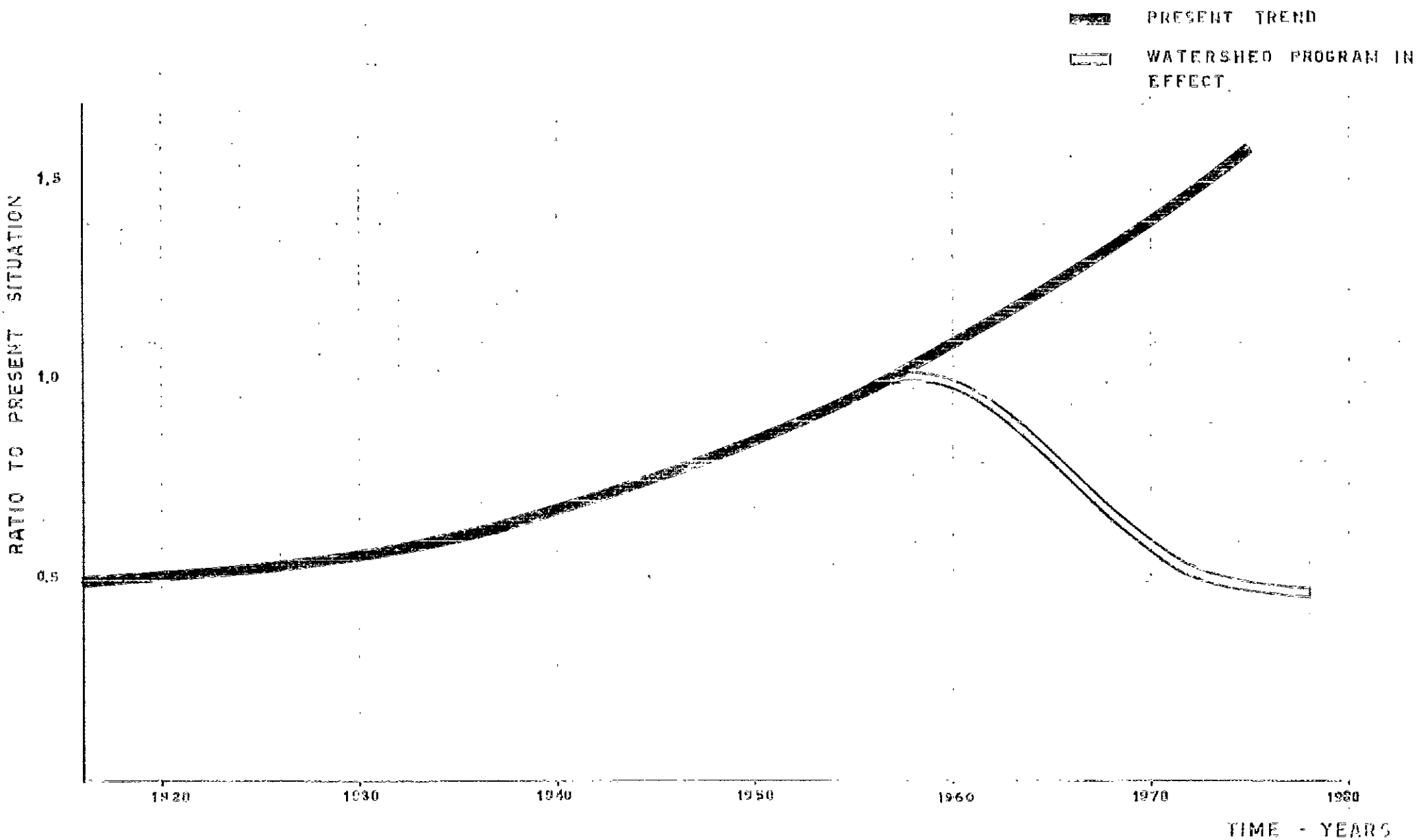
# PLATE · 5 · CUMULATIVE COSTS



# PLATE 1 - HYDROGRAPH OF MEGENIN FLOOD OF MARCH 1956




| | | |
|---|---|---|
| GROSS FLOOD VOLUME | 2,997,000 | $m^3$ |
| CHANNEL FLOW | 1,450,000 | $m^3$ |
| FLOOD PLAIN FLOW | 1,547,000 | $m^3$ |

. WADI . MEGENIN .

# PLATE 1a . TREND OF AVERAGE ANNUAL DISCHARGES OF FLOODWATER AND SEDIMENT