AN ABSTRACT OF THE THESIS OF

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Title: AN ECONOMIC ANALYSIS OF IRRIGATION DEVELOPMENT IN NAM PONG IRRIGATION PROJECT, KHON KAEN, THAILAND

Abstract approved:

Stanley F. Miller

The objectives of the study were to: (1) determine, given a fixed government investment in the Nam Pong Irrigation Project, the investment mix between consolidated, structurally improved and unimproved lands and the crops to be grown on these lands which will maximize returns to land and government investment; (2) evaluate the value of irrigation water in crop production for various periods of water supply from the Nam Pong Irrigation Project; (3) evaluate an effect of the irrigation development on employment and the irrigation water utilization; and (4) examine changes in the irrigation development, returns to land and government investment, land use alternatives, value of irrigation water, employment and irrigation water utilization resulting from the variation in the government investment.

The study covered one year (the 1977 wet season and the 1978 dry season) utilizing information obtained from a farm survey, the RID-IRRI water management research program for Northeast Thailand, and various offices of Thailand Royal Irrigation Department.

A linear programming model was developed for this study. The model consisted of three main irrigation development activities: (a) land consolidation, (b) structural improvement, and (c) unimprovement. In the dry season, each of these three main activities included four minor land use alternatives--rice production, vegetable production, other field crop production, and fallow land. During the wet season, both the land consolidation and unimprovement activities had three land use alternatives--rice production, vegetable production, and fallow land. The structural improvement activity considered only rice production and fallow land use alternatives in the wet season.

The constraints included in the model were land, area allowed for vegetable production, labor by month, irrigation water by two-week, cash operating capital, and government budget.

At the assumed 17.3 million dollar government investment, the optimal irrigation development included 17,840 hectares of consolidated land, 5,899 hectares of structurally improved land with the remaining 24,661 hectares left undeveloped. This investment yielded an annual net benefits to the investment of 3,766,566 dollars, a benefit-cost ratio of 2.31 and an internal rate of return of 21.8

percent. The values of February 2-15 and October 16-31 irrigation waters were 1.87 and 0.86 cents per cubic meter, respectively. The investment also caused a reduction in the unemployment by 2,909,127 mandays per year.

When the government investment was allowed to vary, the amount of consolidated land increased with the investment while the quantity of unimproved area decreased with the investment. The annual net benefits to government investment reached the maximum value of 5,808,572 dollars at 32 million dollar investment. At this level of investment, the benefit-cost ratio and the internal rate of return were 1.95 and 18 percent, respectively. The total reduction in unemployment resulting from a 32 million dollar investment was estimated to be 3,872,862 mandays per year.

The major conclusions of the study were: (1) maximum government investment in the irrigation development is not to be more than 32 million dollars, ceteris paribus; (2) investment in the irrigation development caused a higher cropping intensity and employment than without the investment; (3) annual returns to land and the investment and annual net benefits to the investment increased as the investment increased and they reached the maximum at 32 million dollar investment. (At that level of investment, the benefit-cost ratio was 1.95 and the internal rate of return was 18 percent); and (4) the investment in the irrigation development caused irrigation water to be more valuable.

An Economic Analysis of Irrigation Development
in Nam Pong Irrigation Project,
Khon Kaen, Thailand

by

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I. INTRODUCTION

The Role of Irrigation in Agricultural Production

One of the basic human needs is food. As the population increases the demand for food is growing, but land required for food production is becoming more and more scarce. One way to keep the growth rate of food at least as high as that of population is to increase agricultural productivity.

Agricultural productivity can be increased through a number of practices. Among them are improvement in and adoption of seeds, fertilizer, insecticides, herbicides, and irrigation. Of the five mentioned factors, many consider irrigation to be the most crucial (Bhuiyan *et al*. 1978).

Irrigation not only determines the intensity to which agricultural land is used in agricultural production but it also affects the adoption of new technologies. Farmers with adequate and stable supplies of water tend to use more inputs and better cultural practices for their rice crops than do farmers with unstable and insufficient water (Wickham 1974). Fewer farmers adopted high agricultural productivity practices such as high yielding rice varieties, chemical fertilizer in rainfed areas than in partially or fully irrigated areas (Sriswasdilek 1973).

Inadequate irrigation drastically reduces yield improvements of modern, nitrogen-responsive rice. The limitation is two-fold: at any nitrogen level, the expected yield of rice is reduced by lack of irrigation in the wet season and by inadequate irrigation in the dry season; and insufficient irrigation reduces the optimum level of nitrogen use by reducing the profitability and increasing the risk (Rosegrant 1976).

Irrigation in Thailand

Agriculture has long been the dominant sector in Thailand's economy. The average agricultural share of the gross domestic product during the period of 1970-1976 was 28.1 percent (Bank of Thailand 1976 and 1977). But its growth rate during the same period was only 3.0 percent, compared with population growth rate of 3.38 percent (United Nations 1976). Therefore, if the country wants to maintain food self-sufficiency and foreign exchange earnings from agriculture, the rate of agricultural production must be increased. Increased agricultural production now or in the future cannot be met from area expansion since there is no great quantity of new land waiting to be opened for agriculture. The main increase in agricultural production must come from making better use of land already farmed. More efficient crop production will help, for example, better varieties, more fertilizer, insecticide, etc. But the adoption of these production practices depends largely on irrigation. Therefore, irrigation is essential to increased agricultural production in Thailand.

Irrigation Development in Thailand

Modern irrigation or water resource development in Thailand was begun in 1902 (RID 1976a). In that year the government of Thailand negotiated with the government of the Netherland East Indies for the servies of an irrigation engineer, Mr. J. Homan Van der Heide, to draw up an overall irrigation plan for the nation. He recommended that a big barrage be built on the Chao Phya River in the Province of Chainat (Panyadhibya 1961).

His scheme included the development of irrigation projects in the north and other parts of the country. The overall project cost estimated at that time was 2.3 million dollars spreading over a 12-year period. The government did not have enough funds for all the projects. Only the small works of dredging the existing canals and the construction of sluices and locks in the south central region were undertaken. Van der Heide was Director General of the Royal Irrigation Department until 1909. He resigned and went home after the government postponed indefinitely the irrigation work. The Royal Irrigation Department was abolished in 1912 (Panyadhibya 1961).

The work done under Van der Heide's supervision did not function adequately. The canals could not be used for irrigation when the water did not raise to the level that would inundate the rice fields. The project supplied supplemental water to only 20, 000 hectares. The years 1909-1912 were years of drought and as a result, the economy of the country became very unbalanced. King Rama VI (King Vajiravudh) ordered irrigation and drainage evaluation to be carried out again. Sir Thomas Ward, an English irrigation expert of the government of India, was employed by Thailand in 1913 to check Van der Heide's irrigation project proposals. He confirmed the former plan, but instead of laying out the whole scheme as a big project, he divided it into many small projects. According to Ward, Thailand at that time was not ready to undertake the big project. The government accepted the plan and started the first gravity irrigation project on the Pasak River. The Royal Irrigation Department was reestablished to operate the small projects along the lines proposed by Thomas Ward. Since then modern irrigation projects have been constructed and expanded to all parts of the country (Panyadhibya 1961).

In the northern part, modern irrigation was started in 1928; in the northeastern section in 1939; and in the southern part in 1947 (RID 1976a).

Types of Irrigation Works in Thailand

There are three main types of irrigation works in Thailand. The first two, translated from the laws of Thailand, are "State Irrigation" and "People Irrigation" projects. Both are constructed by government. The government pays all construction costs from the national budget. The only difference is that State Irrigation Projects are operated and maintained by government staff while People Irrigation Projects are operated and maintained by the direct beneficiaries under the supervision of local administrative officers. The People Irrigation projects carry out the works which are outside the area of the State Irrigation projects (Panyadhibya 1961).

The third type of irrigation work is the private irrigation project which is constructed and all expenses paid by the farmers themselves. Most of these projects are small, benefiting only a limited area in a community or village. The people in the northern part have had considerable experience in constructing private irrigation projects for many hundreds of years (Panyadhibya 1961).

Irrigated Area in Thailand

Currently the government of Thailand is spending about two-thirds of its agricultural expenditure on irrigation (Bhuiyan 1977). As of October 1975, the irrigated area in Thailand was 2,419,109 hectares (RID 1976a). About 68 percent of this area (1,653,188 hectares) is located in the central plain while six percent (147,472 hectares) is located in the southern part of the country. In October 1975, the northern part ranked number two in terms of irrigated area with 379,792 hectares or about 16 percent of the country's irrigated area. At the same time about ten percent of the country's irrigated area or 238,658 hectares were irrigated in the northeastern part of the country.

Irrigation Improvement in Thailand

Many of irrigation projects in Thailand that were constructed in the past are needing improvement. This is needed for two main reasons. First, the irrigation infrastracture of some projects have deteriorated. Second, water distribution networks within the projects have not been working properly resulting in low water use efficiency. The government of Thailand has realized these problems and spent considerable money to solve them. During the third five-year national economic and social development plan (1972-1976) approximately 11.7 million dollars were spent on irrigation improvements (RID 1977).

Irrigation improvements can be classified into two major types, structural improvement and land consolidation.

1. Structural improvement includes repairing, desilting, lining, and expanding irrigation and drainage canals; repairing and/or

replacing water control structures; improving service roads and communication systems.

Structural improvement is being conducted in three irrigation projects in the northeastern part of Thailand. They are Lam Phra Plerng Project, Nakorn Ratchasima Province; Lam Pao Project, Kalasin Province; and the left bank section of Nam Pong Project, Khon Kaen Province. The planned improvement began in 1975 and will cover an area of 9,100 hectares in Lam Phra Plerng Project, 18,200 hectares in Lam Pao Project, and 14,700 hectares on the left bank section of the Nam Pong Project (RID 1977).

2. Land consolidation is more intensive than structural improvement. It includes all works done in structural improvement plus other work. Land consolidation work implemented in Thailand includes the following activities (Attayodhin 1977, IRRI 1977, RID 1975a and 1975b):

a. construction of minor irrigation system to supply water to each farm,

b. construction of minor drainage system to drain excess water from each field,

c. construction of farm roads along the irrigation ditches to improve the accessibility of the farmers' fields and to facilitate operation and maintenance of the irrigation system,

d. clearing and levelling of areable land to improve water control, and

e. rearrangement of land shapes and farm boundaries and reallocation of farm plots to ensure efficient farming operations.

Land consolidation in Thailand was first implemented in 1969 (Attayodhin 1977). As of September 30, 1975, 8,400 hectares in the central plain and 96 hectares on the right bank section of the Nam Pong Project in the northeast were consolidated (RID 1976a). Approximately 416,000 hectares of northern Chao Phya irrigated area in the central plain are planned to be consolidated by the year of 2001, and 9,760 and 12,000 hectares of Nam Oon Project and the right bank section of the Nam Pong Project, respectively, in the northeast (RID 1976a and 1977).

Objectives of this Study

The objectives of this study are:

1. to determine, given a fixed government investment in the Nam Pong Irrigation Project, the investment mix between consolidated, structurally improved and unimproved lands and the crops to be grown on these lands which will maximize returns to land and government investment.

2. to evaluate the value of irrigation water in crop production for

various periods of water supply from the Nam Pong Irrigation Project.

3. to evaluate an effect of the irrigation development on employment and the irrigation water utilization.

4. to examine changes in the irrigation development, returns to land and government investment, land use alternatives, value of irrigation water, employment and irrigation water utilization resulting from the variation in the government investment.

Content and Organization of this Study

Selected literature on research methods for water resource development and their applications is reviewed in Chapter II. The methodology of this study is also discussed in Chapter II. Chapter III provides general background information on Northeast Thailand, Khon Kaen Province, and the Nam Pong Irrigation Project. Summary data from a survey of representative farms is also presented in Chapter III.

Chapter IV presents the linear programming model used in the analysis and the assumptions and constraints applied to the model. The results of the analysis are discussed in Chapter V. Chapter VI summarizes relevant conclusions of the analysis and recommendations.

II. LITERATURE REVIEW ON RESEARCH METHODS FOR WATER RESOURCE RESEARCH

Introduction

This chapter reviews selected methodologies employed by economists to study water resource projects. Most of the studies are related to water resource projects in the Asian and American continents with a few from Australia and Africa. The last section of the chapter discusses the use of a static linear programming model for optimizing irrigation development.

Classification of Water Resource Research

Halter and Miller (1966) and Dorfman (1965) classified water resource research models into two broad categories, namely, analytical and simulation models. Several examples of analytical models were given by Halter and Miller (1966).

In this study, methodology employed by economists for studying water resource projects will be classified into five groups. They are:

1. Regression analysis
2. Mathematical programming
3. Simulation
4. Benefit-cost analysis
5. Comparative and historical analysis.

Regression Analysis and Its Application in Water Resource Research

Regression analysis and production function analysis can be considered jointly as a water resource research technique. This technique has been widely used in estimating the value of and demand for irrigation water and the impact of irrigation water on farm production and income. Hartman and Anderson (1962) estimated the value of irrigation water to individual farms and the aggregate value of the Colorado-Big Thompson system to the area. Data from farm sales records were used in multiple regression analysis. The selling price of farms was regressed against assessed value of buildings, total acres of farm land, shares of irrigation water company stock, and the year of sale. The results show that regression estimates from farm sales are consistent with market sales of irrigation company water stock and reflect purchasers' estimates of the value of water. Regression estimates provide a basis for estimating the value of supplemental water provided by the Colorado-Big Thompson system, and also for estimating value of water to individual farms.

Miller (1965) used both production function analysis and linear programming to compare alternative methods of valuing water used in irrigation in the Willamette Valley. Three methods were compared: production function analysis using survey data, production function analysis using data from controlled experiments, and linear programming. The results indicate that the marginal value productivity schedules of water of the controlled experiments were generally greater than those of the survey. Therefore, if an agency were pricing water, the price to agriculture could be set higher for the same quantity of water using the experimental results than using survey results.

Moorti and Mellor (1973) estimated marginal value product for irrigation water from State and private tubewells in Aligarh district in Uttar Pradesh, India. In the study, gross return per hectare was regressed against fertilizer and water. The results show that the regression coefficients for water and fertilizer are significant at 10 and 5 percent level, respectively, for both State and private tubewell farms. The marginal value product for water from private tubewell is higher than that from State tubewell (0.0959 rupees per hectare vs. 0.0603 rupees per hectare).

Gardner and Fullerton (1968) used regression analysis to explain a time series of rental prices for an area in Utah where four companies freely exchanged water after a long period during which only intracompany transfers were permitted. The study reports the gains in value of productivity of water that followed relaxation of a policy forbidding anything but intracompany transfers in an area where several mutual irrigation companies operate.

Dhawan (1973) estimated elasticity of demand for irrigation water in Uttar Pradesh, India. He estimated a single-equation linear model from time series data and found that the elasticity of irrigation demand with respect to index of actual rainfall, index of agricultural wholesale prices, and price of irrigation water, at the mean levels of these variables, are -0.57, 0.72 and -0.24, respectively.

Herdt (1972) estimated the impact of rainfall and irrigation on production of ten important crops (wheat, mung bean, barley, rape and mustard, rice, maize, _jowar_, _bajra_, sugarcane, and cotton) for each of 12 districts (Kangra, Ludhiana, Gurgaon, Jullundur, Hoshiarpur, Rhotak, Amritsar, Karnal, Hissar, Ambala, Ferozepore and Gurdaspur) in Punjab, India. For each crop, actual irrigated acreage, actual irrigated yield, actual non-irrigated acreage, and actual non-irrigated yield were each regressed against expected price of the crop, expected price index of the inputs and consumption goods, rainfall in each month, time, and acreage irrigated by canals. The results show that the total area irrigated by canals had a significant effect on both area and yield of nearly every irrigated crop in nearly every district. The area of irrigated crops was not affected by rainfall, and only the yields of irrigated wheat, irrigated mung bean and irrigated sugarcane were significantly affected by rainfall. However, among the non-irrigated crops several rainfall variables proved to be significant.

Rosegrant (1976) used multiple regression techniques to estimate the yield benefits of modern rice varieties from irrigation in the Philippines. He concluded that irrigation and nitrogen fertilizer are complementary factors of production for modern rice varieties. Non-existent and inadequate irrigation in the Philippines drastically reduce the yield benefits of modern nitrogen-responsive rice. The limitation occurs in two ways: 1) at any nitrogen level, the expected yield of rice is reduced by lack of irrigation in the wet season and by poor quality irrigation in the dry season; and 2) the lack of high quality irrigation reduces the optimum level of nitrogen by reducing the profitability and increasing the risk of nitrogen use. Depending on the rate of seepage and percolation at an irrigation site, the yield benefit of wet season irrigated rice over rainfed rice is 350-750 kilograms per hectare at the optimal nitrogen level. In the dry season, an improvement from low to medium quantity irrigation boosts yields 500-750 kilograms per hectare, and an increase from medium to high quantity gives yield benefits of 400-800 kilograms per hectare, depending on seepage and percolation rates.

Hayami and Kikuchi (1975) studied the investment inducement for irrigation in the Philippines. Irrigable area controlled by the Philippine National Irrigation Administration was regressed against benefit-cost ratios of investment in irrigation and land scarcity index. The results show that both the benefit-cost ratio and land scarcity index are highly significant variables which together explain approximately 75 percent of the variation in the increment of irrigable area controlled by the National Administration.

Oboh (1974) used regression analysis to study the cost-size relationships of twelve rural water districts in Oklahoma. The regression equation using number of customers as the independent variable indicated that the annual average total cost per customer decreased as the number of customers increased, until a minimum cost of 67.80 dollars was achieved at 900 customers. Thereafter, the annual average costs increased as the number of customers increased. When the volume of water produced and distributed annually by the districts was explicitly introduced in the equation with number of customers as the independent variable, the regression equations showed that for districts which produced and distributed five million gallons of water annually, the minimum annual average total cost per customer was 73 dollars; while it was 77 dollars at ten million gallons of water when the number of customers was 300. At 50 million gallons annually, the minimum average total cost per customer was 87 dollars when the number of customers was 600. Minimum annual average total cost was 99 dollars when the number of customers was 1,000 and the amount of water produced and distributed annually by the district was 100 million gallons.

Mathematical Programming and Its Application in Water Resource Research

Programming in water studies has been used mainly in models to derive information for decision-making on water allocation and in more comprehensive planning at the project, and national levels (Capel 1971). It has also been used to estimate demand schedules for water and to forecast water use under specified assumptions.

Heady (1961), in his article "Mathematical analysis: Models for quantitative application in watershed planning," stated that:

> A programming model can be formulated to consider most settings within which watershed might be analyzed. Physical restraints within the watershed can be taken as fixed, while the capital required for development can be considered as variable. Using a criterion such as the plan which will maximize discounted net revenue (i.e., benefits), we could analyze the amount or scale of investment which is optimum and how this capital should be allocated between alternatives such as dams, channel improvement, farmland treatment, forestry, or conventional farm investments. Or, we can take the amount of capital for watershed development as given and determine how it should be allocated among purely watershed developments. In the latter case, we would not let farm units and the watershed unit compete for the capital allocated for watershed purpose.

Selected studies employing mathematical programming which includes linear programming and quadratic programming are reviewed here.

Maji (1975) employed linear programming technique to simultaneously determine an optimal irrigation policy and an optimal cropping pattern for the Mayurakshi Project in West Bengal, India.

The time horizon considered for the study was one year with twelve monthly decision periods. The results of the study indicated that the existing farm organization, in terms of the irrigation policy and the cropping pattern, was not consistent with an efficient use of labor, land, fertilizer and irrigation water in the controlled area. In particular, the results demonstrated that a shift of emphasis from kharif (summer) irrigation to rabi (winter) irrigation will increase not only the farm income but also the employment of available labor in the traditionally slack season. With mechanization in sowing and harvesting operations, it is possible to increase the net farm income and employment further in years of average rainfall. Even in a year of scanty irrigation supply with the existing level of nitrogen and labor, the net farm income and the employment can be increased over their present level by suitably reorienting the irrigation policy and the cropping pattern in the project area. The results also indicated that the inclusion of commercial crops like potatoes and sugarcane in the optimal cropping pattern was desirable from the standpoint of profit maximization.

Ahmed (1972) developed a linear programming model to project cropping pattern under tubewell irrigation in Bangladesh. He found that, with the existing relative prices of jute and rice, jute production might not be undertaken by the farmers in the irrigated areas. The net income to individual farmers from crop production under irrigated conditions was estimated to increase more than 108 percent over the present income from farming.

Torres (1972) used linear programming technique to evaluate the potential benefits of irrigation water in rice production in the Santa Cruz System, Philippines. The results indicated that the net contribution of irrigation water for the entire system per year ranged from 6.8 million Philippine pesos during late starts to more than 8.29 million pesos for the early planting dates. These amounts represent the value of the added output resulting from the use of irrigation water. On a per hectare basis, the net contribution amounted to about 1,276 pesos. After imputing a value to operator and family labor, the residual amount would be 1,049 pesos per hectare or, at an irrigation rate of 6.5 millimeters per day, this would imply a net contribution of 160 pesos per hectare-millimeter of water.

Prabowo (1978) employed linear programming analysis to examine how to maximize net farm returns in the Solo River Basin in Central Java, Indonesia. Three types of farms--fully irrigated, partially irrigated, and non-irrigated farms--were included in the study. Three linear programming models were constructed, one for each of the three types of farms. The results showed that farms with irrigation and controllable water supplies had potential for much higher incomes than did farms that were only partially irrigated. Unirrigaged farms had the lowest incomes of all. Farmers in the fully irrigated areas typically received and applied more irrigation water than they needed for producing crops at maximum income. By reallocation of this water a larger area actually could be irrigated in an average year. If unirrigated areas with lower income could be given an allocation of irrigation water, total regional income could be increased. The government policy of continuing to give credit to the fully irrigated areas was inefficient. Farmers in the fully irrigated areas could finance themselves. The credit, which was being provided to the fully irrigated areas could be transferred to the partially irrigated and unirrigated areas to finance better crop technology and water resource development.

Singh and Sirohi (1977) used a linear programming framework to determine the optimal allocation of water of Upper Ganga Canal among various branch canals and crops in Western Uttar Pradesh, India. The study included two plans of water allocation. In the first plan, no allocation on the canal water among the various branch canals was done. The quantities of canal water distributed in the existing pattern of each of the six branch canals were taken to be fixed. In each of these six canal regions, their corresponding fixed quantities of available canal water was optimally allocated between various crop areas in each region. The total gross returns of crops increased in the optimal plan in all the regions. The combined increase of all the regions amounted to 436 million rupees which was 16.4 percent of the returns in the existing plan. In the second plan, the total canal water available at the head of the main canal in each period was optimally allocated among the six canal regions and also simultaneously among various crop areas in all the regions. The total returns in the optimal plan increased by 24 percent (649 million rupees) in the command area as a whole.

Parks and Hansen (1978) used linear programming technique in a study of water allocation schemes in Chile. Estimated changes in total farm income and income distribution among farms which would result from three water reallocation alternatives--the current allocation, the equal water-rights per hectare allocation, and the optimum economic allocation--were examined in the study. The results of the study showed that equalizing nominal water right per hectare would result in a regressive income redistribution, but a slight increase in aggregate gross margin. The small farm group would lose compared to the current allocation, whereas medium and large farms would gain. Under the optimal rights allocation, large farms lose compared to the current allocation, whereas medium and small farms gain. A positive income redistribution would result, as well as a small increase in aggregate income.

Johnson (1978) developed a linear programming model to determine the farmers' optimum response to different levels of available water on a 500 acre watercourse on a perennial canal in Sargodha

(Punjab), Pakistan during the winter season. The crop activities were entered into the model not only at optimal yield level, but also at various reduced yield levels due to missed or short irrigations. The principal constraints included in the model were canal water, labor, land and supplemental tubewell water. The results showed that the farmer matched the available water to the crop mix in such a manner to support a higher cropping intensity with lower overall yields. Sensitivity analysis was also used to determine the value for additional units of water at the root zone during each time period. He found that the value of additional water was high at the beginning of the winter and summer seasons with the highest value coming in December when farmers first irrigated wheat after planting and that during the monsoon rains an additional water had no positive value and may even have negative value as it compounded the drainage problems on the watercourse.

Guise and Flinn (1970) utilized quadratic programming to analyze water pricing and allocation decisions for Yanco Irrigation Area in New South Wales, Australia. The results indicated that the historically determined irrigation water prices are in urgent need of revision if resource misallocation is to be minimized. Demand prices for irrigation water differed between regions because of variation in channel losses involved in supplying in each region. A transfer of additional water to irrigation could occur if the electricity could be generated elsewhere at a lower cost.

In deriving seasonal and intraseasonal demand schedules for irrigation water in the Yanco Irrigation Area in Australia, Flinn (1969) used linear programming approach. He found that, for seasonal demand, at water prices less than 6.3 dollars per acre foot, the demand for irrigation water is inelastic, at 6.3 dollars per acre foot the demand has unit elasticity and above this water price demand is elastic. For intraseasonal demand and the price range of 1.0-7.5 dollars per acre foot, the demand for water in summer is extremely inelastic while the demand for water in spring and autumn is elastic if the price of water exceeds 6.2 dollars per acre foot.

A dynamic programming model was developed by Frye (1975) to determine the optimum investment and water delivery decision rules for the Newport Water Department in the Southeastern Planning Area of Rhode Island. Investment alternatives considered in the study as sources of additional water supply for the area are the transfer of groundwater from the Upper Pawcatuck Basin and the transfer of surface water from the proposed Big River Reservoir. The study concluded that ground-water transfer was the economically preferred alternative for additional supply.

Simulation and Its Application in Water Resource Research

Dorfman (1965), in his article "Formal models in the design of water resource system," stated that:

> Two general types of model have been fruitful in the field of water resource development: the simulation model and the analytic model. In simulation models temporal sequences of events are reproduced on electronic computers on a time scale in which minutes represent decades, leading to convenient estimates of the consequences of design decisions even in complicated circumstances. In analytic models consequences are expressed as explicit mathematical functions of design variables. Simulations are awkward when a wide range of decisions has to be evaluated; analytic models cannot be applied to practical problems without drastically simplifying them. But the two methods can be used in tandem, with analytic models delimiting the range within which simulation is required.... The results of a simulation model are more accurate than those of an analytic model but also less informative of the things that we want to know. Besides, we can introduce randomness into a simulation by Monte Carlo trickery, but analytic models can tolerate very few probabilistic complications.

Taylor and North (1976) noted that the existing benefit-cost criteria for evalutaing water resource projects are deterministic and therefore incomplete, since the uncertainty inherent in project outcomes is not considered. In their case study of the Spewrell Bluff Dam Project in Southwest Georgia, they employed Monte-Carlo simulation approach to generate a mean and standard deviation for the benefits, costs, benefit-cost ratio, and net present value. Then, they recommended decision criteria to be used in project selection process. Among these criteria are coefficient of variation, safety first criterion, and graphical investment frontier.

Johnson (1978) used simulation to determine the farmers' optimal response to different levels of available water on a 500 acre watercourse on a perennial canal in Sargodha (Punjab), Pakistan during the summer season. The results showed that the farmer increased his cropping intensity by cutting his crop yields. This cropping was obtained by not attempting to provide optimal amounts of irrigation water to the crops.

Mapp and Eidman (1976) developed a firm-level bioeconomic simulation model capable of stochastically determining yields for the major dryland and irrigated crops in the central basin of the Ogallala Formation (a major unconsolidated aquifer providing irrigation water for much of the Great Plains) as a function of soil moisture and atmospheric stress during critical stages of plant development. The model was used to evaluate three methods of regulating groundwater irrigation--no restriction, a quantity limitation of 1.5 acre feet per acre of water rights, and a graduated tax of 0.50 dollars per acre inch on each additional unit beyond the quantity limitation--for poor (saturated thickness of 100 feet) and adequate (saturated thickness of 325 feet) water resource situations. In the poor water situation, water use under the graduated taxation alternative resulted in a significantly greater level of net farm income than under either unrestricted pumping or a quantity limitation. In the adequate water situation, unrestricted pumping resulted in the greatest water use and highest value of net farm income and the graduated tax-alternative reduced water use significantly while maintaining a level of net farm income comparable to that under restricted pumping.

Johnson (1975) used simulation to develop an integrated approach (incorporating hydrologic, agronomic, and economic considerations) to the optimal management of irrigation water to control waterlogging and salinization in the closed basin portion of the San Luis Valley in Colorado. The study included the following policy alternatives: investment in canal lining for water saving; permitting total conversion to sprinkler irrigation; various restrictions on groundwater pumpage (including a strict groundwater pumpage quota); and a modified quota-market system which allowed exchange of rights to surplus groundwater. The results of the study indicated that it is in the best interests of the Closed Basin water users to increase the number of sprinklers pumping from the shallow groundwater aquifer. This alternative requires that the water users, in conjunction with the Colorado State Engineer, develop a reservoir management system for the shallow aquifer. The general adoption of sprinkler irrigation, combined with an aquifer management program, would reduce waterlogging and avoid considerable nonbeneficial evaporative losses from waterlogged soils.

Benefit-Cost Analysis and Its Application in Water Resource Research

The technique commonly used to compare alternative water development proposals on economic (i.e., efficiency) criteria is benefit-cost analysis. Within the benefit-cost framework, there are three main measures usually used by economists. They are absolute net benefits, benefit-cost ratio, and internal rate of return. Phillips and Schultz (1971) suggest that the internal rate of return is the most general measure of economic efficiency to be used for the ranking of projects with any kind of time distribution of inputs and outputs. It is preferable, they state, to such other frequently recommended measures as absolute net benefits, ratio of benefits to investment costs, or payback period because it ranks alternatives in the order of their per dollar amplifying power independent of the time distribution of their inputs and outputs and independent of the choice of discount rate necessary for any of the other measures.

Katzman and Matlin (1978) used benefit-cost analysis in an economic comparison between conventional and solar photovoltaic energy systems for irrigation in Arizona, the Central Valley of California, West Texas, and Nebraska. The results of the analysis which covers from the year 1977 to 2000 suggested that solar photovoltaic energy systems will become profitable in the middle to late 1980's if the cost of solar modules follows the projections of the Department of Energy.

The results are robust and insensitive to reasonable variations in discount rates, fuel escalation rates, and support system costs. Solar-powered systems will become viable earlier in those areas with larger amount of year-round insolation and/or longer irrigation seasons.

Bailey (1975) used benefit-cost analysis to evaluate the economic feasibility of five watershed programs on the eastern shore of Maryland. Four of the programs were installed in Worcester County and the fifth was installed in Wicomico County. Because yield data over time were unavailable, the study hypothesized three yield level increases. It was found that using the 25 percent yield increase category, three of the five watershed programs were economically feasible, one was marginal and the fifth was infeasible. All were feasible when the 50 percent yield increase category was used.

Ahmed (1972) used internal rates of return to compare the technical alternatives available in tubewell installation in Bangladesh. He found that the internal rates of return for various technical alternatives available in the installation of tubewells varied from 24.6 to 40.1 percent. Drilling techniques and type of engines used had the highest influence on the rates of returns.

A financial analysis approach was employed by Ulsaker (1974) to evaluate potential increases in productivity through alternative investments among small traditional-subsistence farms in the Coastal

Plain of Morocco. Farms were grouped into three groups: traditional-subsistence, improved dryland, and pump irrigation. The results of the study showed that investment in improved practices, including pump irrigation, yielded high returns to farmers and the economy. Farm unit financial returns yielded internal rate of return from 58 to 200 percent, depending upon assumptions, under dryland farming. Farm financial returns under pump irrigation yielded internal rates of return from 210 to 420 percent. An intensive capital and technical assistance program was estimated to yield an internal rate of return of 40 percent for dryland farms when all costs including family labor were included and 180 percent for irrigated farms.

Hayami _et al._ (1977) used benefit-cost analysis to compare the effectiveness of the Philippine government's policies on provision of price incentives with that on investment in irrigation systems to achieve rice self-sufficiency. They concluded that in the long run despite its large initial capital cost, irrigation investment imposed less financial burden on the government than the manipulation of product and input prices. In terms of the social benefit-cost ratio, the irrigation development was clearly more efficient than rice price support. But it became inferior to fertilizer subsidy if a high discount rate was applied to a large-scale high-cost project. Considering the high opportunity cost of government funds, irrigation investment was probably more efficient as a means to achieve self-sufficiency in the

Philippines in the long run than the use of fertilizer subsidy, even though the conventional benefit-cost ratios are comparable. However, the social rate of discount for government investment can be higher than assumed in the analysis. The rate of discount for future rice output corresponding to the investment may rise to a very high level in years of rice shortage. In such years, the discount rate for future output conceived by policy makers would become extremely high because it was the rice supply of this year rather than several years later that determined the social stability and, hence, their political position. Therefore, in years of rice shortage, it could become rational for the policy makers to adopt short-run price policies to increase domestic output, despite the long-run inefficiency involved.

In the study of the investments in irrigation construction and land opening for agricultural production in the Philippines, Hayami and Kikuchi (1975) used benefit-cost analysis. The study revealed that for the past two decades investment in irrigation as a means of augmenting land by improving its quality has become increasingly more profitable than investment in external expansion of cultivated area by opening new land. The benefit-cost ratios for the investments in irrigation ranged from 1.4 to 3.4 while they were only 0.9 to 1.3 for the investment in developing new lands.

Carter (1969) utilized benefit-cost analysis to determine the impact of capital development on the national income in the Muda

Irrigation Project in Malaysia. The project was implemented to provide water for the production of a second crop of rice on 260,000 acres with the objective of increasing the income of rice producers and of increasing domestic rice production. The study considered two levels of investment. Condition 1 included only investment in the construction of the engineering works of the project whereas Condition 2 included, in addition to the above, investment in developing technical services (extension services). The results of the study showed that the gross increase in national income by 1977 as a result of the capital investment, the direct benefit, and the import substitution effect of the net increase in domestic rice production was approximately 169 and 213 million dollars for Condition 1 and 2, respectively. When the leakage resulting from the foreign loan repayment was netted out, the annual net change in national income was estimated at about 139 and 183 million dollars for Condition 1 and 2, respectively.

Mukhopadhyay (1973) used benefit-cost analysis to evaluate the economic performance of deep and shallow tubewells in Nadia district of West Bengal, India. Three criteria, namely, benefit-cost ratio, net present worth and internal rate of return were included in the study. At the assumed interest rate of 12 percent and 25 years project life, using the benefit-cost ratio and the net present worth criteria, deep tubewells were preferred to shallow tubewells. But shallow tubewells were preferred from the point of view of net present worth at and above 20 percent discount rate or benefit-cost ratio at and above 25 percent discount rate. The choice also turned in favor of shallow tubewells on the basis of internal rate of return.

Kumar (1974) studied the impact of field channels on cropping pattern, cropping intensity, and the benefit-cost ratio of the field channel development in the Hirakud canal system in Sambalpur district of Orissa, India. He found that the cropping intensity of the villages that did not have field channels (control villages) was 184.7 percent. In the villages having field channels (improved villages) cropping intensity increased from 187 percent before the field channels were constructed to 196 percent after the construction was completed. Approximately 72 percent of cultivated area in the improved villages was planted to high-yielding varieties of rice during the rabi (winter) season as compared to only 54 percent in the control villages. At nine percent interest rate and 20 percent depreciation on investment, the field channel development project gave an annual benefit-cost ratio of 10.39.

Flinn (1971) pointed out two weaknesses in the use of benefit-cost analysis. They are (a) the partial framework within which specific water development proposals are often analyzed and (b) the insufficient account that is often taken of the possibility of adjusting the scale of the development or the intensity of use of the water. Further, because the management of water has been traditionally in the hands of engineers, the water market has tended to become supply oriented. As a result, one alternative rarely considered when there are pressures on regulated supplies of water is the possibility of reallocating water between users within an existing system. The reallocation of presently regulated supplies of water may allow the postponement or a great reduction of the investment required to meet the planned objective.

Comparative and Historical Analysis and Its Application in Water Resource Research

The last method related to water resource study to be reviewed is comparative and historical analysis. Clark (1972) utilized historical description procedure to study the development of tubewell irrigation in the Punjab, Pakistan from its beginning in the early 1900's up to 1968. He found that the most important factor affecting adoption of tubewell irrigation seemed to be the demonstration effect--the process by which one farmer adopts the innovation as a result of seeing it in successful operation on another farm--and that the wealth of the farmer and the other socioeconomic aspects were less important. Pricing and taxing policies adopted by the Pakistani Government had resulted in such divergence between social and private costs that the farmer had a very strong incentive to invest in the type of tubewell which was substantially more costly to society.

Kahlon et al. (1971) use comparative analysis to study the cropping intensity, the cost-benefit relations in crop production on dry and irrigated lands in the Ferozepur district of Punjab, India. The results showed that the cropping intensities in the unirrigated and irrigated areas were 88.87 and 131.62 percent, respectively. This difference was significant at 1 percent level. The average yields per hectare of different crops were higher in the irrigated area than those in the unirrigated area. The lower yields in the latter case can be partially attributed to the fact that little fertilizer and other yield increasing inputs were used in raising crops. Per hectare returns to fixed farm resources from guara, bajra desi, and mung bean were more in the unirrigated area but crop mixtures such as wheat plus mung bean and barley plus mung bean gave more returns in the irrigated area.

Moorti and Mellor (1972) analyzed the differences in cropping pattern, yield and gross incomes from various crops under different sources of irrigation in the Aligarh district of India. They concluded that private tubewell farms had better control of water supply which resulted in higher cropping intensity, yield and therefore higher crop incomes. Because of uncertainty of supply, farms irrigated by State tubewells planted relatively smaller proportions of high-yielding crop varieties which require intensive and timely application of water.

Charsa was the most costly source of water supply and therefore the cultivators could not afford to grow any improved variety of crops for the same reasons previously mentioned. The Persian wheel farmers though having a low discharge of this equipment had an assured supply of water and they irrigated their fields whenever they needed. But the quantity of discharge was not enough to devote a substantial area to the high-yielding varieties of crops. Thus the two basic factors in the irrigation, i.e., the quantity and timeliness of water application resulted in the variations of farming patterns which ultimately affected incomes.

Scope and Methodological Considerations of the Study

This thesis is designed to: 1) determine, given a fixed government investment in the Nam Pong Irrigation Project, the investment mix between consolidated, structurally improved and unimproved lands and the crops to be grown on these lands which will maximize returns to land and government investment; 2) evaluate the value of irrigation water in crop production for various periods of water supply from the Nam Pong Irrigation Project; 3) evaluate an effect of the irrigation development on employment and the irrigation water utilization; and 4) examine changes in the irrigation development, returns to land and government investment, land use alternatives, value of irrigation water, employment and irrigation water utilization resulting from the variation in the government investment.

This suggests the use of linear programming, one of the research methods reviewed earlier in this chapter. The following section justifies the use of linear programming analysis for the study of the irrigation development.

Justification of the Linear Programming Approach

The advantages of applying linear programming approach for this study include the following:

1. The linear programming model developed for this study (to be presented in Chapter IV) will simultaneously satisfy the first three objectives of the study and the fourth objective will also be satisfied by varying the government investment constraint.

2. The model allows direct evaluation of the effect of government decision in the irrigation development on the incomes of farmers in the project area.

3. The model incorporates the relevant resource constraints affecting the choice of crop productions (activities) for the maximum return.

4. The data available to the researcher do not permit the use of such complex approaches as dynamic programming or simulation.

III. BACKGROUND INFORMATION AND BASE DATA USED IN THE STUDY

This chapter consists of five main sections. The first three sections give the general background information of Northeast Thailand, Khon Kaen Province, and Nam Pong Irrigation Project where this study was conducted. The fourth section describes the survey of representative farms from the study area. Representative farm summary data are given in the last section.

Northeast Thailand

Geographically, Northeast Thailand is a high plateau bounded by Mekong River in the north and east and Dong Praya Yen Mountain in the west (see Figure III-1). Most of the rivers run very rapidly into Mekong River from steep elevations. Three large river basins are in this region. The first one is Mekong Basin having a watershed area of 43,000 square kilometers; the second is Chi Basin with a watershed area of 55,000 square kilometers; and the third is Mun Basin with 82,000 square kilometers (Panyadhibya 1961).

The northeast region accounts for about one-third of Thailand's population and land area (Panyadhibya 1961, RID and IRRI 1976). The regional economy is dominated by agriculture with its share of the gross national product averaging 16 percent (RID and IRRI 1976). Per capita income is 29 percent of the central region excluding Bangkok,

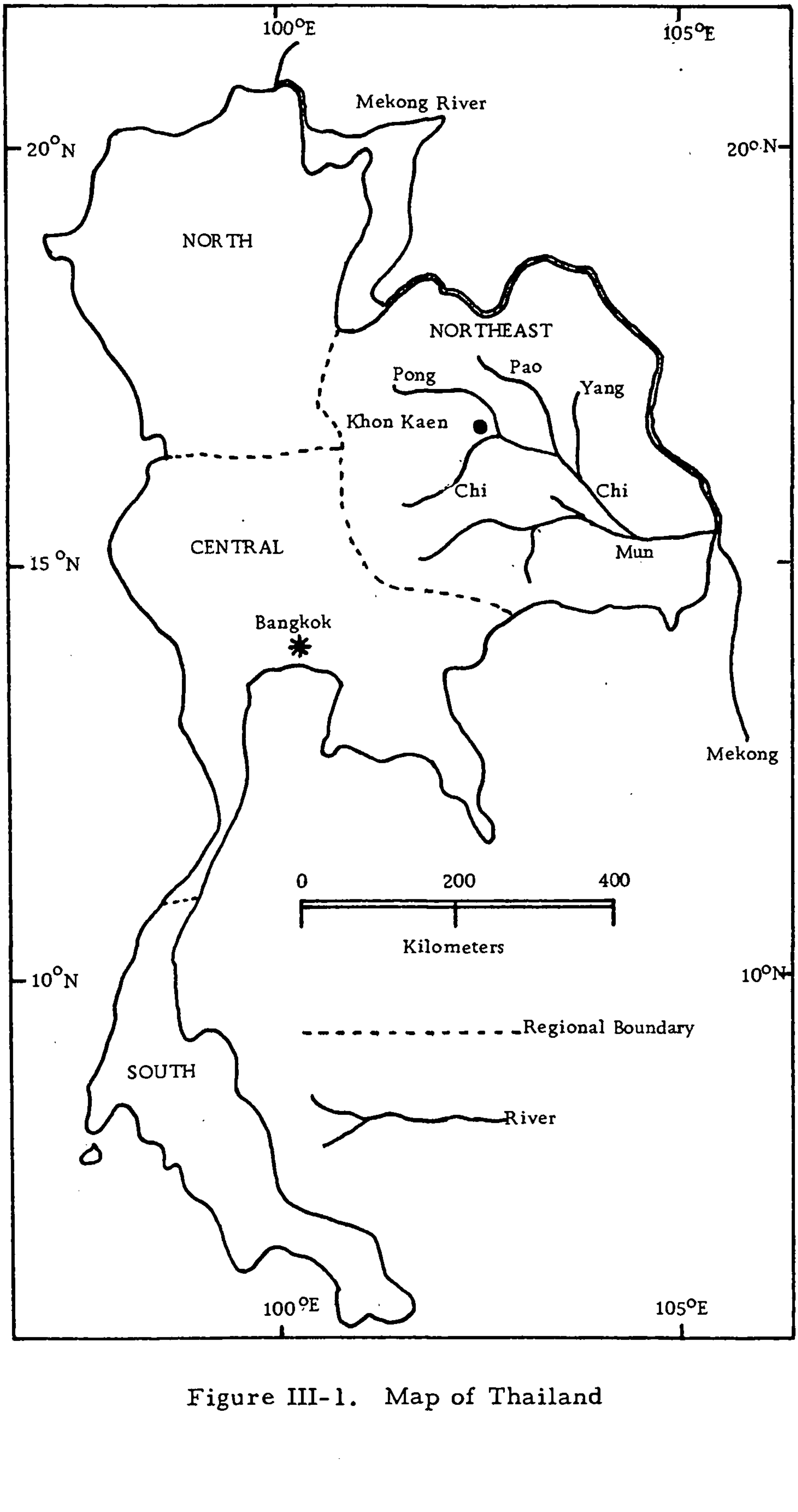

Figure III-1. Map of Thailand

42 percent of the southern region and 67 percent of the northern region (Bank of Thailand 1977).

The climate of Northeast Thailand is tropical and governed by the southwest and northeast monsoons. The average annual rainfall ranges from 1,100 millimeters in the western provinces to over 1,600 millimeters in the eastern provinces. Average temperatures range between 20°C in January and 30°C in April. The relative humidity ranges from 75 to 85 percent in the rainy season and from 55 to 70 percent in the dry season. Evaporation is on the order of 1,800 to 2,000 millimeters (RID and IRRI 1976).

As mentioned earlier, modern irrigation in Northeast Thailand was started in 1939. By the end of 1975, approximately 238,658 hectares were irrigated in this region. About 30 percent of this area is served by 129 tank (small reservoir) irrigation systems. This kind of irrigation system has relatively low capacity ranging from about 16 to 4,000 hectares. Another 52 percent of irrigated area in this region is served by eight potentially large systems with the capacity ranging from 128 to 28,800 hectares. The other 18 percent is served by 13 medium capacity systems (RID 1976a).

General Background Information of Khon Kaen

Khon Kaen is one of the 16 provinces of Northeast Thailand. It is located between 16-17°N and 102-103°E. The total area of

Kohn Kaen is 13, 404 square kilometers or approximately 1.34 million hectares which is about 7.87 percent of the area of Northeast Thailand (Khon Kaen Provincial Office 1978).

Geographically, Khon Kaen is a high plateau called "Korat Plateau." It is a rolling area sloping downward from the west to the east. However, plains are found along some parts of Nam Chi and Nam Pong basins in the northern part of the province.

Soil

Generally, soil in Khon Kaen is sandy. The moisture holding capacity and the fertility of this soil are quite low. In the northern part of the province soil quality in terms of fertility and moisture holding capacity is better. Soil in the southern part is salty and not suitable for cultivation.

Climate

There are three seasons in the Khon Kaen area, summer from February to April, rainy season from May to October, and winter from November to January. Climatological data for Khon Kaen during the period of 1951-1975 are presented in Table III-1. The temperature ranges from 23.2°C in December and January to 30.3°C in April with a yearly average of 27°C. Relative humidity is lowest in March and highest in September. Rainfall concentrates during

Table III-1. Climatological Data for Khon Kaen during the Period of 1951-1975.

Month	Temperature (°C)	Humidity (%)	Rainfall (mm)	Evaporation (mm)
January	23. 2	64	8. 9	168. 1
February	25. 9	62	18. 0	174. 2
March	28. 7	61	37. 2	218. 0
April	30. 3	64	61. 6	231. 5
May	29. 5	72	165. 4	210. 9
June	28. 7	76	179. 6	169. 6
July	28. 2	77	156. 3	176. 4
August	27. 7	80	186. 8	159. 9
September	27. 2	82	266. 0	144. 3
October	26. 7	80	89. 4	163. 7
November	25. 1	70	15. 9	164. 8
December	23. 2	66	2. 7	167. 6
Year	27. 0	71	1, 187. 8	2, 149. 0

Source: Climatological Data of Thailand, 25 year Period (1951-1975) (Meteorological Department, 1977).

May to September with the highest amount of 266 millimeters in September and the lowest of 2.7 millimeters in December. The total rainfall per year is 1,187.8 millimeters. The average raining day per year during the period of 1972-1976 is 138 with 118 days during the rainy season and the other 20 days spread throughout the rest of the year (Khon Kaen Provincial Office 1978). Evaporation is in the range of 144-232 millimeters per month. The average evaporation per year is 2,149 millimeters.

Population

In 1977 the total population in Khon Kaen was 1,256,885 of which approximately 82 percent were farmers (Khon Kaen Provincial Office 1978). The population density was approximately 94 persons per square kilometer. During 1971-1977 the population growth rate was 2.59 percent per year.

The growth rate of total population during 1970-1975 was slower than the growth rate of the working age group (15-60 years of age). In 1970 approximately 49 percent of the total population was in the working age group and it increased to about 50 percent in 1975 (Khon Kaen Provincial Office 1978).

Water Resource

There are two important rivers running through Khon Kaen Province. The first one is Nam Chi and the second is Nam Pong. Besides, there are 25 small natural water resources scattered throughout the province with a water surface area not less than 0.64 square kilometers (Khon Kaen Provincial Office 1978).

The most important water resource development in Khon Kaen is the Ubolratana Reservoir. This reservoir is located approximately 50 kilometers northwest from the city of Khon Kaen. Its storage capacity is 2,550 million cubic meters (Khon Kaen Provincial Office 1976). Approximately 40 kilometers downstream from the reservoir is a diversion dam called Nong Wai. This dam was constructed to regulate the irrigation flow from the Ubolratana Reservoir in the Nam Pong Irrigation Project area. As of October, 1975 this project covered an area of 18,720 hectares (RID 1976a).

Also, there are seven tank (small reservoir) irrigation projects in Khon Kaen. As of October, 1975 these seven projects served an area of 2,578 hectares (RID 1976a). Four other small reservoirs also existed in the province in October, 1975. These reservoirs were built to store water for domestic consumption only. Their total storage capacity at that time was approximately 2.09 million cubic meters (RID 1976a).

Economic Condition

Khon Kaen's economy is dominated by agriculture. In 1972 Khon Kaen's gross domestic product was 107.6 million dollars of which 31.82 percent came from agriculture. The share of agriculture in the provincial gross domestic product increased to 33.32 percent in 1976. In that year gross domestic product was 215.2 million dollars with 71.7 million dollars derived from agriculture (Khon Kaen Provincial Office 1978).

Agriculture

The most important crops grown in Khon Kaen area are rice, kenaf and casava. In 1976 the area planted to rice was 235,002 hectares. Kenaf was planted on 27,928 hectares while casava occupied 47,534 hectares (Khon Kaen Provincial Office 1976 and 1978). The average yields of rice, kenaf and casava were 1469, 881 and 8638 kilograms per hectare, respectively.

Various agricultural research institutions exist in and around Khon Kaen City. Among the local institutions are the Rice Experiment Station (rice breeding and cultural improvement), the Agricultural Experiment Station (seed production for upland crops), the Sericulture Station (mulberry propagation and technical guidance on sericulture development), the Fishery Station (distribution of fish fries), and the Soil and Water Conservation Center. The Khon Kaen University also undertakes agricultural research in various fields. Nearby are the Tha Phra Livestock Breeding Station working on cattle breeding and management studies, and the Northeast Agricultural Center which concentrates on upland crop research.

General Information of Nam Pong Irrigation Project

The Nam Pong Irrigation Project is located in Khon Kaen Province. This project was started in 1965 and the planned completion date was 1978 (RID 1976a). As of October, 1975 the project served an area of 18,720 hectares. It is anticipated that 48,400 hectares will be served by the project when it is completed (RID 1977).

The project comprises the following main components:

1. The Ubolratana Dam and Reservoir. They were constructed on the Nam Pong River and completed in 1965 (ADB 1971, Sanyu Consultants Inc. 1977). The Ubolratana Dam and Reservoir were constructed for hydro-power generation, irrigation and flood control. The reservoir's capacity is 2,550 million cubic meters (Terasart 1977). The surface area of the full reservoir at the elevation of 182 meters above the mean sea level is 410 square kilometers. The average annual inflow at the dam site is 1,920 million cubic meters (RID 1976b).

The dam is rock filled with a clay core. Its base and crest are at 176 and 185 meters above the mean sea level, respectively. Its length including the spillway is 800 meters. The spillway itself is 100 meters long. Four 25 x 6 meters self-regulating radial gates were installed on its crest (RID 1976b).

The reservoir and its 25 MW power plant are operated by the Electricity Generating Authority of Thailand (RID 1976b). The water released from the reservoir for hydro-power generation is discharged into the Nam Pong River.

2. The Nong Wai Diversion Dam. In 1966 the Nong Wai

Diversion Dam was constructed approximately 40 kilometers downstream of the Ubolratana Dam. The Nong Wai Diversion Dam was constructed for irrigation purpose. This dam was designed to establish sufficient hydrolic head at the intakes for the left and right bank main canals and the required tail water for the turbines. According to the agreement, the Electricity Generating Authority of Thailand will maintain an average discharge of 45 cubic meters per second from the Ubolratana Reservoir, out of which 30 and 15 cubic meters per second are to be diverted to the left and right bank main canals, respectively (ADB 1971).

The Nong Wai Diversion Dam is ungated, with a length of 125 meters and crest height of 5.9 meters (Paranakian 1978, RID 1976b). Headwork structures are located at each end of the dam for water delivery to the left and right main canals.

3. Canals and laterals. There are two main canals, the left and right bank canals, in the Nam Pong Irrigation Project. At the intakes of the left and right bank canals there are two 4.00 x 2.25 and two 2.20 x 3.15 meters steel gates, respectively. The flow capacity of the left bank canal is 35 cubic meters per second and of the right bank is 15 cubic meters per second (Terasart 1977).

Besides the main canal which is approximately 83 kilometers long, the left bank subsystem includes 27 laterals and sublaterals with a total length of approximately 195 kilometers (Land

Development Department 1977). This subsystem is expected to be completed in 1980 and will serve an area of 35,712 hectares (Mongkolnaowarut 1978).

The right bank subsystem includes, other than the main canal which is about 47 kilometers long, eight laterals and sublaterals with a total length of approximately 58 kilometers (Land Development Department 1977). The construction of the subsystem was completed in 1972 and it is serving an area of 12,688 hectares (Mongkolnaowarut 1978).

Survey of Representative Farms

The Nam Pong Irrigation Project considered in this study is relatively large covering an area of 48,400 hectares. The total number of farms within the project area is estimated to be 18,632. With such a large population, the cost of gathering and analyzing the data of all the farm units is prohibitivie. The practical approach to the problem is to gather and analyze the data of representative farms.

Selection of Sample Farms

All farms in the Nam Pong Irrigation Project area can be stratified into three main categories according to the level of irrigation development. The first category includes farms that are located in land consolidated (LC) area. The second and third categories consist of farms located in structurally improved (SI) and unimproved (UI)[1] areas, respectively.

A two-stage sampling procedure was employed to obtain sample farms. The two stages were: First, irrigation units (tertiary units) that could not be accessible all seasons and/or could not permit an accurate measurement of quantity of irrigation water used within the units were eliminated from the population list (the reasons for this elimination are given below). The irrigation units were then selected from each category of farms from the remaining list. Four units were selected from the LC area and four and six units from the SI and UI areas, respectively. Second, farms were selected independently from each of the 14 selected units in such a way that the farms selected from each selected unit must be scattered throughout the unit. The total number of farms selected for this study was 181.

The reasons for employing this sampling procedure were:

1. All the irrigation units selected for the study must be accessible all seasons in order to be able to collect data for the study.

2. These selected irrigation units must also permit an accurate measurement of quantity of irrigation water used within the units, i.e., each of these units must receive irrigation water only from its turnout,

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[1]Hereafter LC, SI and UI stand for land consolidated, structurally improved and unimproved, respectively.

not from nearby units or other sources unless a measurement can be made, and irrigation water in each of these units must not leak to other units unless the quantity leaked can be measured.

3. The farms selected from each selected irrigation unit must scatter throughout the irrigation unit as much as possible in order to be good representatives of the farms in the unit.

The characteristics of the 14 selected irrigation units and the distribution of sample farms are presented in Table III-2. All irrigation units selected to represent the land consolidated and structurally improved areas are served by the right and left main canals, respectively.[2] Five of the units selected to represent the unimproved area are served by the right main canal and one by the left main canal. The service area varies among the selected irrigation units from approximately 23 hectares in the land consolidated area to 144 hectares in the unimproved area. The average service areas in the land consolidated and structurally improved areas are about 40 hectares per unit while it is 104 hectares per unit in the unimproved area.

The total farms selected to represent the land consolidated and

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[2] At the time that the survey was conducted all consolidated and structurally improved areas were located on the areas served by the right and left main canals, respectively, while some of the unimproved areas were served by the right main canal and some by the left main canal.

Table III-2. Characteristics of the Selected Irrigation Units and the Distribution of the Sample Farms in Nam Pong Irrigation Project, Khon Kaen, Thailand, 1977.

Unit No.	Type of Development[1]	Location Name	Canal/ Lateral[2]	Distance (Km.)[3]	Service Area (Ha.)	No. of Farms Selected
1	LC	Ko Tha 1	RMC	33+400	38.08	10
2	LC	Ko Tha 2	RMC	33+600	60.00	10
3	LC	Pra Khu 3	RMC/2R-3L	2+970	38.88	12
4	LC	Pra Khu 5	RMC/2R-3L	2+300	23.52	12
5	SI	Huai Chan	LMC/1R	2+800	48.00	12
6	SI	Nua Check	LMC/1R	2+830	24.48	10
7	SI	Kut Lom	LMC/1R	5+795	61.92	12
8	SI	Ta Dua Noi	LMC/1R	6+500	28.16	10
9	UI	Don Du	RMC/2R-3L	0+827	40.80	15
10	UI	Kok Noi	RMC/4L	6+300	144.00	19
11	UI	Phu	RMC/5L	1+600	56.80	13
12	UI	Tao Nor	RMC	28+980	43.20	8
13	UI	Dong Pong	RMC/3L	2+400	44.64	15
14	UI	Hua Bung	LMC/3R	0+500	89.92	23

[1]LC, SI and UI stand for land consolidated, structurally improved and unimproved respectively.

[2]RMC and LMC stand for right main canal and left main canal respectively. R and L that follow the number stand for right and left respectively.

[3]Distance from the origin of canal or lateral.

structurally improved areas are 44 farms each. Ninety-three farms were selected from the unimproved area.

Farm interviews were conducted four times during October, 1977 to June, 1978. Two of them (one after crop planting and the other after crop harvesting) were designed to gather data for the 1977 wet season[3] crop production. The other two were for the 1978 dry season crop production.

Representative Farm Summary Data

In this section information obtained from the farm survey is summarized for the two seasons, the 1977 wet season and the 1978 dry season.

Family Size

The average family size for the three types of irrigation development were approximately the same in both 1977 wet and 1978 dry seasons (Table III-3). In the 1977 wet season, there were 7.0 family members for the LC and 6.8 for both the SI and UI areas. There were very small changes in family size from the 1977 wet season to the 1978 dry season for the SI and UI areas. In the 1978 dry season they increased to 6.9. This increase is very small and the farm survey

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[3]Wet season is approximately from May to November and dry season from December to April.

Table III-3. Farm Family Size in Nam Pong Irrigation Project, Khon Kaen, Thailand, 1977 Wet Season and 1978 Dry Season.

Type of Irrigation Development	No. of Farms	Family Size			
		Children (<16 yrs)	Active Adults (16-60 yrs)	Elderly Persons (>60 yrs)	Total
1977 wet season					
Land consolidated	44	3.1	3.5	0.4	7.0
Structurally improved	44	2.5	3.8	0.5	6.8
Unimproved	93	2.6	3.8	0.4	6.8
1978 dry season					
Land consolidated	44	3.0	3.6	0.4	7.0
Structurally improved	44	2.5	3.9	0.5	6.9
Unimproved	93	2.6	3.9	0.4	6.9

data do not reveal whey there was an increase. For the LC area the family size remained unchanged between the two seasons.

In both seasons the majority of family members were active adults whose ages were between 16-60 years. These adults are important to farm family in terms of labor supply. In the SI and UI areas the number of active adults were a little higher (3.8 in the 1977 wet season and 3.9 in the 1978 dry season) than that in the LC area (3.5 and 3.6 in the 1977 wet and the 1978 dry season, respectively).

Farms Cultivated in Dry Season

All of the 181 farms sampled for this study were cultivated during the 1977 wet season. However, not all of them were cultivated during the 1978 dry season. Table III-4 gives the number of sample farms that were cultivated in the 1978 dry season for each group of irrigation development. In the LC area 41 out of 44 farms or about 93 percent of the sample farms were cultivated. Only 75 and 44 percent of the sample farms in the SI and UI areas, respectively, were cultivated during the 1978 dry season.

Table III-5 lists the reasons given by the sample farmers for leaving their farms uncultivated in the 1978 dry season. In the LC area, not having enough water, bad soil quality and not having enough labor were the reasons given by the farmers. In the SI area, approximately 45 percent of the uncultivated farms was caused by the lack of labor. Lack of seed and too much water on the farms were the second most important factors causing the farms in this area to be uncultivated. The water problem which includes not having enough water and no water on the farms at all was the dominant factor reported by the farmers in the UI area. It was approximately 70 percent of the total reasons given by the farmers. Another one-fifth of the reasons reported was lack of labor.

Table III-4. Number of Cultivated Farms in Nam Pong Irrigation Project, Khon Kaen, Thailand, 1978 Dry Season.

Type of Irrigation Development	No. of Sample Farms	Cultivated Farms in Dry Season	
		Number	% of Sample
Land consolidated	44	41	93.18
Structurally improved	44	33	75.00
Unimproved	93	41	44.09

Farm Resources

Farm resource categories discussed in this section include land, working animals, and farm machinery and equipment.

Land

Land resource in this study can be classified into two categories:

Table III-5. Reasons for Leaving Whole Farms Uncultivated in 1978 Dry Season in Nam Pong Irrigation Project, Khon Kaen, Thailand.

Reasons for Leaving Whole Farm Uncultivated	Type of Irrigation Development[1]		
	Land Consolidated	Structurally Improved	Unimproved
Not enough water (1)	1 (33.33)	1 (9.09)	8 (15.39)
Soil quality is not good (2)	-	1 (9.09)	1 (1.93)
Not enough labor (3)	-	5 (45.46)	11 (21.15)
Too much water (4)	-	2 (18.18)	1 (1.92)
Lack of capital (5)	-	-	1 (1.92)
Lack of seed (6)	-	2 (18.18)	-
No water at all (7)	-	-	28 (53.85)
(1) and (2)	1 (33.33)	-	-
(1) and (3)	1 (33.34)	-	1 (1.92)
(3) and (6)	-	-	1 (1.92)

[1] Figures in parentheses are percentage.

land inside the selected irrigation units and land outside the selected irrigation units. Here, land inside the selected irrigation units means farm land located within the selected irrigation units mentioned earlier while land outside the selected irrigation units means farm land that is located outside the selected irrigation units.

Table III-6 shows the average farm area for each type of irrigation development in both the 1977 wet and the 1978 dry seasons. In the 1977 wet season, all sample farms were cultivated while not all of them were cultivated in the 1978 dry season. Therefore, two averages were computed for the 1978 dry season: one for all sample farms and the other for cultivated farms only. The average farm area for all farms remained unchanged between the two seasons. The SI area had the biggest farm size (3.49 hectares) compared to the UI and LC areas where the average farm sizes were 2.45 and 2.16 hectares, respectively. Considering only the farm area within the selected irrigation units, the SI area still had the biggest farm size (1.84 hectares). The average farm area inside the selected irrigation units in the UI and LC areas were 1.59 and 1.48 hectares, respectively.

For cultivated farms only, the average farm size in the LC area was 2.15 hectares of which 1.53 hectares located within the selected irrigation units. The SI and UI areas had the average farm size of 3.68 and 2.54 hectares, respectively. The average farm

Table III-6. Average Farm Area in Nam Pong Irrigation Project, Khon Kaen, Thailand, 1977 Wet Season and 1978 Dry Season.

Type of Irrigation Development	Farm Area (ha/farm)		
	Inside the Selected Irrigation Unit	Outside the Selected Irrigation Unit	Total
1977 wet season			
Land consolidated	1.48	0.68	2.16
Structurally improved	1.84	1.65	3.49
Unimproved	1.59	0.86	2.45
1978 dry season (all farms)			
Land consolidated	1.48	0.68	2.16
Structurally improved	1.84	1.65	3.49
Unimproved	1.59	0.86	2.45
1978 dry season (cultivated farms only)			
Land consolidated	1.53	0.62	2.15
Structurally improved	2.08	1.60	3.68
Unimproved	1.72	0.82	2.54

areas inside the selected irrigation units were 2.08 hectares for the SI area and 1.72 hectares for the UI area.

Before proceeding further it is important to note that not all of the farms cultivated in the 1978 dry season utilized all of their farm areas inside the selected irrigation units. Table III-7 gives the number of farms partly cultivated in the 1978 dry season. In the LC area, 30 farms or approximately 73 percent of cultivated farms were partly cultivated. Twenty-eight farms or approximately 85 percent of cultivated farms in the SI area were partly cultivated while all of the cultivated farms in the UI area were partly cultivated.

The reasons for leaving some parts of the farms uncultivated are listed in Table III-8. Not having enough labor was reported to be the most important problem in all areas. It was approximately 27, 29 and 46 percent of the total reasons given by the farmers in the LC, SI and UI areas, respectively. Not having enough seed, leaving uncultivated area for wet season seedbed, and not having enough water were other main reasons in the LC area. In the SI area, not having enough water and not having enough seed each contributed one-fourth of all the reasons reported by the farmers. Approximately one-third of the farmers in the UI area reported that water problem (some had too much water and some had too little water) caused them to leave some parts of their farms uncultivated.

Table III-9 shows how farm lands were allocated among various

Table III-7. Number of Farms Partly Cultivated in 1978 Dry Season in Nam Pong Irrigation Project, Khon Kaen, Thailand.

Type of Irrigation Development	Number of Sample Farms	Number of Cultivated Farms	Partly Cultivated Farms		
			Number	% of Sample Farms	% of Cultivated Farms
Land consolidated	44	41	30	68. 18	73. 17
Structurally improved	44	33	28	63. 64	84. 85
Unimproved	93	41	41	44. 09	100. 00

Table III-8. Reasons for Leaving Some Parts of the Farms Uncultivated in 1978 Dry Season in Nam Pong Irrigation Project, Khon Kaen, Thailand.

Reasons for Leaving Part of the Farm Uncultivated	Type of Irrigation Development[1]		
	Land Consolidated	Structurally Improved	Unimproved
Not enough labor (1)	8 (26.67)	8 (28.57)	19 (46.34)
Leave it for wet season seedbed (2)	4 (13.34)	-	1 (2.44)
Leave it for grazing land (3)	1 (3.33)	-	1 (2.44)
Soil quality is not good (4)	2 (6.67)	-	-
Not enough water (5)	3 (10.00)	7 (25.00)	6 (14.63)
Leave it for storing water for vegetable production (6)	1 (3.33)	-	-
Not enough seed (7)	6 (20.00)	7 (25.00)	2 (4.88)
It is the first time to raise crops in dry season (8)	1 (3.33)	2 (7.14)	1 (2.44)
Too much water (9)	2 (6.67)	1 (3.57)	7 (17.07)
It will be difficult to grow rice in wet season (10)	-	3 (10.72)	-
(1) and (4)	-	-	1 (2.44)
(1) and (5)	1 (3.33)	-	1 (2.44)
(1) and (7)	-	-	1 (2.44)
(1) and (9)	-	-	1 (2.44)
(2) and (3)	1 (3.33)	-	-

[1] Figures in parentheses are percentage.

Table III-9. Use of Farm Land Inside the Selected Irrigation Units in Nam Pong Irrigation Project, Khon Kaen, Thailand, 1977 Wet Season and 1978 Dry Season.

Type of Irrigation Development	Farm Land Used for (ha/farm)[1]									
	Rice Production		Vegetable[2] Production		Other[3] Field Crop Production		Fallow		Total	
1977 wet season										
Land cons.	1.47	(99.26)	0.002	(0.13)	-		0.009	(0.61)	1.48	(100.00)
Struct. imp.	1.83	(99.46)	-		-		0.01	(0.54)	1.84	(100.00)
Unimproved	1.50	(94.34)	0.02	(1.26)	-		0.07	(4.40)	1.59	(100.00)
1978 dry season (all farms)										
Land cons.	0.66	(44.60)	0.11	(7.43)	0.09	(6.08)	0.62	(41.89)	1.48	(100.00)
Struct. imp.	0.49	(26.63)	0.03	(1.63)	0.08	(4.35)	1.24	(67.39)	1.84	(100.00)
Unimproved	0.01	(0.63)	0.05	(3.14)	0.04	(2.52)	1.49	(93.71)	1.59	(100.00)
1978 dry season (cultivated farms only)										
Land cons.	0.71	(46.40)	0.12	(7.84)	0.10	(6.54)	0.60	(39.22)	1.53	(100.00)
Struct. imp.	0.65	(31.25)	0.04	(1.92)	0.11	(5.29)	1.28	(61.54)	2.08	(100.00)
Unimproved	0.05	(2.91)	0.11	(6.39)	0.06	(3.49)	1.50	(87.21)	1.72	(100.00)

[1] Figures in parentheses are percentage of the total.

[2] Vegetable includes squash, pumpkin, string bean, egg-plant, cucumber, chinese cabbage, radish, onion, kale, celery, bitter cucumber, cauliflower, lettuce, watercress, garlic and chili.

[3] Other field crop includes peanut, mung bean and corn.

uses. In the 1977 wet season, almost all of the farm land (99 percent in the LC and SI areas and 94 percent in the UI area) was used for rice production. A very small area (less than one percent and about one percent in the LC and UI areas, respectively) was used for vegetable production. The UI area had higher proportion of fallow land (4.40 percent) than the LC and SI areas (0.61 and 0.54 percent, respectively).

Allocation of farm lands among various uses in the 1978 dry season was computed for two cases: one for all sample farms and the other for cultivated farms only. For all farms, about 45, 7 and 6 percent of farm land in the LC area was used for rice, vegetable and other field crop production, respectively. The remaining farm land in this area was fallow. Approximately two-thirds of farm land in the SI area was fallow. Rice, vegetable and other field crop occupied about 26, 2 and 4 percent of farm land, respectively, in the SI area. In the UI area, a very small fraction of farm land was used in production (0.63, 3.14 and 2.52 percent for rice, vegetable and other field crop, respectively). About 94 percent was fallow land.

The pattern of farm land allocation among various uses on cultivated farms only is similar to that on all farms. The only difference is that the proportion of fallow land is lower on cultivated farms only because uncultivated farms are not included in the computation.

Working Animal and Machinery and Equipment

The average values of working animals, machinery and equipment per farm are given in Table III-10 for each irrigation development area in both the 1977 wet and the 1978 dry seasons. Again, two kinds of average are given for the dry season, one for all farms and the other for cultivated farms only. The value of both working animals and machinery and equipment in any season or in any case were higher in the SI area than in the other two areas. This is partially due to the fact that the SI area had bigger farm size (see Table III-9).

The value of working animals per farm in the SI area in the 1977 wet season was 379 dollars. They were 238 and 256 dollars in the LC and UI areas, respectively. In the 1978 dry season, for all farms, the value of working animals in the SI area increased to 395 dollars while in the LC and UI areas they decreased to 235 and 244 dollars, respectively. There were no differences in values of working animals in the LC area in the 1978 dry season between all farms and cultivated farms only. But the differences occurred in the SI and UI areas. In the SI area there was a very small increase (four dollars) from all farms to cultivated farms only while a relative large decrease (30 dollars) was observed in the UI area.

The value of machinery and equipment in the 1977 wet season

Table III-10. Average Value of Working Animal, Machinery and Equipment Per Farm in Nam Pong Irrigation Project, Khon Kaen, Thailand, 1977 Wet Season and 1978 Dry Season.

Type of Irrigation Development	Value of Capital Resource ($/farm)		Total
	Working Animal	Machinery and Equipment	
1977 wet season			
Land consolidated	238	104	342
Structurally improved	379	132	511
Unimproved	256	50	306
1978 dry season (all farms)			
Land consolidated	235	95	330
Structurally improved	395	108	503
Unimproved	244	46	290
1978 dry season (cultivated farms only)			
Land consolidated	235	96	331
Structurally improved	399	108	507
Unimproved	214	56	270

in the LC, SI and UI areas were 104, 132 and 50 dollars, respectively. All these values decreased in the 1978 dry season. This decrease may be interpreted to represent their depreciation. In the 1978 dry season, for all farms, the values of machinery and equipment in the LC, SI and UI areas declined to 95, 108 and 46 dollars, respectively. There was no difference in value of machinery and equipment in the SI area in the 1978 dry season between all farms and cultivated farms only. But there was a very small increase (one dollar) in the LC area and relatively large increase (ten dollars) in the UI area from all farms to cultivated farms only.

Technical (Input/Output) Coefficients

The technical (input/output) coefficients to be presented in this section include land, labor, irrigation water, cash operating capital and government budget coefficients.

Land Coefficient

One of the objectives of this study, as stated previously, is to determine, given a fixed government investment in the Nam Pong Irrigation Project, the investment mix between consolidated, structurally improved and unimproved lands which will maximize returns to land and government investment. This means that in the study it is to determine how many hectares are to be developed. Therefore, all the coefficients to be used in the analyses hereafter whether they are return, cost, labor input, water input or other will be measured on a per hectare basis.

Labor Coefficient

Labor coefficient is expressed in terms of mandays per month per hectare for each crop grown. The coefficients derived for this study were based on averaged data from the sample farm survey. The labor coefficients for each crop grown in each irrigation development area are presented in Table III-11 for the 1977 wet season and Table III-12 for the 1978 dry season.

Land preparation for the wet season crops began as early as May and all crops were not harvested until January. For the dry season crops, some of land preparation was done as early as January and most of the crops were harvested in May and June. Considerably more labor was required in vegetable production than in rice or other field crop production especially during the period after planting until harvesting. During this period, in vegetable production, many mandays were required for watering, weed control, fertilizer application, insecticide application, etc.

In the wet season, most of the labor required for rice production was in the months of June and July during which transplanting was performed and November and December when rice was harvested.

Table III-11. Labor Use in Crop Production in Each Month in 1977 Wet Season in Nam Pong Irrigation Project, Khon Kaen, Thailand.

Month	Labor (Manday/Hectare)[1]				
	Land Consolidated		Structurally Improved	Unimproved	
	R	V	R	R	V
January	-	88.88	0.25	0.88	6.38
February	-	-	-	-	-
March	-	-	-	-	-
April	-	-	-	-	-
May	4.44	-	5.94	7.19	8.19
June	24.38	-	12.00	20.44	27.81
July	32.00	386.50	35.50	25.00	39.94
August	5.31	142.06	6.19	5.56	49.13
September	4.00	142.06	1.94	1.94	172.50
October	7.69	177.81	2.38	6.06	145.81
November	31.94	193.25	36.25	29.50	91.81
December	22.13	71.06	15.81	12.81	33.50
Total	131.89	1201.62	116.26	109.38	575.07

[1] R = Rice, V = Vegetable.

Table III-12. Labor Use in Crop Production in Each Month in 1978 Dry Season in Nam Pong Irrigation Project, Khon Kaen, Thailand.

Month	Labor (Manday/Hectare)[1]								
	Land Consolidated			Structurally Improved			Unimproved		
	R	V	O	R	V	O	R	V	O
January	16. 31	119. 44	5. 88	6. 69	5. 25	-	39. 69	199. 19	44. 00
February	47. 00	147. 63	48. 13	42. 38	133. 31	36. 06	12. 63	209. 88	47. 50
March	14. 88	96. 69	14. 69	21. 06	119. 56	33. 81	6. 44	166. 38	22. 75
April	5. 63	45. 75	60. 38	4. 13	53. 13	17. 31	6. 50	66. 63	62. 06
May	31. 69	10. 06	56. 94	7. 06	14. 69	41. 19	14. 69	17. 00	94. 19
June	42. 56	-	-	35. 75	-	9. 81	50. 44	1. 19	71. 75
July	-	-	-	24. 38	-	-	-	-	-
August	-	-	-	-	-	-	-	-	-
September	-	-	-	-	-	-	-	-	-
October	-	-	-	-	-	-	-	-	-
November	-	-	-	-	-	-	-	-	-
December	-	51. 50	-	-	-	-	-	-	-
Total	158. 07	471. 07	186. 02	141. 45	325. 94	138. 18	130. 39	660. 27	342. 25

[1] R = Rice, V = Vegetable, O = Other field crops.

Labor required for vegetable production came mostly from labor in the months of July through November when such activities as watering, weed control, fertilizer application, insecticide application, etc. were carried out.

In the wet season, considerably more labor per hectare was used in vegetable production in the LC area than in the UI area. This difference is probably due to a farm survey error because there was only one sample farm that planted vegetables and the planted area was very small, 0.12 hectares.

Rice production in the dry season in the SI area began a little later than in the LC and UI areas. In the LC and UI areas transplanting was done mostly in January and February and harvesting in May and June. These two activities were done about one month later in the SI area. Most of the labor used in rice production in the dry season in the LC and UI areas was labor in the months of January, February, May and June while it was in February, March, June and July in the SI area.

Dry season vegetable production required a considerable amount of labor during the period from January to April. Most of the labor used for other field crop production was performed during February, March, April and May in the LC and SI areas while in the UI area it was during January, February, April, May and June.

Irrigation Water Coefficient

Irrigation water coefficient is expressed in terms of cubic meter per hectare (m^3/ha) per two weeks. The coefficients derived for this study were based on the sample farm survey data and the data supplied by the engineering section of RID-IRRI[4] water management research program for Northeast Thailand.

Because the engineering section of the RID-IRRI water management research program for Northeast Thailand did not have water data for the period before October, 1977 to supply to this study, the irrigation water coefficients for only three periods in the wet season (October 1-15, October 16-31 and November 1-15) were computed in this study. In the dry season the data in all periods were available so a complete set of irrigation water coefficients were computed. There were nine periods altogether in the dry season. They are Jan. 19-Feb. 1, Feb. 2-15, Feb. 16-Mar. 1, Mar. 2-15, Mar. 16-29, Mar. 30-Apr. 12, Apr. 13-26, Apr. 27-May 10 and May 11-24.

The irrigation water coefficients for each crop in each irrigation development area are listed in Table III-13 for the 1977 wet season and in Table III-14 for the 1978 dry season. Since this study

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[4]RID means Thailand Royal Irrigation Department.
IRRI means the International Rice Research Institute, Philippines.

Table III-13. Quantity of Irrigation Water Needed to Produce Crops in 1977 Wet Season in Nam Pong Irrigation Project, Khon Kaen, Thailand.

Period [1]	Irrigation Water (M^3/Hectare) [2]				
	Land Consolidated		Structurally Improved	Unimproved	
	R	V	R	R	V
October 1-15	1259	2182	255	760	676
October 16-31	1736	3670	517	1143	983
November 1-15	595	977	-	650	700

[1] Data in other periods are not available.

[2] R = Rice, V = Vegetable.

Table III-14. Quantity of Irrigation Water Needed to Produce Crops in 1978 Dry Season in Nam Pong Irrigation Project, Khon Kaen, Thailand.

Period	Irrigation Water (M^3/Hectare)[1]								
	Land Consolidated			Structurally Improved			Unimproved		
	R	V	O	R	V	O	R	V	O
Jan. 19-Feb. 1	2105	1758	1855	737	707	675	13361	10547	5404
Feb. 2-15	1754	1730	1822	5054	4849	4572	7183	10425	8338
Feb. 16-Mar. 1	1131	1740	1862	4179	4024	3367	8552	9632	6560
Mar. 2-15	1005	1512	1611	2468	2448	1648	10968	15983	15040
Mar. 16-29	1187	1665	1772	1846	1711	1423	9681	15896	14169
Mar. 30-Apr. 12	1044	1774	1898	1691	1720	1576	12545	12853	10693
Apr. 13-26	1483	1324	1421	-	-	-	9727	7198	11189
Apr. 27-May 10	874	794	-	-	-	-	8440	9755	22094
May 11-24	-	-	-	-	-	-	7229	7229	7229
Total	10583	12297	12241	15975	15459	13261	87686	99518	100716

[1] R = Rice, V = Vegetable, O = Other field crops.

does not have a complete set of wet season irrigation water coefficients, most of the attention will be directed to dry season coefficients.

In the LC area one hectare of rice required 10,583 cubic meters of irrigation water while vegetable and other field crop required 12,297 and 12,241 cubic meters, respectively. Three studies on rice water consumptive use conducted by IRRI in the Philippines show approximately the same amount of water required by rice. In the 1969 dry season, an IRRI experiment on water management practices indicated that rice flooded to a constant depth of 2.5 centimeters from transplanting to maturity required 11,470 cubic meters of water per hectare (IRRI 1970). The result of a study on water use after transplanting conducted by IRRI in Luzon, Philippines in the 1970 dry season shows that 11,480 cubic meters per hectare of water was used by rice (IRRI 1973). Another IRRI's study on water balance components after transplanting in six pilot areas in Upper Pampanga River Project in the Philippines in the 1974 dry season reported that with continuous method of irrigation, 10,420 cubic meters per hectare of water was used by rice (IRRI 1975).

Freeman et al. (1976) studied total water application to tomato by trickle and furrow irrigation systems in Australia. They concluded that with the furrow system the amount of water supplied to tomato was 150% E_o, where E_o is evaporation from a free water surface and is approximately 80% of U.S. Class A pan evaporation, i.e.,

$E_o = 0.8\ E_{pan}$.

In the LC area E_{pan} during January 19 to May 24, 1978 was 811.25 millimeters. Therefore, following the study of Freeman et al., the amount of water required for vegetable production in the LC area has to be in the neighborhood of 9,735 cubic meters per hectare. Comparing the amount of water required for vegetable production that was computed for this study and the above estimate, the amount of water computed for this study is approximately 26 percent higher than the above estimate.

Gonzales et al. (1965) conducted corn irrigation trials in the Lamao Experiment Station in the Philippines. Their results show that during 1960-1961 dry season yields of corn among 5249, 6833, 8417, 10001 and 11585 cubic meters per hectare treatments were not significantly different.

In the SI area the amount of irrigation water required for crop production was slightly higher than in the LC area but between the UI and LC areas the difference was very large. These differences were largely due to two main factors: the proportion of the area planted to crops to the total area and the condition of irrigation infrastructure. The proportion of the area planted to crops to the total area in the LC area was at a relatively high level while they were at an intermediate and a low level in the SI and UI areas, respectively (see Table III-9). The more scattered the planted areas, the more irrigation water conveyance loss.

Table III-15 shows, according to the farmers' opinions, the areas that receive less irrigation water than required, more irrigation water than required, and just the right amount of irrigation water in each irrigation development area in both the 1977 wet and the 1978 dry seasons. In the 1978 dry season, higher proportion (54 percent) of the area in the UI category than in the SI (15 percent) and LC (10 percent) categories received inadequate irrigation water. The reverse was true for the proportion of the area that received just the right amount of water. This is one of the indications of high conveyance loss in the UI area. Farmers' opinions regarding the need in improvements of the irrigation system which can be interpreted to reflect the condition of the irrigation infrastructure are presented in Table III-16. More than one-half of the farmers in the LC area reported no need in any improvements while approximately one-third and one-fourth of the farmers in the SI and UI areas, respectively, reported that they did not need any improvements in the irrigation system. This means that among the LC, SI and UI areas irrigation infrastructure in the LC area was the best and in the UI was the worst.

When irrigation infrastructure is in good condition water use efficiency will be high and it will be low when the infrastructure is bad, given that other things are the same between these two cases.

Table III-15. Adequacy of Irrigation Water on Farms in Nam Pong Irrigation Project, Khon Kaen, Thailand, 1977 Wet Season and 1978 Dry Season.

Type of Irrigation Development	Area (ha/farm) Receives Water[1]			Total Area (ha/farm)
	Less Than Required	More Than Required	Just the Right Amount	
1977 wet season				
Land consolidated	0.17 (11.48)	0.03 (2.03)	1.28 (86.49)	1.48 (100.00)
Structurally improved	0.44 (23.91)	0.20 (10.87)	1.20 (65.22)	1.84 (100.00)
Unimproved	0.40 (25.16)	0.17 (10.69)	1.02 (64.15)	1.59 (100.00)
1978 dry season				
Land consolidated	0.15 (10.13)	0.10 (6.76)	1.23 (83.11)	1.48 (100.00)
Structurally improved	0.28 (15.22)	0.10 (5.43)	1.46 (79.35)	1.84 (100.00)
Unimproved	0.86 (54.09)	0.07 (4.40)	0.66 (41.51)	1.59 (100.00)

[1] Figures in parentheses are percentage of total area.

Table III-16. Farmers' Opinions Regarding Improvements of the Irrigation System in Nam Pong Irrigation Project, Khon Kaen, Thailand, 1978 Dry Season.

Kind of Improvement Needed	Number of Farmers Reporting in[1]		
	Land Consolidated Area	Structurally Improved Area	Unimproved Area
None (1)	24 (54.55)	14 (31.82)	23 (24.73)
Irrigation ditch be higher (2)	5 (11.36)	1 (2.27)	5 (5.38)
Ditch concrete lining (3)	3 (6.82)	2 (4.54)	-
Ditch repair (4)	1 (2.27)	7 (15.91)	-
Provide more ditches (5)	1 (2.27)	4 (9.09)	8 (8.60)
Improve irrigation ditch (6)	-	-	9(9.68)
Improve drainage system (7)	3 (6.82)	3 (6.82)	3 (3.22)
Desilting (8)	2 (4.55)	2 (4.55)	6 (6.45)
Levelling field (9)	3 (6.82)	2 (4.55)	10 (10.75)
Land consolidation (10)	-	1 (2.27)	2 (2.15)
Supply more water (11)	-	7 (15.91)	8 (8.60)
Supply water earlier (12)	-	-	1 (1.07)
Supply water in dry season (13)	-	-	6 (6.45)
No fighting for water (14)	1 (2.27)	-	1 (1.07)
(2) and (11)	-	-	2(2.15)
(4) and (11)	-	1 (2.27)	-
(5) and (7)	-	-	1 (1.08)
(5) and (9)	-	-	1 (1.08)
(5) and (11)	-	-	1 (1.08)
(6) and (7)	-	-	1 (1.08)
(6) and (9)	-	-	3 (3.22)
(8) and (11)	1 (2.27)	-	1(1.08)
(11) and (14)	-	-	1 (1.08)

[1] Figures in parentheses are percentage of total.

Therefore, it can be concluded that irrigation water requirement in crop production in the SI and UI areas was higher in the LC area and in the UI area was higher than in the SI area.

Cash Operating Capital Coefficient

Cash operating capital coefficient is expressed in terms of dollar per hectare. The coefficients derived for this study were based on averaged data from the sample farm survey. In this study cash cost includes costs of seeds, fertilizer, other chemicals, gas and oil for tractors and water pumps, interest on borrowed money, and hired labor.

The coefficients for each crop in each irrigation development area are presented in Table III-17 for the 1977 wet season and in Table III-18 for the 1978 dry season. In the 1977 wet season total cash cost in rice production in the LC area was approximately 40 percent higher than in the SI and UI areas. The main components of the cost were hired labor, fertilizer and seed. Costs of vegetable production were about the same in the LC and UI areas. The major costs were seeds, fertilizers and other chemicals.

In the 1978 dry season total cash cost in rice production in the UI area which was 111.55 dollars per hectare was about 15 and 274 percent higher than in the LC and SI areas, respectively. The major differences were that farmers in the UI area used more fertilizer,

Table III-17. Cost and Return of Crop Production in 1977 Wet Season in Nam Pong Irrigation Project, Khon Kaen, Thailand.

Cost or Return	US$ / Hectare[1]				
	Land Consolidated		Structurally Improved	Unimproved	
	R	V	R	R	V
Cost of:					
Seed	4.58	130.50	4.58	4.28	351.47
Fertilizer	10.39	162.90	5.20	9.47	47.07
Other chemicals (insecticide, herbicide, etc.)	0.92	95.66	1.83	0.61	26.28
Gas and oil for tractor	-	-	-	-	-
Gas and oil for water pump	0.61	2.75	0.92	1.53	1.53
Interest on borrowed money	3.06	3.67	1.53	2.14	2.14
Hired labor	28.42	-	20.17	15.28	1.22
Total cash cost	47.98	395.48	34.23	33.31	429.71
Family and exchange labor	73.04	881.42	66.63	69.38	422.07
Interest on working animal investment	7.64	10.09	9.17	7.95	7.73
Depreciation of machinery and equipment	9.47	22.92	8.86	5.20	5.20
Interest on machinery and equipment investment	2.75	7.33	2.75	1.22	1.22
Total non-cash cost	92.90	921.76	87.41	83.75	435.82
Total cost	140.88	1317.24	121.64	117.06	865.53
Gross return	332.21	1089.24	284.23	229.52	779.22
Return to land and government investment	191.33	-228.00	162.59	112.46	-136.31

[1] R = Rice, V = Vegetable.

Table III-18. Cost and Return of Crop Production in 1978 Dry Season in Nam Pong Irrigation Project, Khon Kaen, Thailand.

Cost or Return	US$/Hectare [1]								
	Land Consolidated			Structurally Improved			Unimproved		
	R	V	O	R	V	O	R	V	O
Cost of:									
Seed	5.50	8.25	46.76	3.36	15.28	14.67	5.50	256.72	58.07
Fertilizer	38.51	68.15	9.17	20.48	34.84	8.25	37.59	78.55	19.25
Other chemicals (insecticide, herbicide, etc.)	4.89	46.45	14.06	6.11	18.64	3.67	8.56	56.54	6.11
Gas and oil for tractor	0.31	-	-	-	-	-	-	-	-
Gas and oil for water pump	1.53	0.31	-	0.31	0.31	0.31	15.28	12.22	10.70
Interest on borrowed money	3.06	3.36	3.36	4.28	3.67	3.36	16.81	14.36	22.62
Hired labor	42.79	1.83	15.28	6.11	-	-	27.81	7.64	7.33
Total cash cost	96.59	128.35	88.63	40.65	72.74	30.26	111.55	426.03	124.08
Family and exchange labor	88.94	345.66	114.91	97.19	239.00	101.47	70.60	473.11	241.44
Interest on working animal investment	10.09	10.70	10.09	21.70	24.14	22.62	38.81	43.40	36.67
Depreciation of machinery and equipment	16.20	6.42	6.72	17.42	21.70	18.03	33.62	44.93	42.18
Interest on machinery and equipment investment	4.89	1.22	1.22	5.20	7.03	5.50	7.64	11.31	11.31
Total non-cash cost	120.12	364.00	132.94	141.51	291.87	147.62	150.67	572.75	331.60
Total cost	216.71	492.35	221.57	182.16	364.61	177.88	262.22	998.78	455.68
Gross return	332.52	586.19	210.57	276.59	559.90	106.97	239.30	1327.02	479.52
Return to land and government investment	115.81	93.84	-11.00	94.43	195.29	-70.91	-22.92	328.24	23.84

[1] R = Rice, V = Vegetable, O = Other field crops.

water, hired labor and borrowed more money than the farmers in the SI area. Farmers in the LC area similarly used more fertilizer and hired labor than farmers in the SI area. Also, total cash costs in vegetable and other field crop productions in the UI area were higher than in the LC and SI areas. Besides a very high seed cost in the UI area where onion and garlic were grown, other causes of the differences in vegetable and other field crop productions among the three areas were similar to that in rice production.

Government Budget Coefficient

In this study, government budget coefficient means the average amount of money spent by the government in developing the irrigation system. It is expressed in terms of dollars per hectare. The coefficients derived for this study were based on the data supplied by various offices of Thailand Royal Irrigation Department.

The coefficient for land consolidation and its detail are presented in Table III-19. To consolidate one hectare of land in the Nam Pong Irrigation Project, the government had to spend 867.36 dollars. This is considered to be cheap when compared with 1,000 dollars in the Philippines (Wickham et al. 1977) and 20,000 dollars in Japan (Bhuiyan 1977). The major components of the cost of land consolidation in the Nam Pong Irrigation Project were the costs of land levelling, irrigation structures, and road and irrigation ditch

Table III-19. Cost of Land Consolidation in Nam Pong Irrigation Project, Khon Kaen, Thailand.

Activity	Cost (US$/Ha.)
Survey and issue title deed	64.18
Design and engineering	10.70
Land clearing	21.39
Land levelling	284.23
Road construction including fills for irrigation ditch	131.42
Excavation of irrigation ditch and drain ditch	16.81
Structure	232.89
Supervision and administration	50.73
Rehabilitation of main system	55.01
Total	867.36

Source: Unpublished data supplied by Nong Wai Pioneer Agriculture Project Office, Khon Kaen, Thailand.

construction.

The coefficient for structural improvement is presented in Table III-20. The cost of structural improvement was 307.15 dollars per hectare. About one-third of this cost was the cost of rehabilitation of the main system, and another 57 percent of the total cost was the cost of construction of irrigation and drainage systems.

Return to Land and Government Investment in the Irrigation Development

Return to land and government investment in the irrigation development was computed by subtracting cash and non-cash costs which includes costs of family and exchange labor, interest on working animal investment, depreciation of machinery and equipment, and interest on machinery and equipment investment from gross return from crop production.

In the cases of vegetable production and other field crop production, gross returns were computed by adding the value of crop sales to the estimated value of crop consumed by farm families. But in the case of rice production, gross return was computed by multiplying yield by the average price of rice in the study area.

Considering the possible effect of increased supplies on prices of these crops, a maximum area allowed for vegetable production is set (to be described later in Chapter IV). But rice and other field

Table III-20. Cost of Structural Improvement in Nam Pong Irrigation Project, Khon Kaen, Thailand.

Activity	Cost (US $/Ha.)
1. Survey	5.20
2. Design and engineering	4.58
3. Construction of irrigation and drainage system	175.73
4. Supervision and administration	21.09
5. Rehabilitation of main system	100.55
Total	307.15

Source: Activities 1 and 2: Unpublished data supplied by Royal Irrigation Department, Bangkok, Thailand.

Activities 3 and 4: Unpublished data supplied by Northeast Ditch and Dike Office, Khon Kaen, Thailand.

Activity 5: Unpublished data supplied by Nam Pong Irrigation Office, Khon Kaen, Thailand.

crop productions are not restricted. Increased supplies are not considered to affect prices for the rice and field crops since they are not perishable and can be easily stored. Moreover, the quantities produced in the study area of these crops are small compared with the regional and national production. For example, Thailand's rice production during the period of 1972-1977 was 14.1 million metric tons per year (Bank of Thailand 1977). The study area is less than one percent of the national rice area (IRRI 1975).

Returns to land and government investment are presented in Table III-17 for the 1977 wet season and in Table III-18 for the 1978 dry season. In the 1977 wet season, only rice production yielded a positive return while vegetable production yielded a negative return in all cases. If the cost of family and exchange labor which were about 67 and 49 percent in the LC and UI areas, respectively, were eliminated from the cost of production, vegetable production also gave positive returns.

In the dry season, rice production in the UI area gave negative returns while positive returns were obtained in the other two areas. This is because the yield in the UI area was relatively low. It was only 72 and 87 percent of the yields in the LC and SI areas, respectively. Vegetable production in the UI area was the most profitable among the three areas. It yielded the return of 328.24 dollars per hectare while the returns in the LC and SI areas were 93.84 and

195.29 dollars per hectare, respectively. Other field crop production seems to be unattractive because it yielded a return of only 23.84 dollars per hectare in the UI area while negative returns were obtained in the other two areas.

Considering the returns from crop production, a question may be asked why some crops which yielded negative returns such as wet season vegetables and dry season other field crops were produced. This can be explained as follows: First, the major cost of production of these crops was the cost of family and exchange labor. Its share in the total cost of production ranged from approximately 49 to 67 percent. This kind of labor was also assumed in the study to have an opportunity cost of 0.75 dollars per day which was the minimum wage rate for agricultural labor imposed by law in that region. But in the actual situation, these family and exchange labors may have had a lower opportunity cost since there are few alternatives available. Therefore, if the wage rate for the family and exchange labor was reduced by two-thirds, all crops would have yielded positive returns. Second, these crops occupied a very small fraction of the total area (see Table III-9), and are important for family subsistence, therefore, the value to the family may be much higher than the price assumed in the study.

IV. THE LINEAR PROGRAMMING MODEL USED IN THE ANALYSIS OF THE IRRIGATION DEVELOPMENT

This chapter includes two main sections. The first section described the detailed structure of the linear programming model. Assumptions and constrained levels applied to the model are given in the second section.

Structure of the Model

The linear programming model developed for this study is designed to: 1) determine, given a fixed government investment in the Nam Pong Irrigation Project, the investment mix between consolidated, structurally improved and unimproved lands and the crops to be grown on these lands which will maximize returns to land and government investment; 2) evaluate the value of irrigation water in crop production for various periods of water supply from the Nam Pong Irrigation Project; 3) evaluate an effect of the irrigation development on employment and the irrigation water utilization; and 4) examine changes in the irrigation development, returns to land and government investment, land use alternatives, value of irrigation water, employment and irrigation water utilization resulting from the variation in the government investment.

The model consists of three main irrigation development activities: (a) land consolidation, (b) structural improvement, and

(c) unimprovement. In the dry season each of these three main activities includes four minor land use alternatives--rice production, vegetable production, other field crop production, and fallow land. During the wet season both the land consolidation and unimprovement activities have three land use alternatives--rice production, vegetable production and fallow land. The structural improvement activity has only rice production and fallow land use alternatives in the wet season.

The constraints included in the model are land, area allowed for vegetable production, labor, irrigation water, cash operating capital, government budget and the equality between the developed areas in the dry and the wet seasons.

The mathematical formulation of the model is:

Maximize $Z = \sum_{i=1}^{20} c_i X_i$ subject to

Land resource in dry season

(1) $$\sum_{i=1}^{12} a_{01,i} X_i = b_1$$

Land resource in wet season

(2) $$\sum_{i=13}^{20} a_{02,i} X_i = b_2$$

Maximum area allowed for vegetable production in dry season

(3) $$a_{03,i}(X_2 + X_6 + X_{10}) \leq b_3$$

Maximum area allowed for vegetable production in wet season

(4) $$a_{04,i}(X_{14} + X_{19}) \leq b_4$$

January labor

(5) $$\sum_{i=1}^{20} a_{05,i}X_i \leq b_5$$

February labor

(6) $$\sum_{i=1}^{12} a_{06,i}X_i \leq b_6$$

March labor

(7) $$\sum_{I=1}^{12} a_{07,i}X_i \leq b_7$$

April labor

(8) $$\sum_{i=1}^{12} a_{08,i}X_i \leq b_8$$

May labor

(9) $$\sum_{i=1}^{20} a_{09,i}X_i \leq b_9$$

June labor

(10) $$\sum_{i=1}^{20} a_{10,i}X_i \leq b_{10}$$

July labor

(11) $$\sum_{i=1}^{20} a_{11,i}X_i \leq b_{11}$$

August labor

(12) $$\sum_{i=13}^{20} a_{12,i}X_i \leq b_{12}$$

September labor

(13) $$\sum_{i=13}^{20} a_{13,i}X_i \leq b_{13}$$

October labor

(14) $$\sum_{i=13}^{20} a_{14,i}X_i \leq b_{14}$$

November labor

(15) $$\sum_{i=13}^{20} a_{15,i}X_i \leq b_{15}$$

December labor

(16) $$\sum_{i=1}^{20} a_{16,i}X_i \leq b_{16}$$

January 19-February 1 irrigation water

(17) $$\sum_{i=1}^{12} a_{17,i}X_i \leq b_{17}$$

February 2-15 irrigation water

(18) $$\sum_{i=1}^{12} a_{18,i}X_i \leq b_{18}$$

February 16-March 1 irrigation water

(19) $$\sum_{i=1}^{12} a_{19,i}X_i \leq b_{19}$$

March 2-15 irrigation water

(20) $$\sum_{i=1}^{12} a_{20,i}X_i \leq b_{20}$$

March 16-29 irrigation water

(21) $$\sum_{i=1}^{12} a_{21,i}X_i \leq b_{21}$$

March 30-April 12 irrigation water

(22) $$\sum_{i=1}^{12} a_{22,i}X_i \leq b_{22}$$

April 13-26 irrigation water

(23) $$\sum_{i=1}^{12} a_{23,i}X_i \leq b_{23}$$

April 27-May 10 irrigation water

(24) $$\sum_{i=1}^{12} a_{24,i}X_i \leq b_{24}$$

May 11-24 irrigation water

(25) $$\sum_{i=1}^{12} a_{25,i}X_i \leq b_{25}$$

October 1-15 irrigation water

(26) $$\sum_{i=13}^{20} a_{26,i}X_i \leq b_{26}$$

October 16-31 irrigation water

(27) $$\sum_{i=13}^{20} a_{27,i}X_i \leq b_{27}$$

November 1-15 irrigation water

(28) $$\sum_{i=13}^{20} a_{28,i}X_i \leq b_{28}$$

Cash operating capital

(29) $$\sum_{i=1}^{20} a_{29,i}X_i \leq b_{29}$$

Government budget

(30) $$\sum_{i=1}^{20} a_{30,i}X_i \leq b_{30}$$

Land consolidated areas in dry and wet seasons are equal

(31) $$\sum_{i=1}^{20} a_{31,i}X_i = 0$$

Structurally improved areas in dry and wet seasons are equal

(32) $$\sum_{i=1}^{20} a_{32,i}X_i = 0$$

Unimproved areas in dry and wet seasons are equal

(33) $$\sum_{i=1}^{20} a_{33,i}X_i = 0$$

and nonnegativity constraint

(34) $$X_i \geq 0$$

where:

i = index of activity: i = 1, 2, 3, . . . , 20

(1 = rice production in land consolidated area in dry season

2 = vegetable production in land consolidated area in dry season

3 = other field crop production in land consolidated area in dry season

4 = fallow land in land consolidated area in dry season

5 = rice production in structurally improved area in dry season

6 = vegetable production in structurally improved area in dry season

7 = other field crop production in structurally improved area in dry season

8 = fallow land in structurally improved area in dry season

9 = rice production in unimproved area in dry season

10 = vegetable production in unimproved area in dry season

11 = other field crop production in unimproved area in dry season

12 = fallow land in unimproved area in dry season

13 = rice production in land consolidated area in wet season

14 = vegetable production in land consolidated area in wet season

15 = fallow land in land consolidated area in wet season

16 = rice production in structurally improved area in wet season

17 = fallow land in structurally improved area in wet season

18 = rice production in unimproved area in wet season

19 = vegetable production in unimproved area in wet season

20 = fallow land in unimproved area in wet season)

Z = total return to land and government investment in the irrigation development

c_i = per hectare return to land and government investment in the irrigation development from activity i

X_i = hectares used in activity i

$a_{01,i}$ = 1 = land area in dry season needed for one hectare production of activity i

$a_{02,i}$ = 1 = land area in wet season needed for one hectare production of activity i

$a_{03,i}$ = 1 = land area in dry season needed for one hectare production of vegetable

$a_{04,i}$ = 1 = land area in wet season needed for one hectare production of vegetable

$a_{05,i}$ = quantity of January labor needed for one hectare production of activity i

$a_{06,i}$ = quantity of February labor needed for one hectare production of activity i

$a_{07,i}$ = quantity of March labor needed for one hectare production of activity i

$a_{08,i}$ = quantity of April labor needed for one hectare production of activity i

$a_{09,i}$ = quantity of May labor needed for one hectare production of activity i

$a_{10,i}$ = quantity of June labor needed for one hectare production of activity i

$a_{11,i}$ = quantity of July labor needed for one hectare production of activity i

$a_{12,i}$ = quantity of August labor needed for one hectare production of activity i

$a_{13,i}$ = quantity of September labor needed for one hectare production of activity i

$a_{14,i}$ = quantity of October labor needed for one hectare production of activity i

$a_{15,i}$ = quantity of November labor needed for one hectare production of activity i

$a_{16,i}$ = quantity of December labor needed for one hectare production of activity i

$a_{17,i}$ = quantity of January 19-February 1 irrigation water needed for one hectare production of activity i

$a_{18,i}$ = quantity of February 2-15 irrigation water needed for one hectare production of activity i

$a_{19,i}$ = quantity of February 16-March 1 irrigation water needed for one hectare production of activity i

$a_{20,i}$ = quantity of March 2-15 irrigation water needed for one hectare production of activity i

$a_{21,i}$ = quantity of March 16-29 irrigation water needed for one hectare production of activity i

$a_{22,i}$ = quantity of March 30-April 12 irrigation water needed for one hectare production of activity i

$a_{23,i}$ = quantity of April 13-26 irrigation water needed for one hectare production of activity i

$a_{24,i}$ = quantity of April 27-May 10 irrigation water needed for one hectare production of activity i

$a_{25,i}$ = quantity of May 11-24 irrigation water needed for one hectare production of activity i

$a_{26,i}$ = quantity of October 1-15 irrigation water needed for one hectare production of activity i

$a_{27,i}$ = quantity of October 16-31 irrigation water needed for one hectare production of activity i

$a_{28,i}$ = quantity of November 1-15 irrigation water needed for one hectare production of activity i

$a_{29,i}$ = amount of cash operating capital needed for one hectare production of activity i

$a_{30,i}$ = one-half of government budget needed for improvement of irrigated area needed for one hectare production of activity i

$a_{31,i}$ = 1 for i = 1, 2, 3 and 4

= -1 for i = 13, 14 and 15

= 0 for i = 5, 6, 7, 8, 9, 10, 11, 12, 16, 17, 18, 19 and 20

$a_{32,i}$ = 1 for i = 5, 6, 7 and 8

= -1 for i = 16 and 17

= 0 for i = 1, 2, 3, 4, 9, 10, 11, 12, 13, 14, 15, 18, 19 and 20

$a_{33,i}$ = 1 for i = 9, 10, 11 and 12

= -1 for i = 18, 19 and 20

= 0 for i = 1, 2, 3, 4, 5, 6, 7, 8, 13, 14, 15, 16 and 17

Choice of Objective Function for Model

For individual producers who operate in competitive markets for both factors and outputs, their objectives are profit maximization. The prices for all factors and outputs are exogenously determined. Within an aggregate context there are many producers producing the same products and using the same inputs. In this case, the assumption of exogenously determined prices for all factors and outputs is no longer tenable (McCarl and Spreen). The inclusion of price responsive demand for output and supply of input schedules into a linear programming model is more appropriate. Moreover, Samuelson (1952) suggested that a model incorporates demand for outputs in other regions as well as the domestic demand.

Incorporating product demand functions into a planning model designed for the purpose of analyzing policy alternatives, rather than assuming exogenously determined product prices, has three principal advantages (Duloy and Norton 1975). First, it allows the model to correspond to a market equilibrium. Second, it allows the model greater flexibility. For instance, substitution between capital and labor, corresponding to different factor price ratios, can occur not only directly through the technology set or through changes in the commodity mix of trade, but also through substitution in demand due to changing relative prices of products which are more or less labor-or capital-intensive. Third, it permits an appraisal of the distribution between consumers and producers of benefits accruing from changes in output.

When a regional model includes price responsive demand for output and supply of input schedules, the objective function becomes the maximization of producers' plus consumers' surpluses. Each producing unit seeks to maximize profits, without knowledge of or attempting to maximize surplus. The regional supply curve is an aggregate of all producers marginal cost curves. The region's aggregate demand for factors is an aggregate marginal value curve of all producers. And the optimal solution at the aggregate level is a competitive equilibrium.

In the case of the linear programming model developed for the Nam Pong Irrigation Project, the prices of outputs and inputs are assumed to be exogenously determined. Thus the objective of maximizing producers' plus consumers' surpluses is the same as maximizing producers' profit which is defined as net return to land. The assumption of exogenous prices is considered to be reasonable because the project covers an area of 48,400 hectares which is only 0.28 percent of the national farm area or 0.83 percent of the Northeast

Region's farm area. The supply of rice and other field crops from the project will not affect prices as described earlier in Chapter III. For vegetable production, its upper bound is specified in the model. Moreover, vegetables are partly consumed by farm families so it is difficult to estimate demand for them.

Assumptions and Constrained Levels Applied to the Model

The preceding model contains seven general assumptions of linear programming: (1) additivity of resources and activities, (2) linearity of objective function, (3) nonnegativity of decision variables, (4) divisibility of activities and resources, (5) finiteness of activities and resource restrictions, (6) proportionality of activity levels to resources, and (7) single-value expectations for all resource supplies, input-output coefficients, prices of resources and activities (Agrawal and Heady 1971). Besides these, certain assumptions and constraints specifically apply to the model and are described below.

Return Maximization Assumption

In this study, return means net return to land and government investment in irrigation development. Given the quantities of various resources available in the irrigation project area, it is assumed that the government together with the farmers in the project area will make the best use of the available resources to maximize return to land and the investment. This maximum return can be achieved by determining the optimal combinations of irrigation development and of crop production simultaneously. In the crop production planning stage, it is assumed that the irrigation project represents and is managed as one business firm.

Project Area Assumption and Constrained Level

The area considered in the model is assumed to be the total area served by the irrigation project which is 48,400 hectares. No area larger than that is allowed because it will involve an extra budget for providing irrigation facilities. Besides, an expansion of area is limited by the availability of water to serve the area.

Area for Vegetable Production Assumption and Constrained Level

Vegetables are perishable products. They cannot be kept for a long time after they are harvested since storage facilities are not available in and around the project area. Moreover, they have to be harvested for sale when they mature. Therefore, a maximum level of vegetable production has to be set in order to restrict the supply of vegetables and maintain its price comparable to the price used in the model.

Based on the 1978 dry season farm survey data it is estimated that approximately 1,120 hectares of farm land in the irrigation project were planted to vegetables. Therefore, it is assumed that 1,120 hectares of farm land is the constrained level for vegetable production and that at that level its price will be the same as the one used in the model.

Labor Supply Assumption and Constrained Level

Labor available for agricultural production in the irrigation project area is assumed to come only from farm families residing in the project area. There are two reasons for this assumption. First, farm workers who live around the project area also have to work on their own farms during the production season. Second, even though farm workers who live around the project area are available for farm production in the project area. Only farms in the project area that locate near the boundary will be able to hire those farm workers, since farm roads are poor and farm workers have to return home everyday after finishing their jobs. Therefore, only a very small amount of farm labor, if any, will come from outside the project area. The data from the farm survey also reveal that about five percent of labor used in farm production in the project area was hired labor. This five percent of labor may come from both inside and outside the project area.

Labor supply for agricultural production is also assumed to consist of farm family members whose ages are between 16 to 60 years. Based on these two assumptions and the farm survey data it is estimated that during the dry season labor supply for agricultural production in the project area is 70,926 mandays per day and it is 69,588 mandays per day during the wet season.[5]

Irrigation Water Supply Assumption and Constrained Level

The irrigation water supply in the project area depends on the quantity of water released from the Ubolratana Reservoir for hydropower generation. According to the agreement between the Electricity Generating Authority of Thailand (EGAT) and Thailand Royal Irrigation Department (RID), EGAT will maintain an average discharge of 45 cubic meters per second from the reservoir. Therefore, it is assumed that the supply of water in the project area is fixed at the rate of 45 cubic meters per second.

Cash Operating Capital Supply Assumption and Constrained Level

There are many credit institutions both private and public that offer production loans to farmers in Khon Kaen Province. But the

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[5] The farm survey data do not reveal why the supplies for the two seasons are different.

cheapest source is the Bank for Agriculture and Agricultural Cooperative (BAAC) which is operated by the government. The interest charged by BAAC is one percent per month. Farmers can obtain short-term production loans (one-year loan) from this bank through the agricultural cooperative organization. They may also obtain loans directly from the bank by mortgaging their farm lands to the bank. The maximum amount of short-term loan that farmers can obtain from the bank is 586.80 dollars per family. It is estimated that there are 18,632 farm families in the irrigation project area. Therefore, it is assumed that cash operating capital supply in the project area is 10,933,202 dollars per year.

Government Budget for the Development Assumption and Constrained Level

Information obtained from a Royal Irrigation Department's publication reveal that the government has the budget of approximately 14.2 million dollares to spend on the development of the right bank subsystem of the Nam Pong Irrigation Project (RID 1977). Another 8.8 million dollar budget is to be spent on the development of three irrigation projects: Lam Phra Plerng Project in Nakorn Ratchasima Province, Lam Pao Project in Kalasin Province, and the left bank subsystem of the Nam Pong Project in Khon Kaen Province (RID 1977). The areas proposed to be developed are 9100, 18200 and 14700 hectares in Lam Phra Plerng, Lam Pao and the left bank subsystem of the Nam Pong Project, respectively (RID 1977). Assuming that the 8.8 million dollar budget is to be allocated proportionally to the areas among the three projects, the left bank subsystem of the Nam Pong Project will receive a budget of 3.1 million dollars. Therefore, it is assumed that the government has a total budget of 17.3 million dollars to spend on the development of the Nam Pong Irrigation Project.

Equality Between Developed Areas in Dry and Wet Season Assumption

The last requirement applied in the model is that the developed areas in dry and wet seasons are equal. This means that land consolidated area in dry season is equal to land consolidated area in wet season; structurally improved area in dry season is equal to structurally improved area in wet season; and unimproved area in dry season is equal to unimproved area in wet season.

From the mathematical formulation of the model and the constraints described above, the tableau of the model is presented in Table IV-1.

Table IV-1. Tableau of the Linear Programming Model

Equation No.		Dry Season, Land Consolidated: Rice (1)	Dry Season, Land Consolidated: Vegetable (2)
(0)	Objective function	+115.81	+ 93.84
(1)	Land resource in dry season	+ 1.00	+ 1.00
(2)	Land resource in wet season		
(3)	Maximum area allowed for veg. production in dry season		+ 1.00
(4)	Maximum area allowed for veg. production in wet season		
(5)	January labor	+ 16.31	+119.44
(6)	February labor	+ 47.00	+147.63
(7)	March labor	+ 14.88	+ 96.69
(8)	April labor	+ 5.63	+ 45.75
(9)	May labor	+ 31.69	+ 10.06
(10)	June labor	+ 42.56	
(11)	July labor		
(12)	August labor		
(13)	September labor		
(14)	October labor		
(15)	November labor		
(16)	December labor		+ 51.50
(17)	Jan. 19-Feb. 1 irrigation water	+ 2105	+ 1758
(18)	Feb. 2-15 irrigation water	+ 1754	+ 1730
(19)	Feb. 16-Mar. 1 irrigation water	+ 1131	+ 1740
(20)	Mar. 2-15 irrigation water	+ 1005	+ 1512
(21)	Mar. 16-29 irrigation water	+ 1187	+ 1665
(22)	Mar. 30-Apr. 12 irrigation water	+ 1044	+ 1774
(23)	Apr. 13-26 irrigation water	+ 1483	+ 1324
(24)	Apr. 27-May 10 irrigation water	+ 874	+ 794
(25)	May 11-24 irrigation water		
(26)	Oct. 1-15 irrigation water		
(27)	Oct. 16-31 irrigation water		
(28)	Nov. 1-15 irrigation water		
(29)	Cash operating capital	+ 96.59	+128.35
(30)	Government budget	+433.68	+433.68
(31)	Land consolidated areas in dry and wet seasons are equal	+ 1.00	+ 1.00
(32)	Structurally improved areas in dry and wet seasons are equal		
(33)	Unimproved areas in dry and wet seasons are equal		

Table IV-1. (Continued)

	Dry Season					
	Land Consolidated		Structurally Improved			
Equation No.	Other Field Crop (3)	Fallow Land (4)	Rice (5)	Vegetable (6)	Other Field Crop (7)	Fallow Land (8)
(0)	- 11.00		+ 94.43	+195.29	- 70.91	
(1)	+ 1.00	+ 1.00	+ 1.00	+ 1.00	+ 1.00	+ 1.00
(2)						
(3)				+ 1.00		
(4)						
(5)	+ 5.88		+ 6.69	+ 5.25		
(6)	+ 48.13		+ 42.38	+133.31	+ 36.06	
(7)	+ 14.69		+ 21.06	+119.56	+ 33.81	
(8)	+ 60.38		+ 4.13	+ 53.13	+ 17.31	
(9)	+ 56.94		+ 7.06	+ 14.69	+ 41.19	
(10)			+ 35.75		+ 9.81	
(11)			+ 24.38			
(12)						
(13)						
(14)						
(15)						
(16)						
(17)	+ 1855		+ 737	+ 707	+ 675	
(18)	+ 1822		+ 5054	+ 4849	+ 4572	
(19)	+ 1862		+ 4179	+ 4024	+ 3367	
(20)	+ 1611		+ 2468	+ 2448	+ 1648	
(21)	+ 1772		+ 1846	+ 1711	+ 1423	
(22)	+ 1898		+ 1691	+ 1720	+ 1576	
(23)	+ 1421					
(24)						
(25)						
(26)						
(27)						
(28)						
(29)	+ 88.63		+ 40.65	+ 72.74	+ 30.26	
(30)	+433.68	+433.68	+153.58	+153.58	+153.58	+153.58
(31)	+ 1.00	+ 1.00				
(32)			+ 1.00	+ 1.00	+ 1.00	+ 1.00
(33)						

Table IV-1. (Continued)

	Dry Season				Wet Season		
	Unimproved				Land Consolidated		
Equation No.	Rice (9)	Vegetable (10)	Other Field Crop (11)	Fallow Land (12)	Rice (13)	Vegetable (14)	Fallow Land (15)
(0)	- 22.92	+328.24	+ 23.84		+ 191.33	- 228.00	
(1)	+ 1.00	+ 1.00	+ 1.00	+ 1.00			
(2)					+ 1.00	+ 1.00	+ 1.00
(3)		+ 1.00					
(4)						+ 1.00	
(5)	+ 39.69	+199.19	+ 44.00			+ 88.88	
(6)	+ 12.63	+209.88	+ 47.50				
(7)	+ 6.44	+166.38	+ 22.75				
(8)	+ 6.50	+ 66.63	+ 62.06				
(9)	+ 14.69	+ 17.00	+ 94.19		+ 4.44		
(10)	+ 50.44	+ 1.19	+ 71.75		+ 24.38		
(11)					+ 32.00	+386.50	
(12)					+ 5.31	+142.06	
(13)					+ 4.00	+142.06	
(14)					+ 7.69	+177.81	
(15)					+ 31.94	+193.25	
(16)					+ 22.13	+ 71.06	
(17)	+ 13361	+ 10547	+ 5404				
(18)	+ 7183	+ 10425	+ 8338				
(19)	+ 8552	+ 9632	+ 6560				
(20)	+ 10968	+ 15983	+ 15040				
(21)	+ 9681	+ 15896	+ 14169				
(22)	+ 12545	+ 12853	+ 10693				
(23)	+ 9727	+ 7198	+ 11189				
(24)	+ 8440	+ 9755	+ 22094				
(25)	+ 7229	+ 7229	+ 7229				
(26)					+ 1259	+ 2182	
(27)					+ 1736	+ 3670	
(28)					+ 595	+ 977	
(29)	+111.55	+426.03	+124.08		+ 47.98	+395.48	
(30)					+433.68	+433.68	+433.68
(31)					- 1.00	- 1.00	- 1.00
(32)							
(33)	+ 1.00	+ 1.00	+ 1.00	+ 1.00			

Table IV-1. (Continued)

Equation No.	Wet Season: Structurally Improved: Rice (16)	Wet Season: Structurally Improved: Fallow Land (17)	Wet Season: Unimproved: Rice (18)	Wet Season: Unimproved: Vegetable (19)	Wet Season: Unimproved: Fallow Land (20)		Right Hand Side
(0)	+162.59		+112.46	-136.31			
(1)						=	48,400
(2)	+ 1.00	+ 1.00	+ 1.00	+ 1.00	+ 1.00	=	48,400
(3)						≤	1,120
(4)				+ 1.00		≤	1,120
(5)	+ 0.25		+ 0.88	+ 6.38		≤	2,198,722
(6)						≤	1,985,942
(7)						≤	2,198,722
(8)						≤	2,127,795
(9)	+ 5.94		+ 7.19	+ 8.19		≤	2,198,722
(10)	+ 12.00		+ 20.44	+ 27.81		≤	2,127,795
(11)	+ 35.50		+ 25.00	+ 39.94		≤	2,157,236
(12)	+ 6.19		+ 5.56	+ 49.13		≤	2,157,236
(13)	+ 1.94		+ 1.94	+172.50		≤	2,087,648
(14)	+ 2.38		+ 6.06	+145.81		≤	2,157,236
(15)	+ 36.25		+ 29.50	+ 91.81		≤	2,087,648
(16)	+ 15.81		+ 12.81	+ 33.50		≤	2,157,236
(17)						≤	54,432,000
(18)						≤	54,432,000
(19)						≤	54,432,000
(20)						≤	54,432,000
(21)						≤	54,432,000
(22)						≤	54,432,000
(23)						≤	54,432,000
(24)						≤	54,432,000
(25)						≤	54,432,000
(26)	+ 255		+ 760	+ 676		≤	58,320,000
(27)	+ 517		+ 1143	+ 983		≤	62,208,000
(28)			+ 650	+ 700		≤	58,320,000
(29)	+ 34.23		+ 33.31	+429.71		≤	10,933,202
(30)	+153.58	+153.58				≤	17,286,063
(31)						=	0
(32)	- 1.00	- 1.00				=	0
(33)			- 1.00	- 1.00	- 1.00	=	0

V. ANALYSIS AND RESULTS OF THE STUDY

This chapter is presented in three main sections. The first sections gives the validation of the linear programming model developed for this study. The second section deals with effects of government investment in irrigation development assumed to be 17.3 million dollars. The last section analyzes effects of varying government investment for irrigation development.

Validation of the Model

The linear programming model developed for the study is an abstract attempt to model the real situation. Therefore, it is necessary to check the model's ability to approximate the actual situation. It is not known exactly how much the government had invested in the irrigation development when the farm survey was taken, but from the discussion with irrigation officers it was estimated that the investment was more than zero but less than five million dollars. An evaluation of the validity of the model will be made, therefore, by comparing the actual results from the farm survey with the predicted results for zero and five million dollar investments.

The predicted results of the model indicated that all lands in the project must be left undeveloped at zero investment and 3157, 7364 and 37,879 hectares must be land consolidated, structurally improved and undeveloped, respectively, at five million dollar investment. In the actual situation, 576 hectares were consolidated (RID 1976a and 1977). It is not known exactly how many hectares were structurally improved. However, from the discussion with irrigation officers it was estimated that 2,400 hectares were structurally improved. Since the estimates lie between the amounts predicted at zero and five million dollar investments, the model is assumed to be a satisfactory approximation of the actual situation.

Table V-1 gives the percentage of various land use alternatives from the farm survey results and the predicted results of the linear programming model for zero and five million dollar investments for both the 1977 wet season and the 1978 dry season. For the 1977 wet season, the model gives a very close approximation of the actual situation. The predicted results indicated that all lands must be planted to rice. But the farm survey results indicated that most of the land was planted to rice and a small fraction of it was planted to vegetables and fallowed. This difference may be because vegetable production was considered by the farmers to be profitable for their own consumption as explained in Chapter III.

For the 1978 dry season, the model gives a very close approximation of the actual situation for the unimproved area. But for the land consolidated and structurally improved areas, the predicted results differ somewhat from the actual situation. This difference can be explained as follows: The predicted results of the model are

Table V-1. Actual and Predicted Percentage of Land Use Alternatives in the Nam Pong Irrigation Project, Khon Kaen, Thailand, 1977 Wet Season and 1978 Dry Season.

Land Use Alternatives	Actual (From Farm Survey)	Predicted for Zero Million Dollar Investment	Predicted for Five Million Dollar Investment
	--------Percentage-----------		
Wet Season			
Land consolidated	100.00	-	100.00
Rice production	99.26	-	100.00
Vegetable production	0.13	-	-
Fallow land	0.61	-	-
Structurally improved	100.00	-	100.00
Rice production	99.46	-	100.00
Fallow land	0.54	-	-
Unimproved	100.00	100.00	100.00
Rice production	94.34	100.00	100.00
Vegetable production	1.26	-	-
Fallow land	4.40	-	-
Dry Season			
Land consolidated	100.00	-	100.00
Rice production	44.60	-	100.00
Vegetable production	7.43	-	-
Other field crop production	6.08	-	-
Fallow land	41.89	-	-
Structurally improved	100.00	-	100.00
Rice production	26.63	-	100.00
Vegetable production	1.63	-	-
Other field crop production	4.35	-	-
Fallow land	67.39	-	-
Unimproved	100.00	100.00	100.00
Rice production	0.63	-	-
Vegetable production	3.14	2.31	2.96
Other field crop production	2.52	4.07	-
Fallow land	93.71	93.62	97.04

the results of the long term or final adjustment but the farm survey results were obtained during the transitional phase of the development. During this phase, the farmers in land consolidated and structurally improved areas had not fully adjusted themselves to the new environments and still used previous methods; therefore, they still allocated some parts of their farms to vegetables and other field crops. However, a greater proportion of their farms was planted to rice which is more consistent with the eventual long term results. Also during the transitional phase, the irrigation system was not fully developed resulting in insufficient water for the entire land consolidated and structurally improved areas. If enough time is allowed for the adjustment process, the actual results will be close to the predicted results. This can be supported by the increasing proportion of area planted to rice and the decreasing proportion of fallow land as it moved from undeveloped to developed area. Therefore, the model developed for this study is considered to have ability to approximate the actual situation.

Effects of Government Investment in the Irrigation Development

The results presented in this section are obtained by employing the linear programming model given in Chapter IV utilizing data summarized in Chapters III and IV. There are six subsections. The first states the predicted optimal irrigation development. The predicted optimal enterprise combination is given in the second subsection. The third subsection presents predicted annual returns to land and government investment, annual net benefits to government investment, benefit-cost ratios and internal rates of return from the investment. Shadow prices of limiting resources, predicted quantity of unused labor and irrigation water are discussed in the last three subsections.

Predicted Optimal Irrigation Development

Predicted optimal (economic efficient) irrigation development is presented in Table V-2. Approximately 36.86 percent of the total area in the irrigation project or 17,840 hectares are to be consolidated if maximum economic efficiency is to be obtained. Only 5,899 hectares or 12.19 percent of the total area are to be structurally improved. The other 50.95 percent of the total area or 24,661 hectares will be left undeveloped. At this level of the development all 17.3 million dollars of the budget that the government has for the development purpose will be used.

Predicted Optimal Enterprise Combination

In order to see an effect of the government investment in the irrigation development on predicted optimal enterprise combinations,

Table V-2. Predicted Optimal Irrigation Development Combination Under Alternative Amount of Government Investment in Nam Pong Irrigation Project, Khon Kaen, Thailand.

Government Investment (Million Dollars)	Area (Hectares)			
	Land Consolidated	Structurally Improved	Unimproved	Total
0	-	-	48400	48400
5	3157	7364	37879	48400
10	9729	5083	33588	48400
15	15867	4029	28504	48400
17. 3	17840	5899	24661	48400
20	20184	8118	20098	48400
25	24500	12207	11693	48400
30	27014	21386	-	48400
32	30505	17895	-	48400
35	30505	17895	-	48400

a linear programming run with zero government investment in the irrigation development was made. It represents the situation before irrigation development took place and constitutes the base run.

Predicted optimal enterprise combinations for several levels of investment (zero and 17.3 million dollars are included) are presented in Table V-3 for the dry season and Table V-4 for the wet season. In the dry season, with zero government investment, 93.62 percent of the project area or 45,311 undeveloped hectares will be left unused. The other 2.31 and 4.07 percent (1,120 and 1,969 hectares) will be used for vegetable and other field crop productions, respectively. With a 17.3 million dollar investment, the 17,840 consolidated hectares in the project will be used for rice production. Among the 5,899 hectares of the structurally improved area, only 2,268 hectares or 38.45 percent will be used for rice production. The other 3,631 hectares will be left unused. Vegetable production which is 1,120 hectares will be the land in undeveloped category. The remaining 23,541 hectares of undeveloped land will be left unused. No other field crops will be produced in the dry season. The total unused land is reduced to only 56.14 percent (27,172 hectares) when government investment is 17.3 million dollars compared with 93.62 percent (45,311 hectares) at zero investment.

In the wet season, in both cases--zero and 17.3 million dollar government investments--all lands will only be used for rice

Table V-3. Predicted Optimal Enterprise Combination in Dry Season Under Alternative Amount of Government Investment in Nam Pong Irrigation Project, Khon Kaen, Thailand.

Government Investment (Million Dollars)	Enterprise in Dry Season (Hectares)[1]												
	Land Consolidated				Structurally Improved				Unimproved				
	R	V	O	U	R	V	O	U	R	V	O	U	Total
0	-	-	-	-	-	-	-	-	-	1120	1969	45311	48400
5	3157	-	-	-	7364	-	-	-	-	1120	-	36759	48400
10	9729	-	-	-	5083	-	-	-	-	1120	-	32468	48400
15	15867	-	-	-	2953	-	-	1076	-	1120	-	27384	48400
17.3	17840	-	-	-	2268	-	-	3631	-	1120	-	23541	48400
20	20184	-	-	-	1570	104	-	6444	-	1016	-	19082	48400
25	24500	-	-	-	1047	988	-	10172	-	132	-	11561	48400
30	25143	-	-	1871	970	1120	-	19296	-	-	-	-	48400
32	25143	-	-	5362	970	1120	-	15805	-	-	-	-	48400
35	25143	-	-	5362	970	1120	-	15805	-	-	-	-	48400

[1] R = Rice, V = Vegetable, O = Other field crops, U = Unused land.

Table V-4. Predicted Optimal Enterprise Combination in Wet Season Under Alternative Amount of Government Investment in Nam Pong Irrigation Project, Khon Kaen, Thailand.

Government Investment (Million Dollars)	Enterprise in Wet Season (Hectares)[1]								
	Land Consolidated			Structurally Improved		Unimproved			
	R	V	U	R	U	R	V	U	Total
0	-	-	-	-	-	48400	-	-	48400
5	3157	-	-	7364	-	37879	-	-	48400
10	9729	-	-	5083	-	33588	-	-	48400
15	15867	-	-	4029	-	28504	-	-	48400
17.3	17840	-	-	5899	-	24661	-	-	48400
20	20184	-	-	8118	-	20098	-	-	48400
25	24500	-	-	12207	-	11693	-	-	48400
30	27014	-	-	21386	-	-	-	-	48400
32	30505	-	-	17895	-	-	-	-	48400
35	30505	-	-	17895	-	-	-	-	48400

[1] R = Rice, V = Vegetable, U = Unused.

production.

Predicted Annual Returns to Land and Government Investment, Annual Net Benefits to Government Investment, Benefit-Cost Ratios, and Internal Rates of Return

Predicted annual returns to land and government investment, annual net benefits to government investment, benefit-cost ratios and internal rates of return are presented in Table V-5. With a 17.3 million dollar investment, the annual returns to land and government investment will increase from 5,857,638 to 9,793,789 dollars. At the same time annual irrigation operation and maintenance cost is estimated to increase by 169,585 dollars. Therefore, at 17.3 million dollar investment, annual net benefits to government investment will be 3,766,566 dollars.

The project life of the development was estimated to be 30 years. (RID 1977). With this project life estimation and the market rate of interest of eight percent per year, the 17.3 million dollar irrigation development investment will yield a benefit-cost ratio of 2.31 and an internal rate of return of 21.8 percent.

Shadow Prices of Limiting Resources

One of the important features of linear porgramming is the estimation of shadow prices for various resources. The shadow price indicates which resources are scarce and which are abundant,

Table V-5. Predicted Annual Return to Land and Government Investment, Annual Net Benefit to Government Investment, Benefit-Cost Ratio, and Internal Rate of Return Under Alternative Amount of Government Investment in Nam Pong Irrigation Project, Khon Kaen, Thailand.

Government Investment (Million Dollars)	Annual Return to Land and Government Investment ($)	Annual Irrigation Operation and Maintenance Cost ($) [1]	Annual Net Return to Land and Government Investment ($) [2]	Annual Net Benefit to Government Investment ($) [3]	Benefit-Cost Ratio [4]	Internal Rate of Return [5]
0	5857638	0	5857638	0	-	-
5	7489819	39680	7450139	1592501	3.37	32
10	8439595	95338	8344257	2486619	2.62	25
15	9380529	148967	9231562	3373924	2.38	22
17.3	9793789	169585	9624204	3766566	2.31	21.8
20	10281404	194076	10087328	4229690	2.24	21
25	11159835	239177	10920658	5063020	2.16	20
30	11867823	275847	11591976	5734338	2.04	19
32	11968134	301924	11666210	5808572	1.95	18
35	11968134	301924	11666210	5808572	1.79	16

[1] Irrigation operation and maintenance cost is $9.00/hectare for land consolidated area, and $1.53/hectare for structurally improved area.

[2] Annual net return to land and government investment = Annual return to land and government investment - Annual irrigation operation and maintenance cost.

[3] Annual net benefit to government investment = Annual net return to land and government investment - 5857638.

[4] Benefit = Present value of (annual return to land and government investment - 5857638). Cost = Government investment + Present value of irrigation operation and maintenance cost. Project life = 30 years. Interest rate = 8%.

[5] Return = Annual net benefit to government investment. Cost = Government investment. Project life = 30 years.

and among scarce resources, how much the last unit of each contributes to the value of the outputs.

Shadow prices of limiting resources considered in the model are presented in Table V-6. At a zero government investment in the irrigation development and at the optimal crop production combination previously described, three resources are limited. They are land, land allowed for vegetable production in the dry season and April 27-May 10 irrigation water. Their shadow prices are 112.46 dollars per hectare, 317.71 dollars per hectare and 0.11 cents per cubic meter, respectively.

At a 17.3 million dollar investment and the corresponding optimal crop production combination, five resources are limited. They are land, land allowed for vegetable production in the dry season, government investment budget, February 2-15 irrigation water and October 16-31 irrigation water. Their shadow prices are 102.61 dollars per hectare, 133.46 dollars per hectare, 18.08 cents per dollar, 1.87 cents per cubic meter and 0.86 cents per cubic meter, respectively.

Predicted Quantity of Unused Labor

The predicted quantity of unused labor for several levels of investment and the corresponding optimal crop production combinations are presented in Table V-7. At a zero government investment,

Table V-6. Shadow Price of Limiting Resources Under Alternative Amount of Government Investment in Nam Pong Irrigation Project, Khon Kaen, Thailand.

Government Investment (Million Dollars)	Shadow Price of Limiting Resources						
	Land ($/Ha.)	Land for Vegetable in Dry Season ($/ Ha.)	Government Investment (¢/ $)	Jan. 19- Feb. 1 Irrigation Water (¢/ M^3)	Feb. 2-15 Irrigation Water (¢/M^3)	Apr. 27- May 10 Irrigation Water (¢ / M^3)	Oct. 16-31 Irrigation Water (¢ / M^3)
0	112.46	317.71	-	-	-	0.11	-
5	112.46	150.41	19.00	-	1.71	-	-
10	112.46	150.41	19.00	-	1.71	-	-
15	102.61	133.46	18.08	-	1.87	-	0.86
17.3	102.61	133.46	18.08	-	1.87	-	0.86
20	105.46	104.69	17.57	0.32	1.82	-	0.61
25	105.46	104.69	17.57	0.32	1.82	-	0.61
30	146.83	104.69	5.13	4.49	1.21	-	-
32	150.40	104.70	-	4.49	1.21	-	2.36
35	150.40	104.70	-	4.49	1.21	-	2.36

Table V-7. Predicted Quantity of Unused Labor in Each Month Under Alternative Amount of Government Investment in Nam Pong Irrigation Project, Khon Kaen, Thailand.

Government Investment (Million Dollars)	Unused Labor (Mandays) in Each Month						
	Jan.	Feb.	Mar.	Apr.	May	June	July
0	1846394	1657341	1967578	1930963	1646211	995879	947235
5	1839701	1290413	1810312	2004982	1697544	789261	668272
10	1752112	1078178	1760552	1977400	1520592	545938	701825
15	1670991	879973	1714082	1951641	1356683	327783	721861
17.3	1646299	816242	1699140	1943359	1306740	276277	705115
20	1636399	743685	1683855	1934457	1246879	211149	682434
25	1747363	630658	1672029	1924250	1132800	64670	622021
30	1770930	613830	1670269	1922730	1131674	107815	509945
32	1771802	613830	1670269	1922730	1136910	64605	522161
35	1771802	613830	1670269	1922730	1136910	64605	522161

Table V-7. (Continued)

Government Investment (Million Dollars)	Unused Labor (Mandays) in Each Month					
	Aug.	Sept.	Oct.	Nov.	Dec.	Total
0	1888131	1993752	1863932	659847	1537231	18934494
5	1884281	1987249	1885887	602436	1485718	17946056
10	1887361	1973710	1866780	601796	1431307	17097551
15	1889560	1961066	1852896	593935	1377264	16297735
17. 3	1888875	1957000	1856559	576500	1353261	16025367
20	1888063	1952173	1860908	555801	1324766	15720569
25	1886566	1943281	1868919	517668	1272269	15282494
30	1881412	1938102	1898597	449579	1221301	15116184
32	1884484	1930912	1880064	464623	1199242	15061632
35	1884484	1930912	1880064	464623	1199242	15061632

relatively large quantities of labor are unemployed in January, February, March, April, May, August, September, October and December. The unemployment among these months ranges from 71.26 percent (1,537,231 mandays) in December to 95.50 percent (1,993,752 mandays) in September. The unemployment rate is lowest in November. It is 31.61 percent (659,847 mandays). Approximately 46.80 and 43.91 percent of labor in June and July, respectively, are unemployed. The yearly unemployed labor is 18,934,494 mandays, or 73.84 percent.

At a 17.3 million dollar investment, the unemployment rate in every month, except April and August, is less than that at a zero investment. The differences in the unemployment rates in April and August between these two levels of investment are very small (less than one percent). A 17.3 million dollar investment causes a large decrease in the unemployment in the dry season planting and harvesting months (February, March, May, June and July) since more lands are used in crop production (see Table V-3). In these five months the unemployment rates are reduced to 41.10, 77.28, 59.43, 12.98 and 32.69 percent, respectively.

The effects of a 17.3 million dollar investment on the unemployment rates in January, September, October, November and December are little. The reduction in the unemployment rates in these months ranges from only 0.34 percent in October to 9.10 percent in January.

The total unemployed labor during the year decreases by 2,909,127 mandays when the investment increases from zero to 17.3 million dollars.

Predicted Quantity of Unused Irrigation Water

The predicted quantities of unused irrigation water at various levels of government investment in the irrigation development and the corresponding crop production combinations are presented in Table V-8 for the dry season and Table V-9 for the wet season. They are presented on a two-weekly basis from January 19 to May 24 for the dry season and from October 1 to November 15 for the wet season.[6]

In the dry season, the unused irrigation waters during the periods of January 19-February 1, February 2-15 and February 16-March 1 decrease considerably as the government investment increases from zero to 17.3 million dollars. The decreased quantities are 28,584,776, 26,337,210 and 16,738,989 cubic meters, respectively. The 17.3 million dollar investment will cause relatively small decreases in unused irrigation water during the periods of March 30-April 12 (1,405,002 cubic meters) and April 13-26 (4,424,728 cubic meters). The unused irrigation waters during the other four periods

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[6] Wet season data for the periods other than October 1-15, October 16-31 and November 1-15 are not available.

Table V-8. Predicted Quantity of Unused Irrigation Water in Each Period in Dry Season Under Alternative Amount of Government Investment in Nam Pong Irrigation Project, Khon Kaen, Thailand.

Government Investment (Million Dollars)	Unused Irrigation Water (M^3) in Each Period in Dry Season				
	Jan. 19-Feb. 1	Feb. 2-15	Feb. 16-Mar. 1	Mar. 2-15	Mar. 16-29
0	31, 978, 071	26, 337, 210	30, 726, 522	6, 915, 016	8, 727, 587
5	30, 547, 050	-	9, 298, 537	15, 183, 478	19, 286, 996
10	18, 393, 257	-	11, 397, 292	14, 207, 637	15, 696, 228
15	7, 042, 901	-	13, 357, 308	13, 296, 305	12, 342, 830
17. 3	3, 393, 295	-	13, 987, 533	13, 003, 274	11, 264, 575
20	-	-	14, 839, 508	13, 780, 571	11, 248, 738
25	-	-	17, 099, 875	22, 700, 589	19, 632, 953
30	-	-	17, 436, 402	24, 028, 617	20, 881, 209
32	-	-	17, 436, 402	24, 028, 617	20, 881, 209
35	-	-	17, 436, 402	24, 028, 617	20, 881, 209

Table V-8. (Continued)

Government Investment (Million Dollars)	Unused Irrigation Water (M^3) in Each Period in Dry Season				Total
	Mar. 30-Apr. 12	Apr. 13-26	Apr. 27-May 10	May 11-24	
0	18, 980, 513	24, 337, 420	-	32, 100, 534	180, 102, 873
5	24, 288, 029	41, 688, 877	40, 747, 458	46, 335, 519	227, 375, 944
10	21, 283, 562	31, 942, 039	35, 003, 199	46, 335, 519	194, 258, 733
15	18, 477, 708	22, 839, 524	29, 638, 668	46, 335, 519	163, 330, 763
17. 3	17, 575, 511	19, 912, 692	27, 913, 752	46, 335, 519	153, 386, 151
20	17, 468, 870	17, 187, 124	26, 881, 155	47, 087, 814	148, 493, 780
25	23, 690, 549	17, 150, 706	31, 734, 632	53, 480, 279	185, 489, 583
30	24, 616, 843	17, 145, 284	32, 457, 226	54, 432, 000	190, 997, 581
32	24, 616, 843	17, 145, 284	32, 457, 226	54, 432, 000	190, 997, 581
35	24, 616, 843	17, 145, 284	32, 457, 226	54, 432, 000	190, 997, 581

Table V-9. Predicted Quantity of Unused Irrigation Water in Each Period in Wet Season Under Alternative Amount of Government Investment in Nam Pong Irrigation Project, Khon Kaen, Thailand.

Government Investment (Million Dollars)	Unused Irrigation Water (M^3) in Each Period in Wet Season [1]			Total
	Oct. 1-15	Oct. 16-31	Nov. 1-15	
0	21, 536, 001	6, 886, 802	26, 860, 002	55, 282, 805
5	23, 679, 786	9, 624, 938	31, 820, 413	65, 125, 137
10	19, 248, 286	4, 299, 639	30, 699, 272	54, 247, 197
15	15, 653, 155	-	30, 351, 698	46, 004, 853
17. 3	15, 612, 457	-	31, 675, 452	47, 287, 909
20	15, 564, 141	-	33, 246, 970	48, 811, 111
25	15, 475, 128	-	36, 142, 241	51, 617, 369
30	18, 855, 561	4, 254, 670	42, 246, 443	65, 356, 674
32	15, 351, 305	-	40, 169, 717	55, 521, 022
35	15, 351, 305	-	40, 169, 717	55, 521, 022

[1] Data in other periods are not available.

in the dry season increase as the investment increases from zero to 17.3 million dollars. The increased quantities of unused water range from 2,536,988 cubic meters during the period of March 16-29 to 27,913,752 cubic meters during the period of April 27-May 10.

The overall unused irrigation water in the dry season (from January 19 to May 24) decreases from 180,102,873 to 153,386,151 cubic meters when the investment increases from zero to 17.3 million dollars.

In the wet season, the unused irrigation water increases from 26,860,002 to 31,675,452 cubic meters during the period of November 1-15 as the investment increases from zero to 17.3 million dollars. But they decrease from 21,536,001 to 15,612,457 cubic meters and from 6,886,802 cubic meters to zero during the periods of October 1-15 and October 16-31, respectively. The total unused irrigation water during the three periods in the wet season decreases from 55,282,805 to 47,287,909 cubic meters.

Effects of Varying Government Investment Budget for the Irrigation Development

In this section, the analysis will be made for the effects of varying government investment budget for the irrigation development on predicted optimal irrigation development, predicted optimal enterprise combination, predicted annual returns to land and government investment, annual net benefits to government investment, benefit-cost ratio and internal rates of return, shadow prices of limiting resources, predicted quantity of unused labor, and predicted quantity of unused irrigation water. Seven additional linear programming runs with government budget for the development assumed to be 5, 10, 15, 20, 25, 30 and 35 million dollars were made for this purpose. The reason for not having more runs after the government budget reaches 35 million dollars is that at this level of the government investment budget a portion of the budget has already been left unused.

Predicted Optimal Irrigation Development

Table V-2 shows optimal irrigation development combination for various levels of government investment. Land consolidated area shows positive relationship with the government investment. It increases as the government investment increases until it reaches the maximum of 30,505 hectares when the government investment is 32 million dollars. Unimproved area is negatively related with the government investment. It declines as the government investment increases and it reaches the minimum value of zero as the investment reaches 30 million dollars. The relationship between structurally improved area and the government investment is mixed. At five million dollar investment, structurally improved area is 7,364 hectares. It declines as the investment increases from five to ten and

15 million dollars. After that it increases as the investment increases until it reaches the maximum value of 21, 386 hectares when the investment is 30 million dollars. At 32 million dollar investment, the structurally improved area declines to 17, 895 hectares. The maximum government investment budget for the irrigation development is not to be more than 32 million dollars, ceteris paribus.

Predicted Optimal Enterprise Combination

Predicted optimal enterprise (crop production) combinations for various levels of government investment are presented in Table V-3 for the dry season and Table V-4 for the wet season. In the dry season, at zero development investment only 1, 120 and 1, 969 hectares of the unimproved area are to be used for vegetable and other field crops productions, respectively. The remaining area in the irrigation project, 45, 311 hectares of the unimproved area, is to be left unused. At five and ten million dollar development investments, all land in the consolidated and structurally improved areas should be used for rice production and 1, 120 hectares of the unimproved area for vegetable production. The remaining unimproved area should be fallow. All land in the consolidated area should always be used for rice production except at 30 and 32 million dollar investments 1, 871 and 5, 362 hectares, respectively, will be left unused. Unused land in the structurally improved area begins to occur with

1, 076 hectares at 15 million dollar investment and it increases as the investment increases until it reaches 19, 296 hectares at 30 million dollar investment. At 32 million dollar investment, it declines to 15, 805 hectares. Vegetable production begins to occupy land in the structurally improved area with 104 hectares at 20 million dollar investment. Its area increases to 988, 1, 120 and 1, 120 hectares when investments are at 25, 30 and 32 million dollars, respectively. Rice production occupies the remaining structurally improved area. With the exception of the zero investment, only vegetables are produced in the unimproved area. It occupies 1, 120 hectares of land in this category when the investment is from zero to 17.3 million dollars. When the investment increases to 20 and 25 million dollars its area declines to 1, 016 and 132 hectares, respectively. The major portion of land in the unimproved area, ranging from 93.62 to 98.87 percent depending on the levels of investment, is left unused in the dry season.

In the wet season, all lands in all development categories are to be used only for rice production. No fallow land or other crop production should occur in this season.

Predicted Annual Returns to Land and Government Investment, Annual Net Benefits to Government Investment, Benefit-Cost Ratios, and Internal Rates of Return

Table V-5 shows annual returns to land and government investment, annual net benefits to government investment, benefit-cost ratios and internal rates of return for various levels of government investment in the irrigation development and the corresponding optimal crop production combinations. Both annual returns to land and government investment and annual net benefits to government investment have positive relationship with the government investment. But as the government investment increases their rates of increase decline until they reach zero when the government investment is 32 million dollars. At this level of government investment, annual returns to land and government investment and annual net benefits to government investment are 11,968,134 and 5,808,572 dollars, respectively.

The relationship between government investment and benefit-cost ratio is shown in Figure V-1. At five million dollar investment the benefit-cost ratio is quite high (3.37). Then, it decreases as the investment increases. The rates of decrease are high when the investments are between five to ten million dollars and low between 15 to 30 million dollars. Between ten to 15 and 30 to 32 million dollar investments the rates of decrease in benefit-cost ratio are at

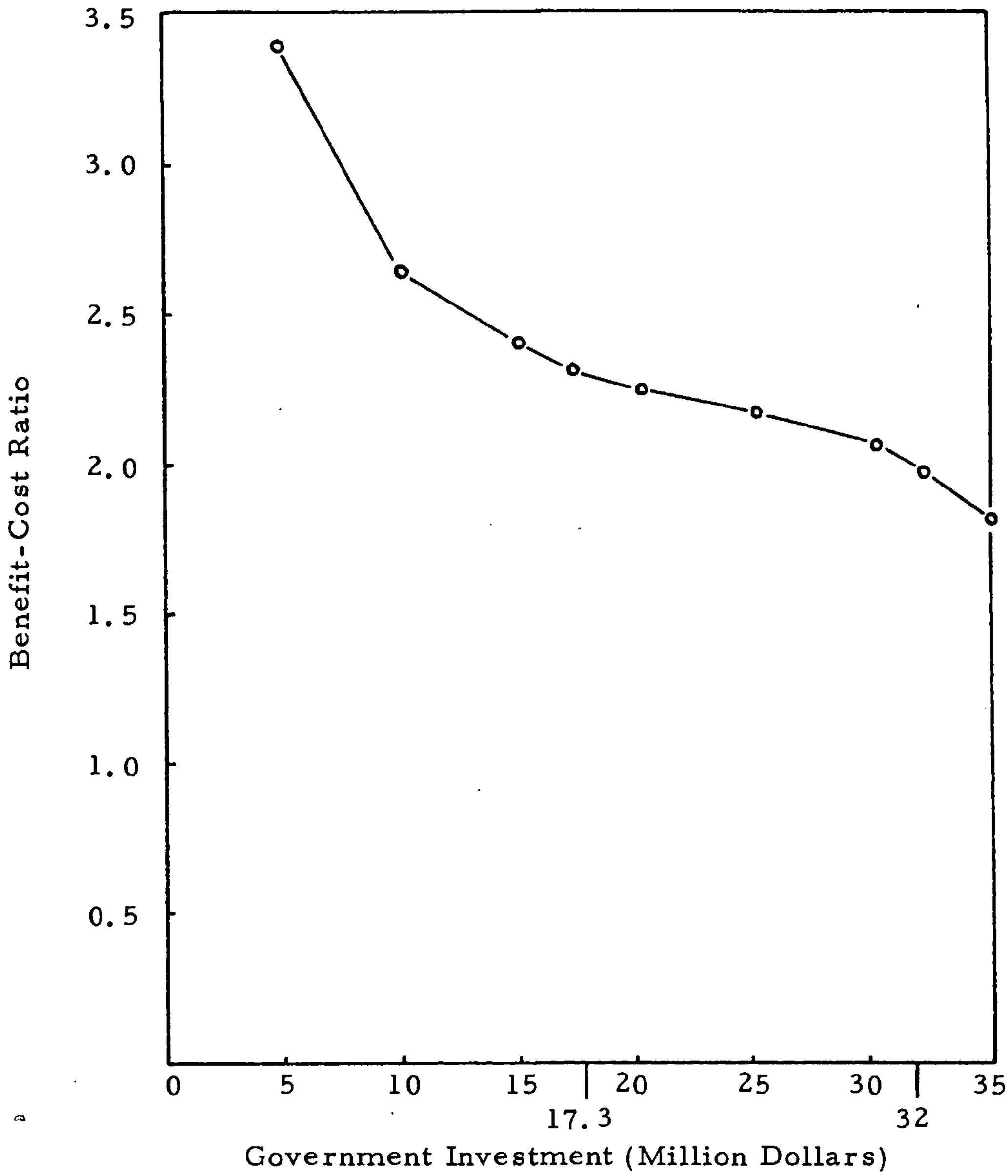

Figure V-1. Relationship between government investment in irrigation development and benefit-cost ratio.

intermediate level. At 32 million dollar investment, which is the maximum investment required for the irrigation development, the benefit-cost ratio is 1.95.

Figure V-2 shows the relationship between government investment and internal rate of return. This relationship is similar to the relationship between government investment and benefit-cost ratio described above. At five million dollar investment the internal rate of return is 32 percent. It decreases as the investment increases. The rates of decrease are high when the investments are between five to ten million dollars and low between 15 to 30 million dollars. Between ten to 15 and 30 to 32 million dollar investments the rates of decrease in internal rate of return are at intermediate level. The internal rate of return at 32 million dollar investment is 18 percent.

Shadow Prices of Limiting Resources

The shadow prices of limiting resources are presented in Table V-6. The shadow price of land does not change much between zero to 25 million dollar investment in the irrigation development. It ranges from 102.61 dollars per hectare when the investments are at 15 and 17.3 million dollars to 112.46 dollars per hectare when the investments are at zero, five and ten million dollars. It increases sharply from 105.46 dollars per hectare at 25 million dollar investment to 146.83 dollars per hectare at 30 million dollar investment

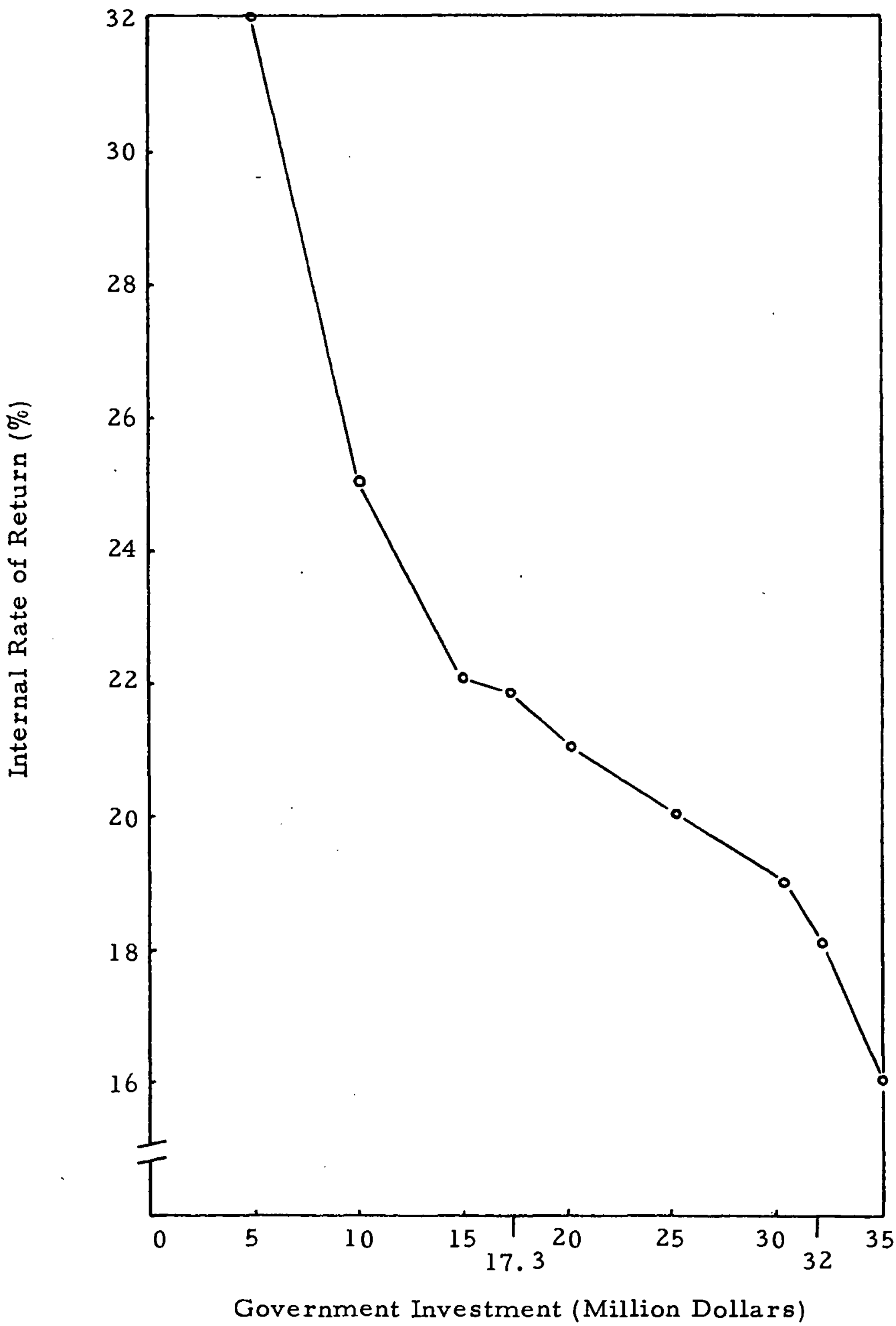

Figure V-2. Relationship between government investment in irrigation development and internal rate of return.

since there is no more unimproved land available for rice production in the wet season (see Table V-4). At 32 million dollar investment it is 150.40 dollars per hectare.

The shadow price of land for vegetable production has negative relationship with the government investment since vegetable production in the unimproved area in the dry season yields the highest return per hectare but it needs considerable resources (see Tables III-12, III-14 and III-18), therefore, when the irrigation project is developed and the available resources are used for other production activities, resources become more scarce for the vegetable production and consequently cause a decline in the shadow price of land for vegetable production. At zero investment, the shadow price of land for vegetable production is 317.71 dollars per hectare. It drops very quickly to 150.41 dollars per hectare at five and ten million dollar investments. Then, it declines again to 133.46 dollars per hectare at 15 and 17.3 million dollar investments and to 104.69 dollars per hectare at 20 million dollar investment. After that it is stable.

The shadow price of the government investment budget also had negative relationship with the investment. It is 19.00 cents per dollar at five and ten million dollar investments. It declines very slowly to 18.08 cents per dollar at 15 and 17.3 million dollar investments and to 17.57 cents per dollar at 20 and 25 million dollar investments. Then, it drops very quickly to 5.13 and zero cents per dollar at 30 and 32 million dollar investments, respectively.

Of all the 12 irrigation water supplies, only four of them are limited at some levels of the government investment. They are January 19-February 1, February 2-15, April 27-May 10 and October 16-31 supplies. The relationships between the shadow prices of these four supplies and the government investment are presented in Figure V-3. January 19-February 1 irrigation water supply has no value until the government investment reaches 20 million dollars. At that level of the investment its price is only 0.32 cents per cubic meter. It increases to 4.49 cents per cubic meter when the investment is 30 million dollars. Then, it remains unchanged.

The shadow price of February 2-15 irrigation water supply is zero at zero government investment. At five million dollar investment, it is 1.71 cents per cubic meter. It is almost stable when the investments are in between five to 25 million dollars. Then, it declines to 1.21 cents per cubic meter at 30 million dollar investment and remains unchanged onwards.

April 27-May 10 irrigation water has no value in crop production except at zero government investment which is only 0.11 cents per cubic meter. The prices of October 16-31 irrigation water are zero between zero to ten million dollar government investment. At

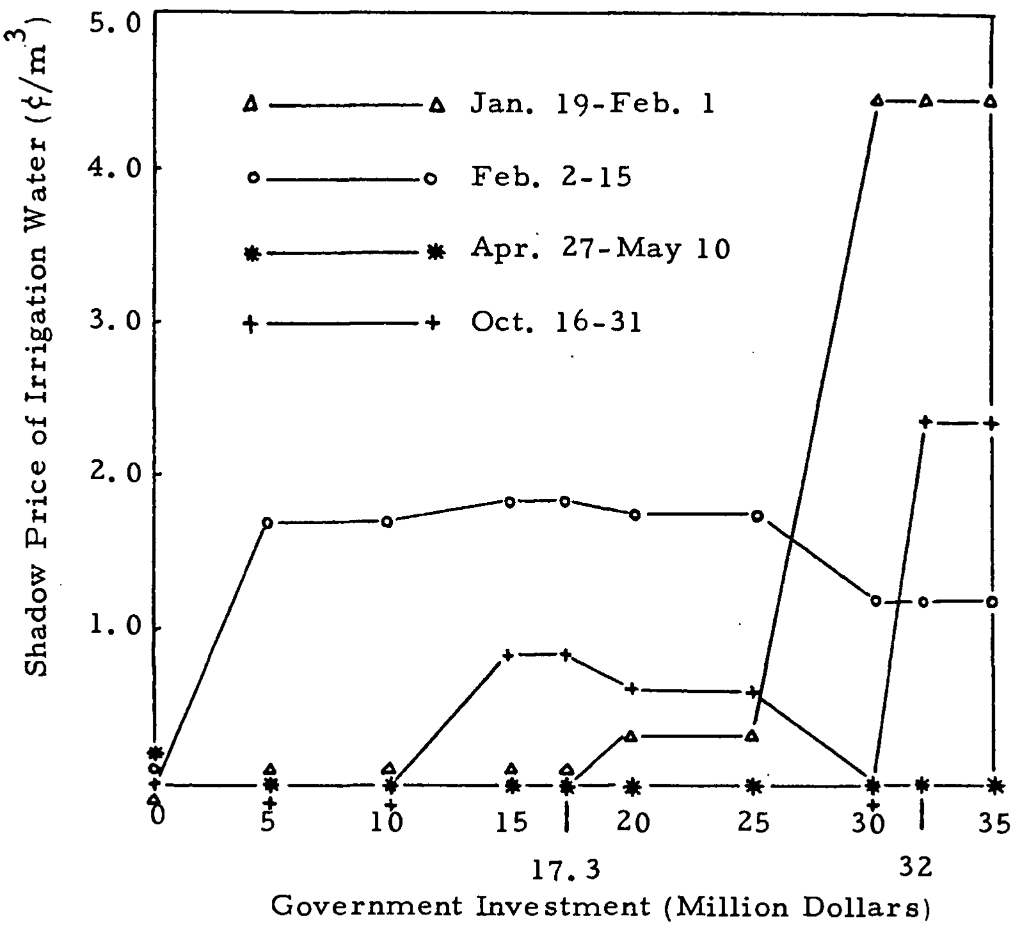

Figure V-3. Relationship between government investment in irrigation development and shadow price of irrigation water.

15 million dollar government investment, it is 0.86 cents per cubic meter and it remains almost unchanged until the investment reaches 30 million dollars it drops to zero again. Then, it again increases to 2.36 cents per cubic meter at 32 million dollar government investment.

It should be noted that the changes in shadow prices of all these limiting resources depend on the level of the government investment and the optimal crop combination corresponding to the level of the investment as well.

Predicted Quantity of Unused Labor

Predicted quantities of unused labor for various levels of the government investment in the irrigation development and the corresponding optimal crop production combinations are presented in Table V-7. The effect of the government investment in the irrigation development on the quantity of unused labor varies considerably from month to month. The government investment has a very little effect on the quantities of unused labor in the months of April, August, September and October. For example, in April unused labor is reduced from 2,004,982 to only 1,922,730 mandays when the government investment increases from five to 32 million dollars. It also has a relatively little effect on unused January and March labors. In January, unused labor decreases from 1,846,394 to 1,636,399 mandays when the government investment increases from zero to 20 million dollars. The intermediate effect of the government investment on unused labor is observed in the months of May, November and December. In May, when the government investment increases from five to 20 million dollars unused labor decreases from 1,697,544 to 1,246,879 mandays. Unused labor in February, June and July is affected by the government investment. June unused labor decreases from 995,879 to 64,605 mandays when the government investment increases from zero to 32 million dollars. From the results described it is noticed that the government investment has more effect on the unused labors in planting and harvesting months (February, May, June, July, November and December) than in other months.

For the total unused labor during the year, there is a negative relationship between government investment and the quantity of unused labor. At low levels of the government investment, the marginal decrease in the quantity of unused labor per unit of government investment is higher than that at the high levels of the government investment.

Predicted Quantity of Unused Irrigation Water

Predicted quantities of unused irrigation water for various levels of the government investment in the irrigation development and the corresponding optimal crop production combinations are presented in Table V-8 for the dry season and in Table V-9 for the wet season. In the dry season, the relationships between the government investment and the quantity of unused irrigation water are different for different periods of water supply. This is due to the influences of the optimal combinations of irrigation development and crop production selected by the linear programming model (see Tables V-2 and V-3). Quantities of unused irrigation water during the periods of January 19-February 1, February 2-15 and April 13-26 decline consistently as the government investment increases. The relationships between the government investment and quantity of unused water during the periods of March 2-15, March 16-29, March 30-April 12 and April 27-May 10 are mixed. As the government investment increases the quantities of unused water in these four periods first decline then they increase when the government investment is approximately 20 million dollars. Quantities of unused irrigation water during the periods of February 16-March 1 and May 11-24 have positive relationship with the government investment. They increase as the government investment increases. With the exception of zero government investment, the overall quantity of unused irrigation water during the nine periods mentioned above first declines as the government investment increases and then it increases when the investment is beyond 20 million dollars.

In the wet season, the government investment in the irrigation development does not have much influence on the quantity of unused irrigation water and there is no clear pattern of the relationship between them. This may be due to the fact that water needed for crop production in the wet season comes mostly from rainfall.

VI. CONCLUSIONS AND RECOMMENDATIONS

Summary and Conclusions

The objectives of this thesis were to: (1) determine, given a fixed government investment in the Nam Pong Irrigation Project, the investment mix between consolidated, structurally improved and unimproved lands and the crops to be grown on these lands which will maximize returns to land and government investment: (2) evaluate the value of irrigation water in crop production for various periods of water supply from the Nam Pong Irrigation Project; (3) evaluate an effect of the irrigation development on employment and the irrigation water utilization; and (4) examine changes in the irrigation development, returns to land and government investment, land use alternatives, value of irrigation water, employment and irrigation water utilization resulting from the variation in the government investment.

A two-stage sampling procedure was employed to obtain 181 representative farms. Ninety-three farms were selected from the unimproved area. The land consolidated and the structurally improved areas were each represented by 44 farms.

The study covers one year (the 1977 wet season and the 1978 dry season) utilizing information obtained from a farm survey, the RID-IRRI water management research program for Northeast

Thailand, and various offices of Thailand Royal Irrigation Department.

A linear programming model was developed for this study. The model consists of three main irrigation development activities: (a) land consolidation, (b) structural improvement, and (c) unimprovement. In the dry season, each of these three main activities includes four minor land use alternatives--rice production, vegetable production, other field crop production, and fallow land. During the wet season, both the land consolidation and unimprovement activities have three land use alternatives--rice production, vegetable production, and fallow land. The structural improvement activity has only rice production and fallow land use alternatives in the wet season.

The constraints included in the model are land, area allowed for vegetable production, labor, irrigation water, cash operating capital, government budget and the equality between the developed areas in the dry and the wet seasons.

Effects of the 17.3 Million Dollar Government Investment in the Irrigation Development

At the assumed 17.3 million dollar government investment, the optimal irrigation development is that 17,840 hectares be consolidated, 5,899 hectares be structurally improved and the remaining 24,661 hectares be left undeveloped. In the dry season, all the 17,840 consolidated hectares are to be used for rice production. About 38.45

percent or 2, 268 hectares of the structurally improved land will be used for rice production. The other 3, 631 hectares will be left unused. Only 1, 120 hectares of the unimproved land are to be used for vegetable production. The remaining 23, 541 hectares of the undeveloped land will be left unused. Comparing this situation with the zero investment situation (the situation before the irrigation development took place) when only 1, 120 and 1, 969 hectares will be used for vegetable and other field crop productions, respectively, it is seen that with the 17. 3 million dollar investment higher proportion of land in the project will be utilized (43. 86 percent versus 6. 38 percent). But in the wet season, in both zero and 17. 3 million dollar investment cases, all lands will be used for rice production.

With the 17. 3 million dollar investment, the annual returns to land and government investment will increase from 5, 857, 638 to 9, 793, 789 dollars. At the same time annual irrigation operation and maintenance cost was estimated to increase by 169, 585 dollars. Therefore, at 17. 3 million dollar investment, annual net benefits to government investment will be 3, 766, 566 dollars.

With a project life of 30 years and an annual interest rate of eight percent, the 17. 3 million dollar development investment will yield a benefit-cost ratio of 2. 31 and an internal rate of return of 21. 8 percent.

At a zero investment, only April 27-May 10 irrigation water has a value in agricultural production. It is 0.11 cents per cubic meter. When the investment is at 17.3 million dollars, the value of the irrigation water in agricultural production changes due to the change in the optimal crop production combination. The value of April 27-May 10 irrigation water becomes zero but February 2-15 and October 16-31 irrigation waters have the value of 1.87 and 0.86 cents per cubic meter, respectively. The value of the government investment is 18.08 cents per dollar at 17.3 million dollar investment.

The 17.3 million dollar investment causes a reduction in the unemployment by 2,909,127 mandays per year (from 18,934,494 to 16,025,367 mandays). This reduction comes mostly from the decrease in the unemployment in the dry season planting and harvesting months (February, March, May, June and July) since more lands are used in crop production.

The unused irrigation water in the dry season (from January 19 to May 24) decreases from 180,102,873 cubic meters at zero investment to 153,386,151 cubic meters at 17.3 million dollar investment. During the period of October 1 to November 15 in the wet season, it decreases from 55,282,805 to 47,287,909 cubic meters.

Effects of Varying Government Investment in the Irrigation Development

The maximum government investment in the irrigation development is not to be more than 32 million dollars, *ceteris paribus*.

Consolidated land is positively related with the government investment. It increases as the government investment increases and reaches the maximum of 30,505 hectares when the investment is 32 million dollars. Unimproved area is negatively related with the investment. Its minimum value is zero when the investment is 30 million dollars. The relationship between structurally improved area and government investment is mixed. At five million dollar investment, it is 7,364 hectares. It declines as the investment increases from five to ten and 15 million dollars. Then it increases as the investment increases until it reaches the maximum of 21,386 hectares when the investment is 30 million dollars. At 32 million dollar investment, it declines to 17,895 hectares.

In the dry season, except at 30 and 32 million dollar investments, all the consolidated land will be used for rice production. Unused land in structurally improved area begins to occur with 1,076 hectares at 15 million dollar investment and it increases as the investment increases until it reaches 19,296 hectares at 30 million dollar investment. At 32 million dollar investment, it declines to 15,805 hectares. Vegetable production begins to occupy land in the structurally improved area with 104 hectares at 20 million dollar investment. Its area increases to 988, 1,120 and 1,120 hectares when the investments are at 25, 30 and 32 million dollars, respectively. Rice production occupies the remaining structurally improved area. With the exception of the zero investment, only vegetables are produced in the unimproved area. It occupies 1,120 hectares of land in this category when the investment is from zero to 17.3 million dollars. When the investment increases to 20 and 25 million dollars its area declines to 1,016 and 132 hectares, respectively. The major portion of the unimproved land is left unused in the dry season.

In the wet season, all lands are used for rice production. No fallow land or other crop production occurs in this season.

Both annual returns to land and government investment and annual net benefits to government investment are positively related with the government investment. At zero investment, they are 5,857,638 and zero dollars, respectively. They increase to 11,968,134 and 5,808,572 dollars, respectively, at 32 million dollar investment.

Both the benefit-cost ratio and the internal rate of return are negatively related with the government investment. They are 3.37 and 32 percent, respectively, when the investment is 5 million dollars. At 32 million dollar investment, they decline to 1.95 and 18 percent, respectively.

January 19-February 1 irrigation water has no value in agricultural production until the government investment reaches 20 million dollars. At that level of investment its price is 0.32 cents per cubic meter. It increases to 4.49 cents per cubic meter when the investment is 30 million dollars. Then, it remains unchanged.

The shadow price of February 2-15 irrigation water is zero at zero government investment. At five million dollar investment, it is 1.71 cents per cubic meter. It is almost stable when the investment is between five and 25 million dollars. Then, it declines to 1.21 cents per cubic meter at 30 million dollar investment and remains unchanged onwards.

April 27-May 10 irrigation water has no value in crop production except at zero government investment which is only 0.11 cents per cubic meter. The prices of October 16-31 irrigation water are zero between zero and ten million dollar government investment. At 15 million dollar investment, it is 0.86 cents per cubic meter and it remains almost unchanged until the investment reaches 30 million dollars it drops to zero. Then, it again increases to 2.36 cents per cubic meter at 32 million dollar investment.

At zero government investment, the unemployment is 18,934,494 mandays per year. It declines consistently as the investment increases and reaches the minimum of 15,061,632 mandays per year at 32 million dollar investment. The government investment has more effect on the unemployment in planting and harvesting months (February, May, June, July, November and December) than in other months.

In the dry season, the relationship between the government investment and the quantity of unused irrigation water are different for different periods of water supply. This is due to the influences of the optimal combinations of irrigation development and crop production selected by the linear programming model. With the exception of zero investment, the overall unused irrigation water in the dry season first declines as the investment increases and then it increases when the investment is beyond 20 million dollars.

In the wet season, the investment does not have much influence on the quantity of unused irrigation water. This is due to the fact that water needed for crop production in the wet season comes mostly from rainfall.

The major conclusions of this study are:

1. The maximum government investment in the irrigation development is not to be more than 32 million dollars, ceteris paribus.

2. The investment in the irrigation development causes a higher cropping intensity (land utilization) and employment than without the investment.

3. Annual return to land and the investment and annual net benefit to the investment increase as the investment increases and they reach the maximum at 32 million dollar investment. At that level of investment, benefit-cost ratio is 1.95 and internal rate of return is 18 percent.

4. The investment in the irrigation development causes irrigation water to be more valuable in crop production than without the investment.

Limitations of the Study

This study has three important limitations. The first one concerns an aggregation problem, i.e., the study aggregated all kinds of vegetables grown in the irrigation project as one group of crops and all kinds of other field crops as another group. These aggregations were forced to be done because the number of farms in the sample that were planted to each kind of these crops was not large enough to represent a group of farms. Because of this aggregation, the study could not specify how many hectares are to be planted to each kind of these crops. As a result of this problem, the optimal irrigation development, the optimal crop production combination, the returns and benefits to the investment, the benefit-cost ratio, the internal rate of return, the shadow prices of resources, the quantity of unused labor, and the quantity of unused irrigation water differ from what they would be if this problem did not exist.

The second limitation is the lack of the wet season irrigation water coefficients for the periods before October 1, 1977 resulted from the unavailability of irrigation water data from the RID-IRRI water management research program for Northeast Thailand. This limitation also affected the results of the study.

The third limitation is that the study could not directly estimate the irrigation water coefficients for rice, vegetables, and other field crops because the quantity of irrigation water used by each group of these crops within a selected irrigation unit could not be measured due to the lack of a measuring device for irrigation water at a farm level. The quantity of irrigation water could be measured only for each of the selected irrigation units. Therefore, the irrigation water coefficients for rice, vegetables, and other field crops were indirectly estimated by first, for each irrigation development category, computing the coefficient for the units that planted only rice, or only vegetables, or only other field crops. Then, this coefficient was substituted into the units that planted rice and vegetables, or rice and other field crops, or vegetables and other field crops and the coefficient for the second group of crops was computed. Finally, the coefficients for the two groups of crops were substituted into the units that planted rice, vegetables, and other field crops and the coefficient for the third group of crops was computed.

Recommendations

Although this study has provided some basic findings, it also involves a problem of application. That is the question remains of how to meet the optimal irrigation development and crop production combinations indicated in the study. If the whole irrigation project area were one farm, this kind of problem would not exist. But this is not the case, many farms are operating in the project area. The government's decision affects all the farmers in the project area. Some of them will gain as a result of that decision while the others will lose. A further study of the welfare economics implications of the government decisions would be useful.

Additionally, a more complete and detailed study than the one covered in this thesis would be valuable. This study should give consideration to:

1. having a larger sample size so it will have enough number of farms in the sample that are planted to each particular kind of vegetables and other field crops. Then, an area that is to be planted to each kind of these crops can be specified.

2. including the irrigation water coefficients in other periods of the wet season that were not included in this thesis because of the unavailability of data.

3. measuring the quantity of irrigation water used by each kind of crops at a farm level.

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APPENDIX

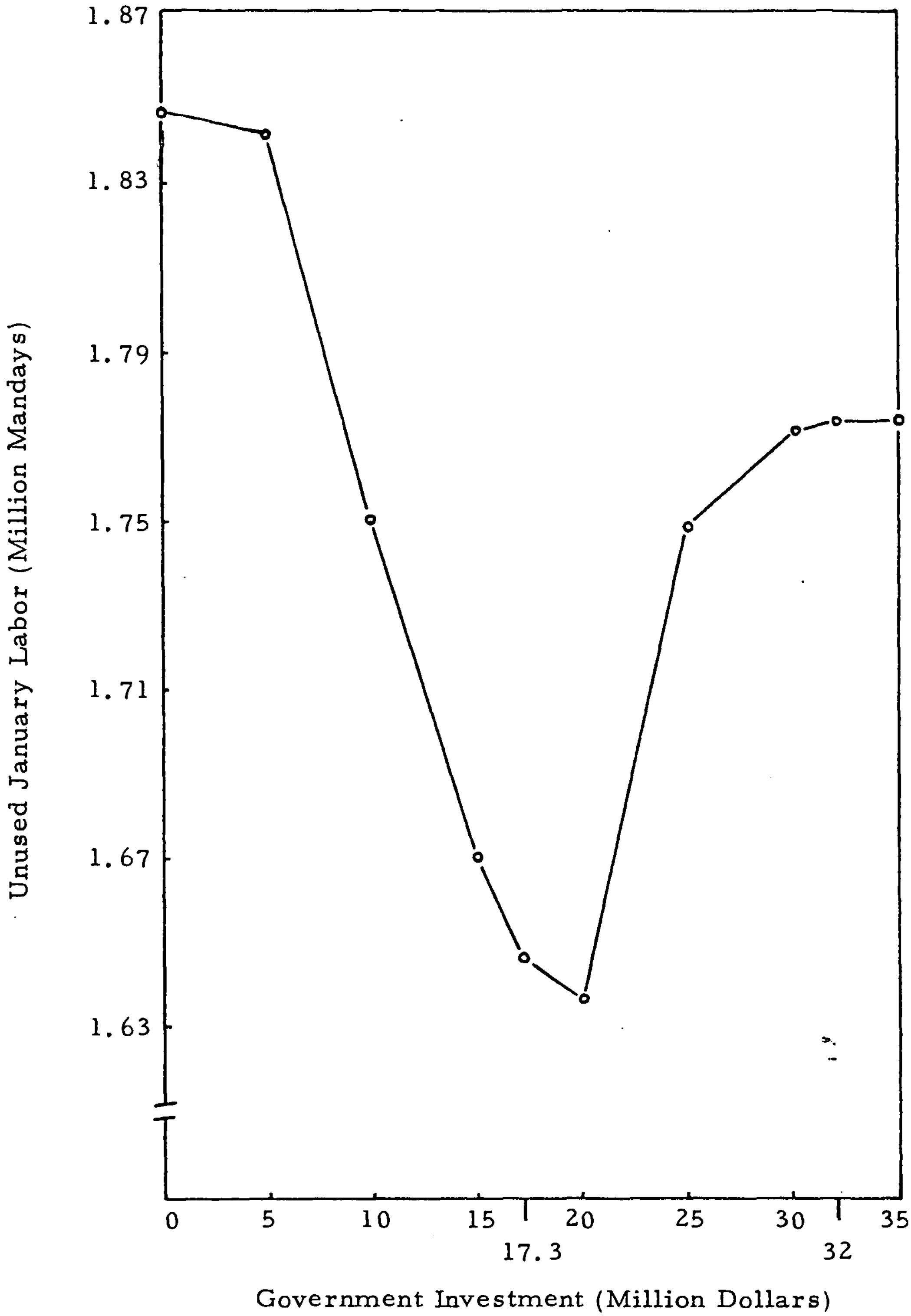

Figure A-1. Relationship between government investment in irrigation development and unused January labor.

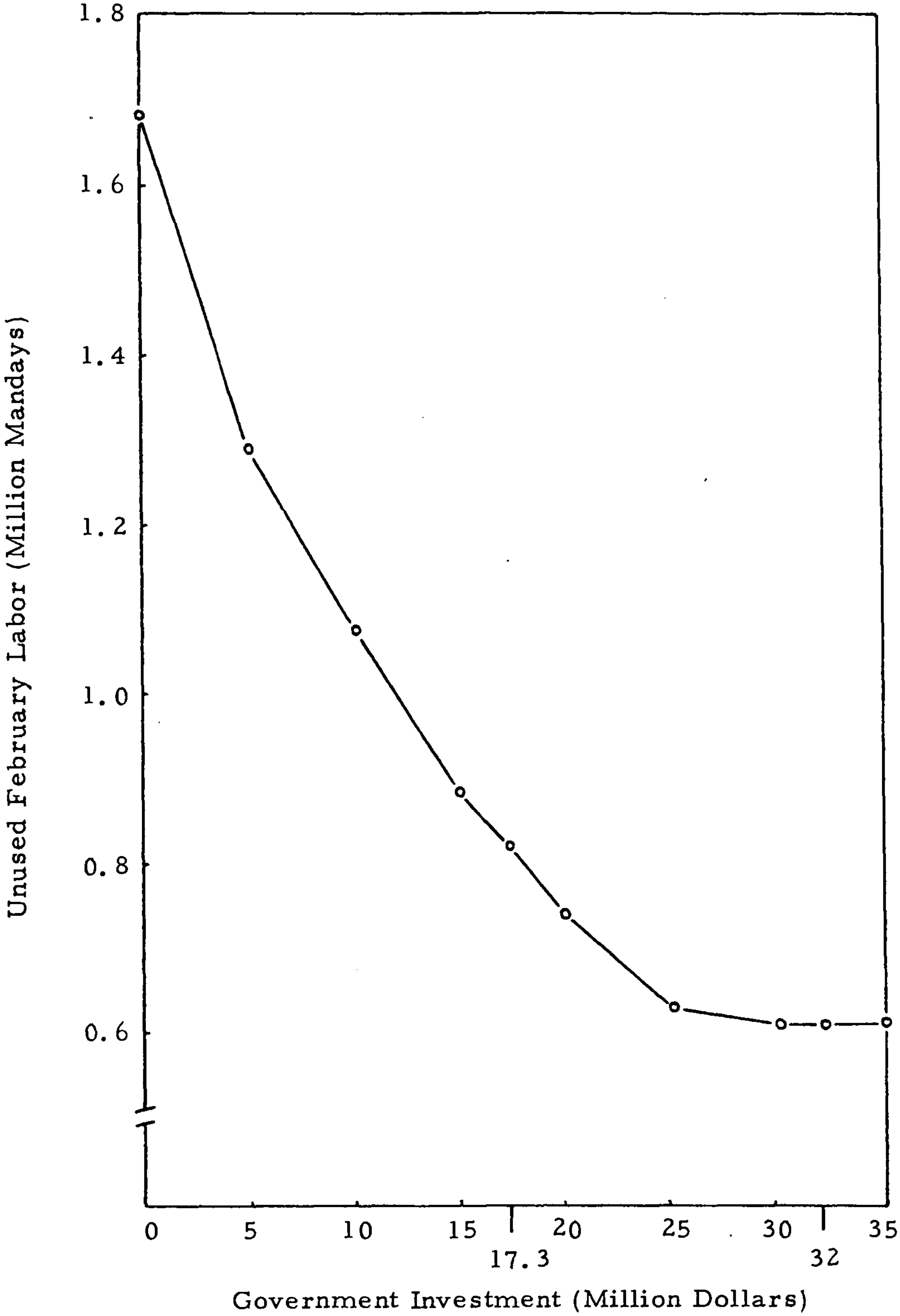

Figure A-2. Relationship between government investment in irrigation development and unused February labor.

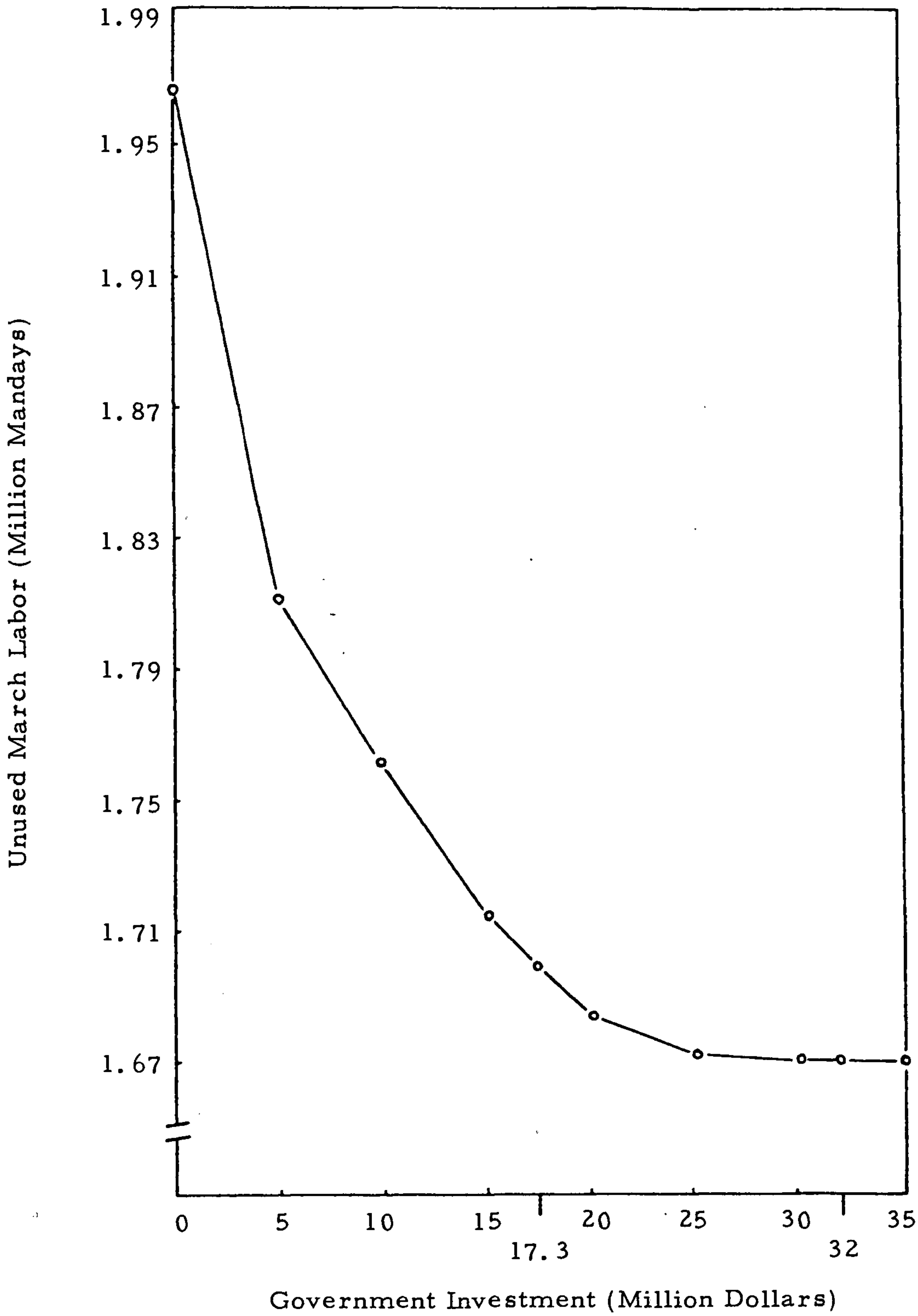

Figure A-3. Relationship between government investment in irrigation development and unused March labor.

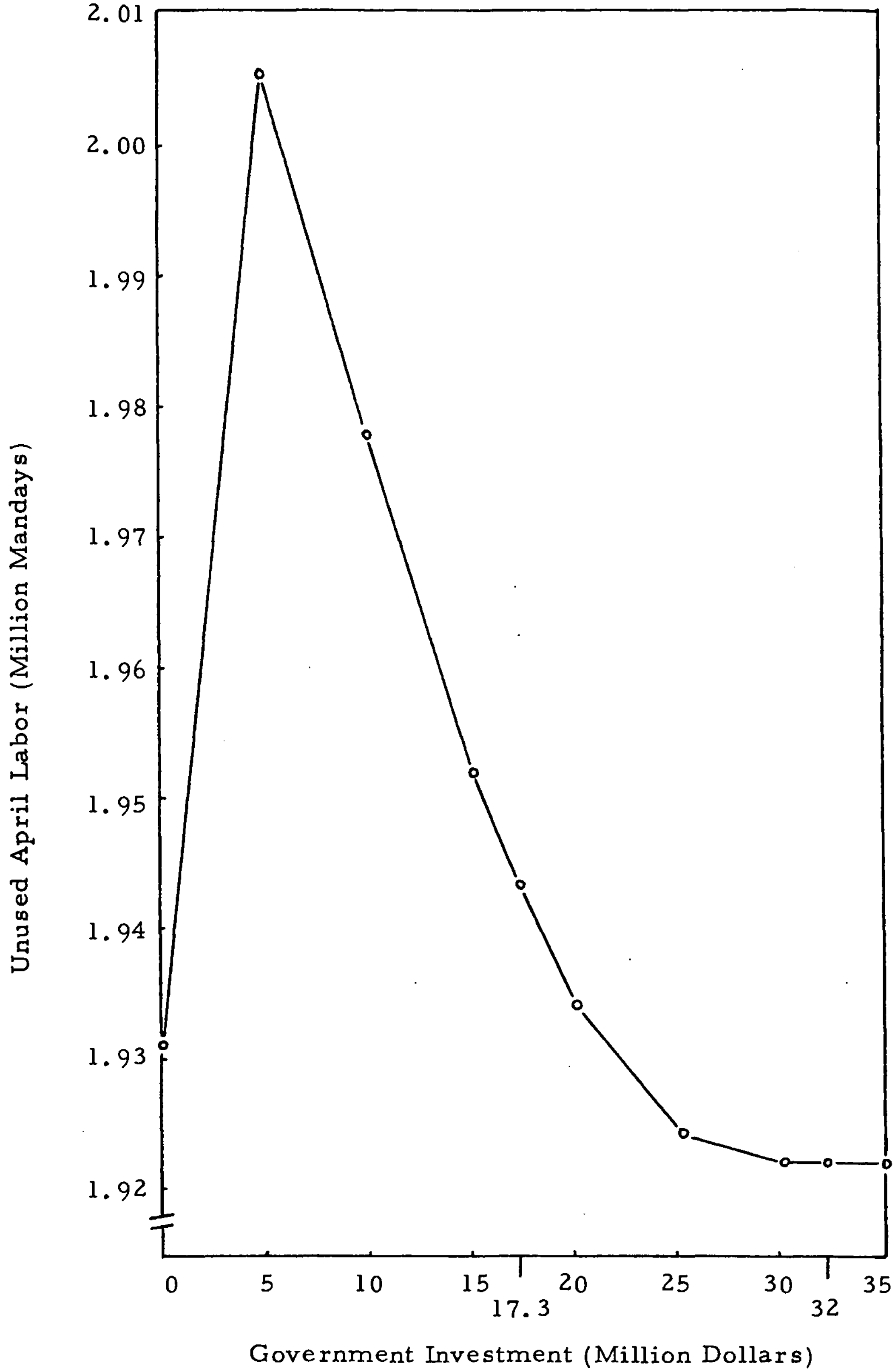

Figure A-4. Relationship between government investment in irrigation development and unused April labor.

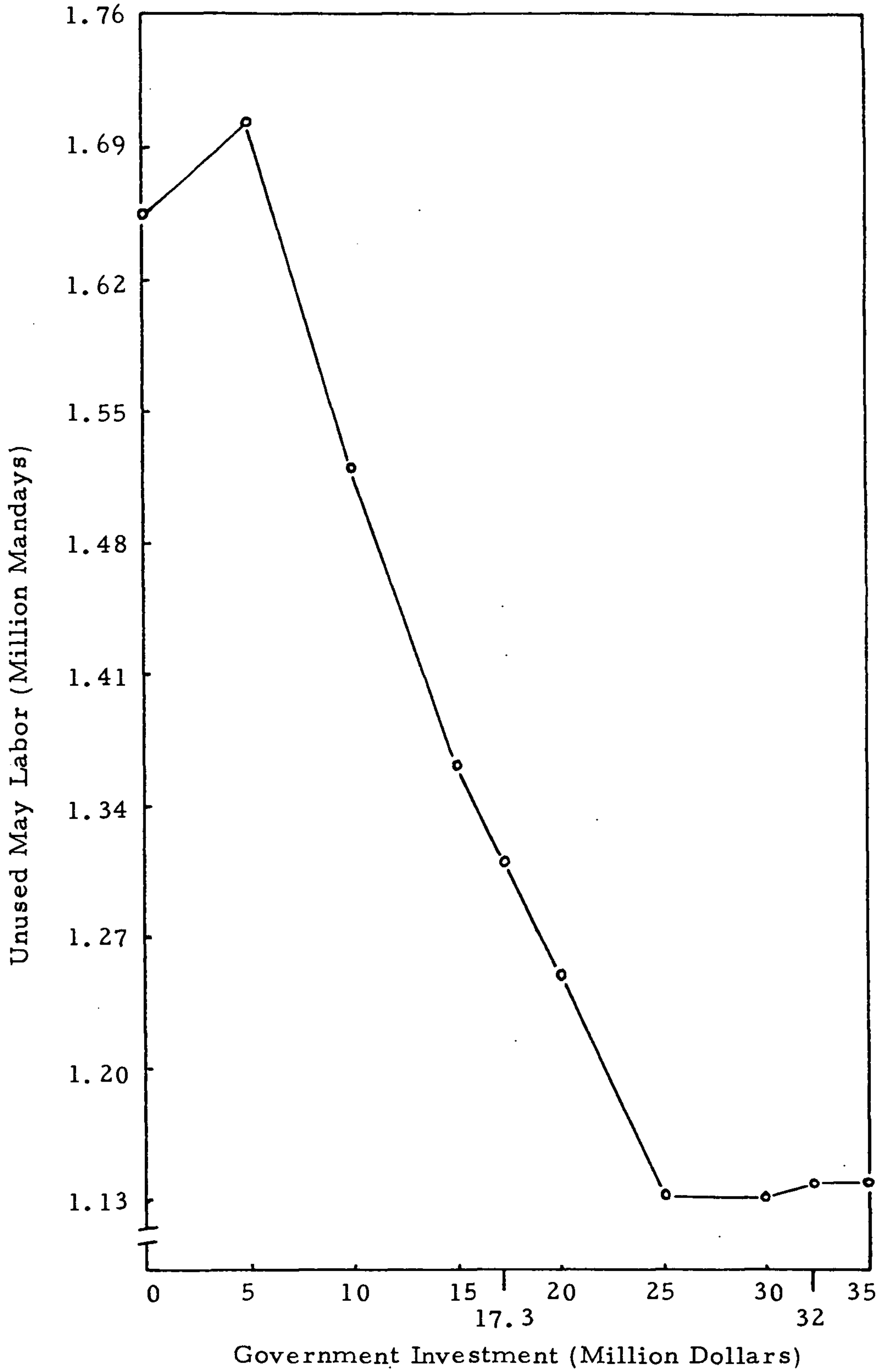

Figure A-5. Relationship between government investment in irrigation development and unused May labor.

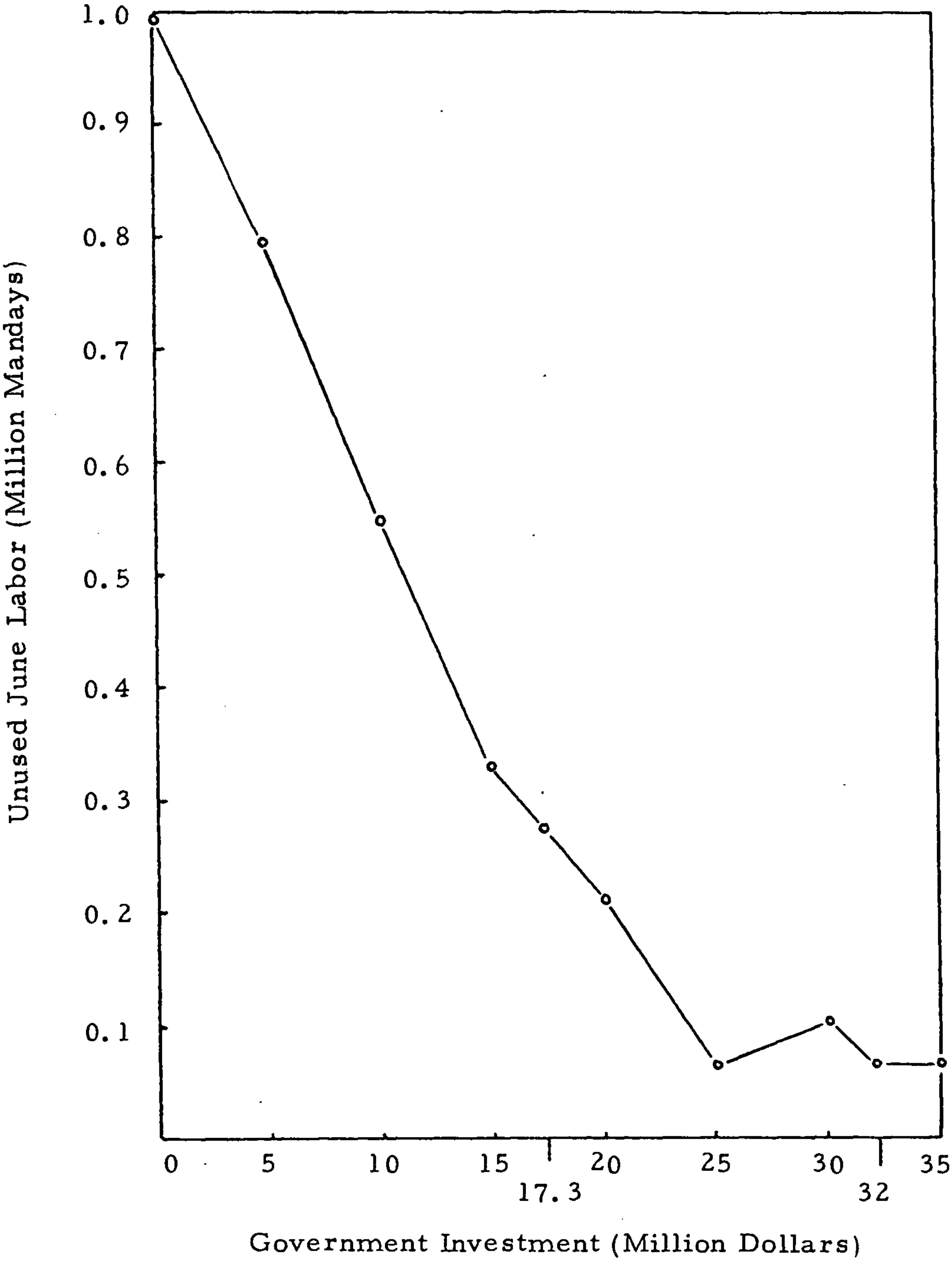

Figure A-6. Relationship between government investment in irrigation development and unused June labor.

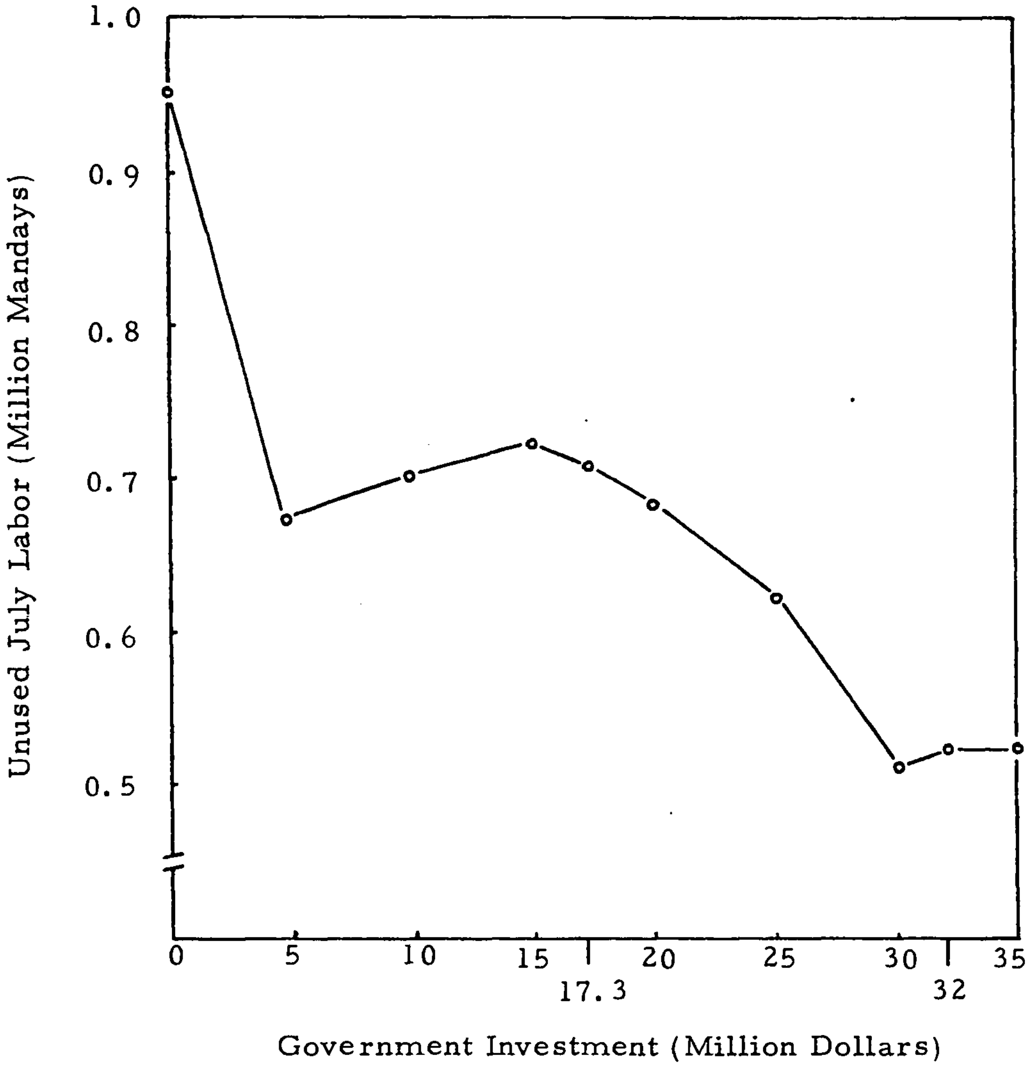

Figure A-7. Relationship between government investment in irrigation development and unused July labor.

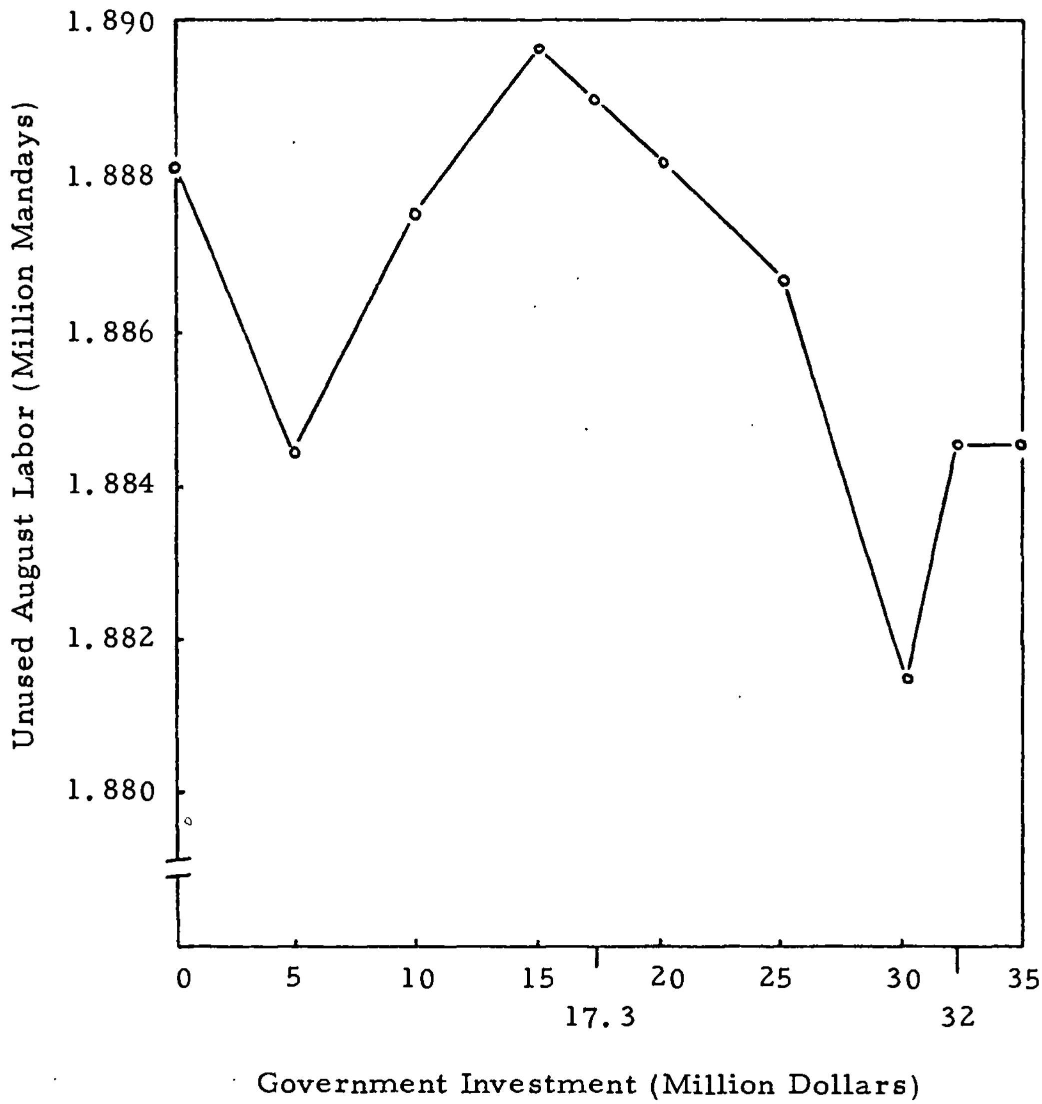

Figure A-8. Relationship between government investment in irrigation development and unused August labor.

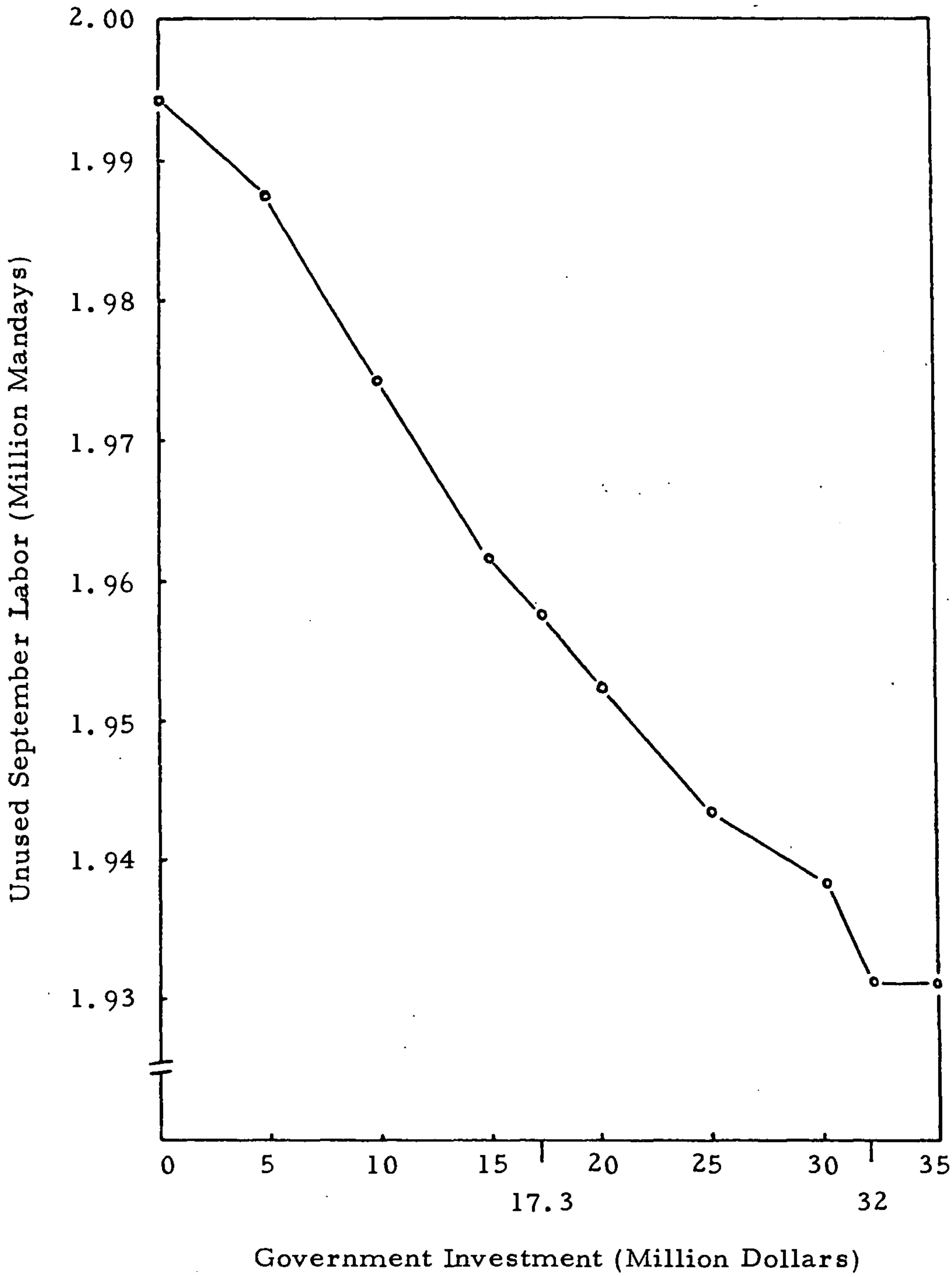

Figure A-9. Relationship between government investment in irrigation development and unused September labor.

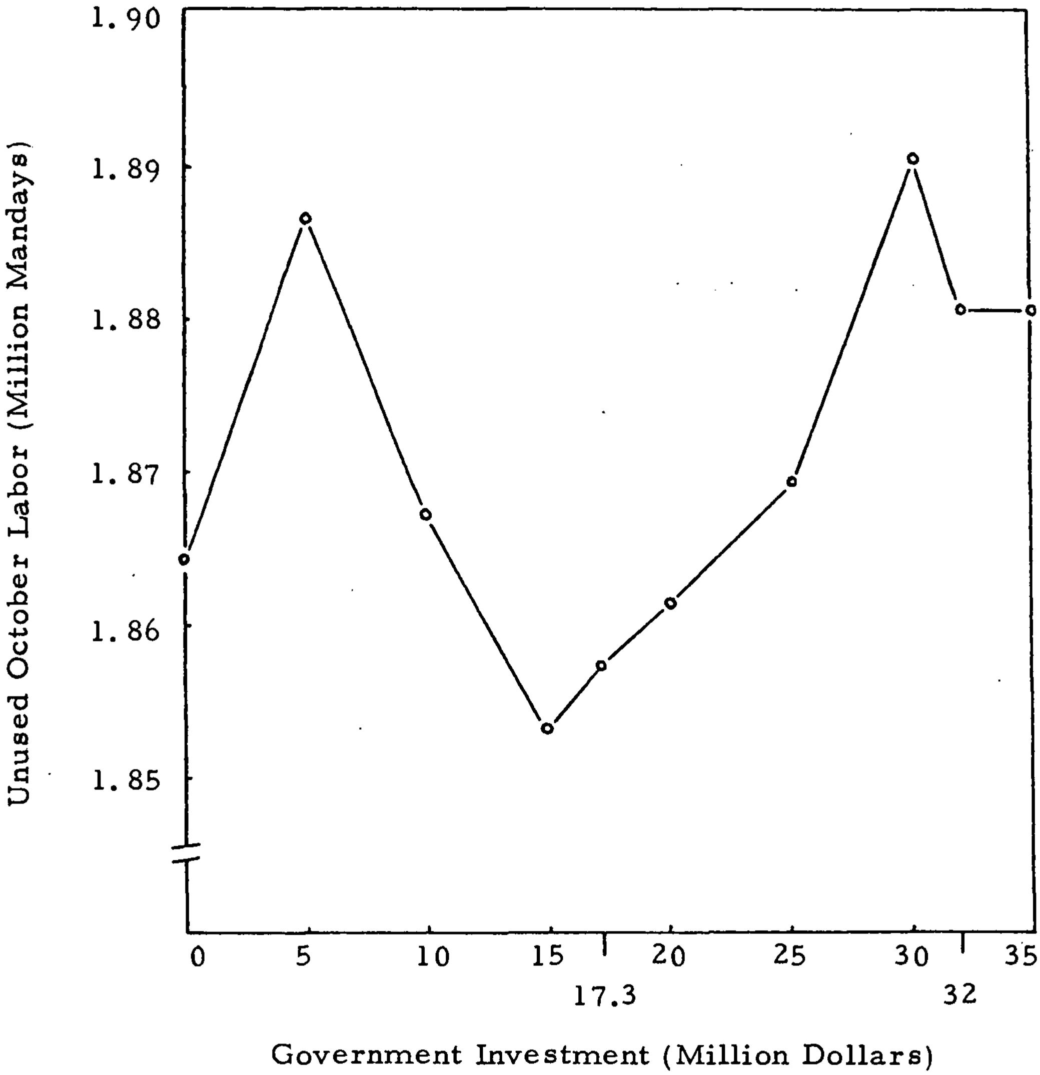

Figure A-10. Relationship between government investment in irrigation development and unused October labor.

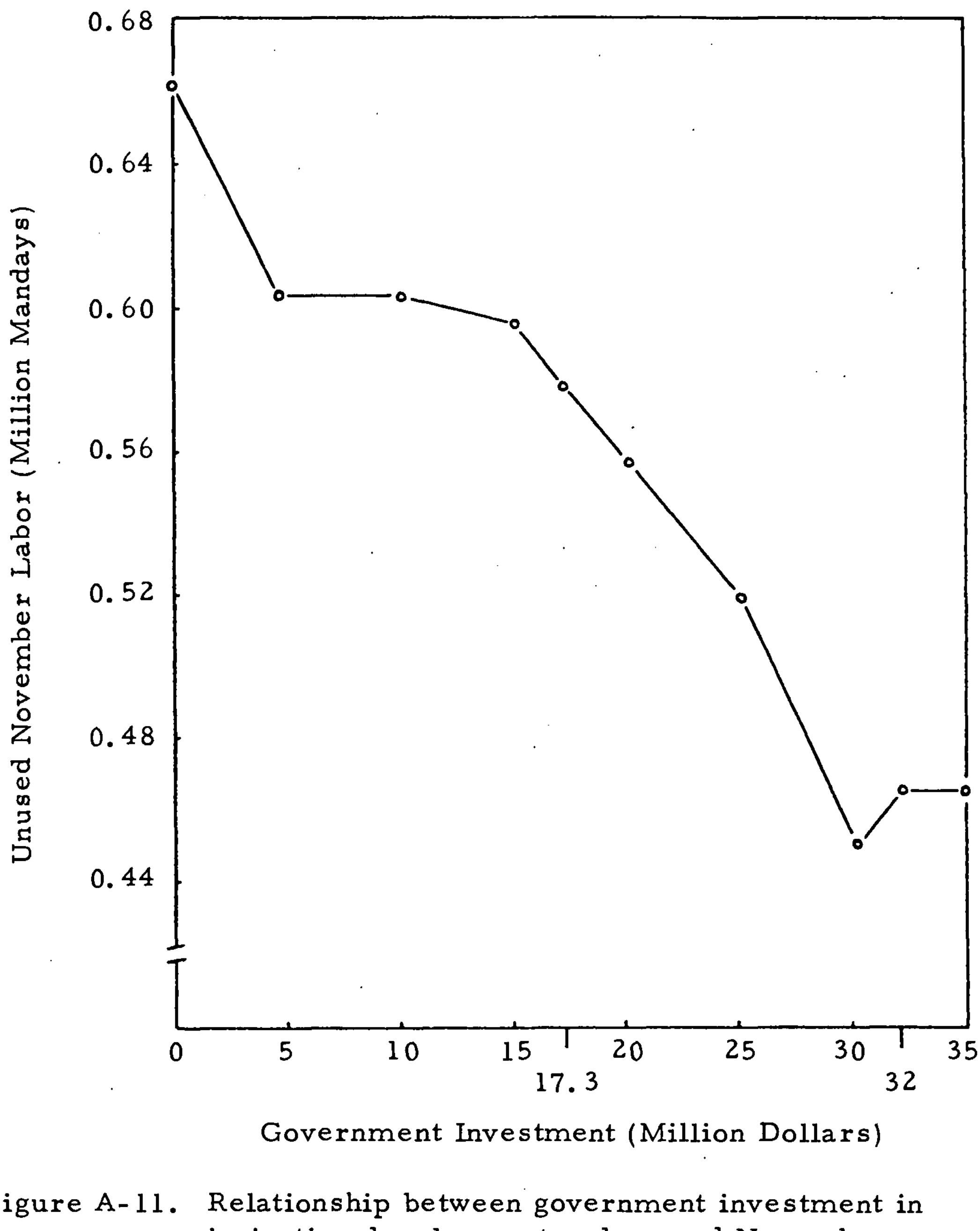

Figure A-11. Relationship between government investment in irrigation development and unused November labor.

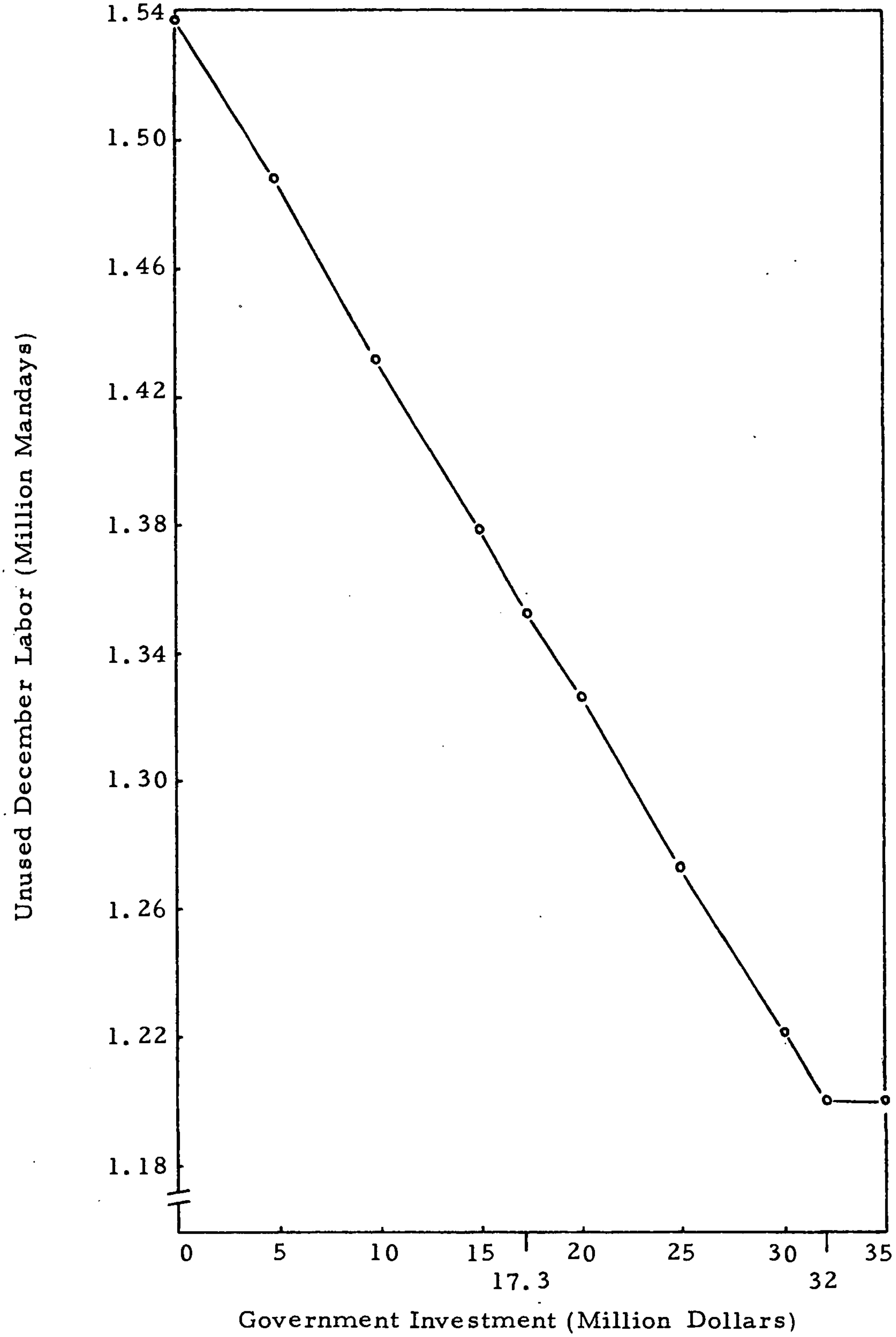

Figure A-12. Relationship between government investment in irrigation development and unused December labor.

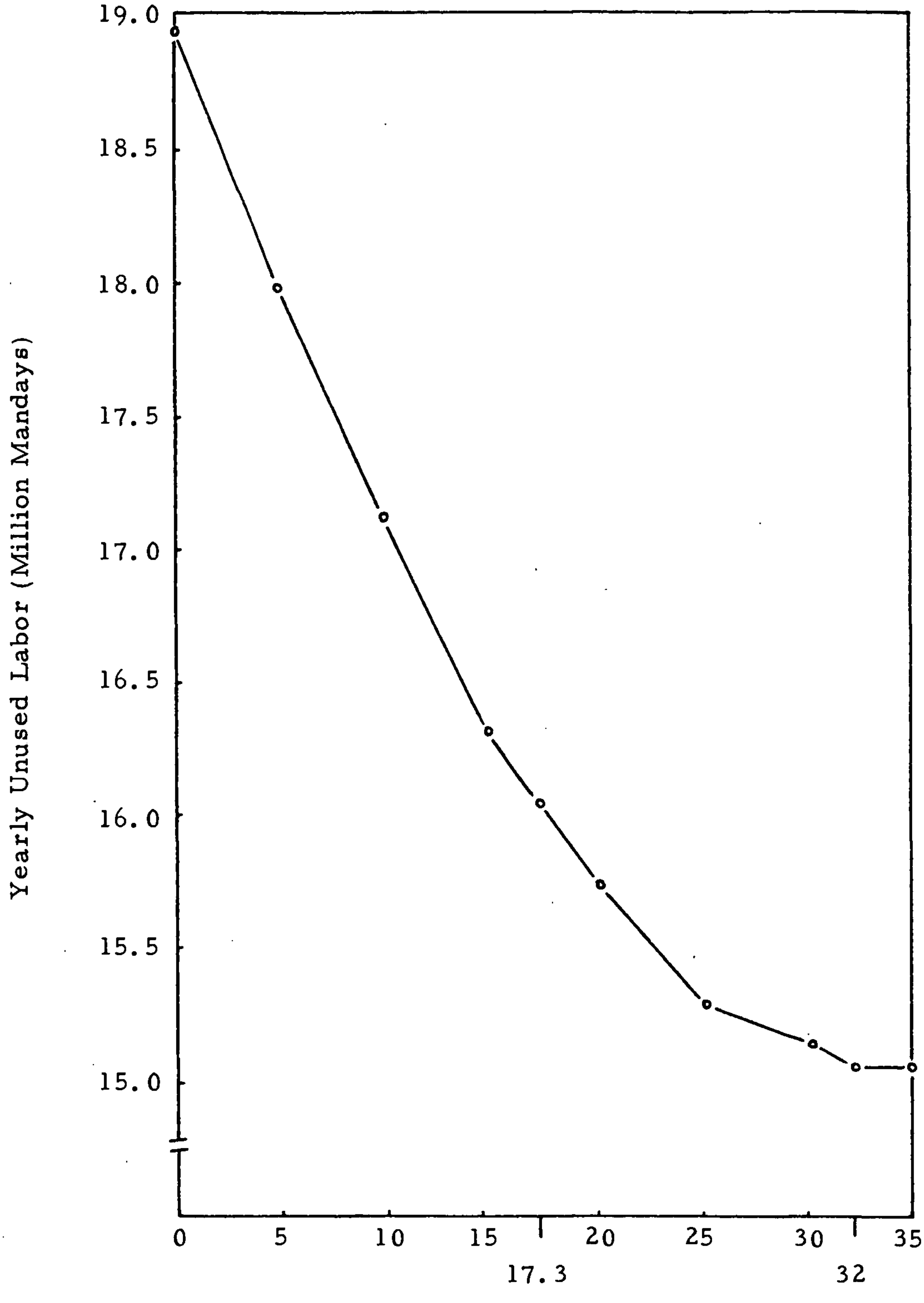

Figure A-13. Relationship between government investment in irrigation development and yearly unused labor.

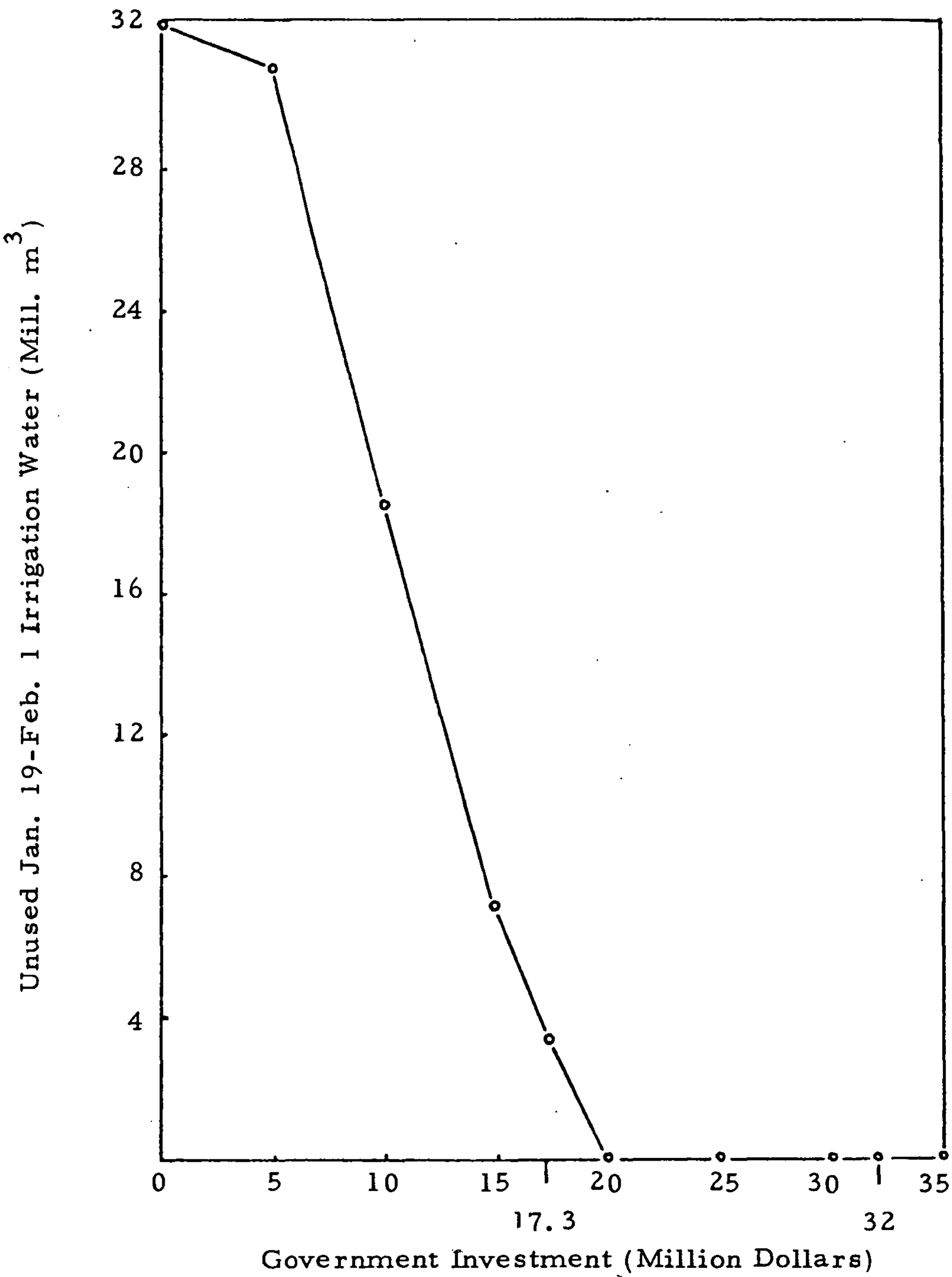

Figure A-14. Relationship between government investment in irrigation development and unused January 19-February 1 irrigation water.

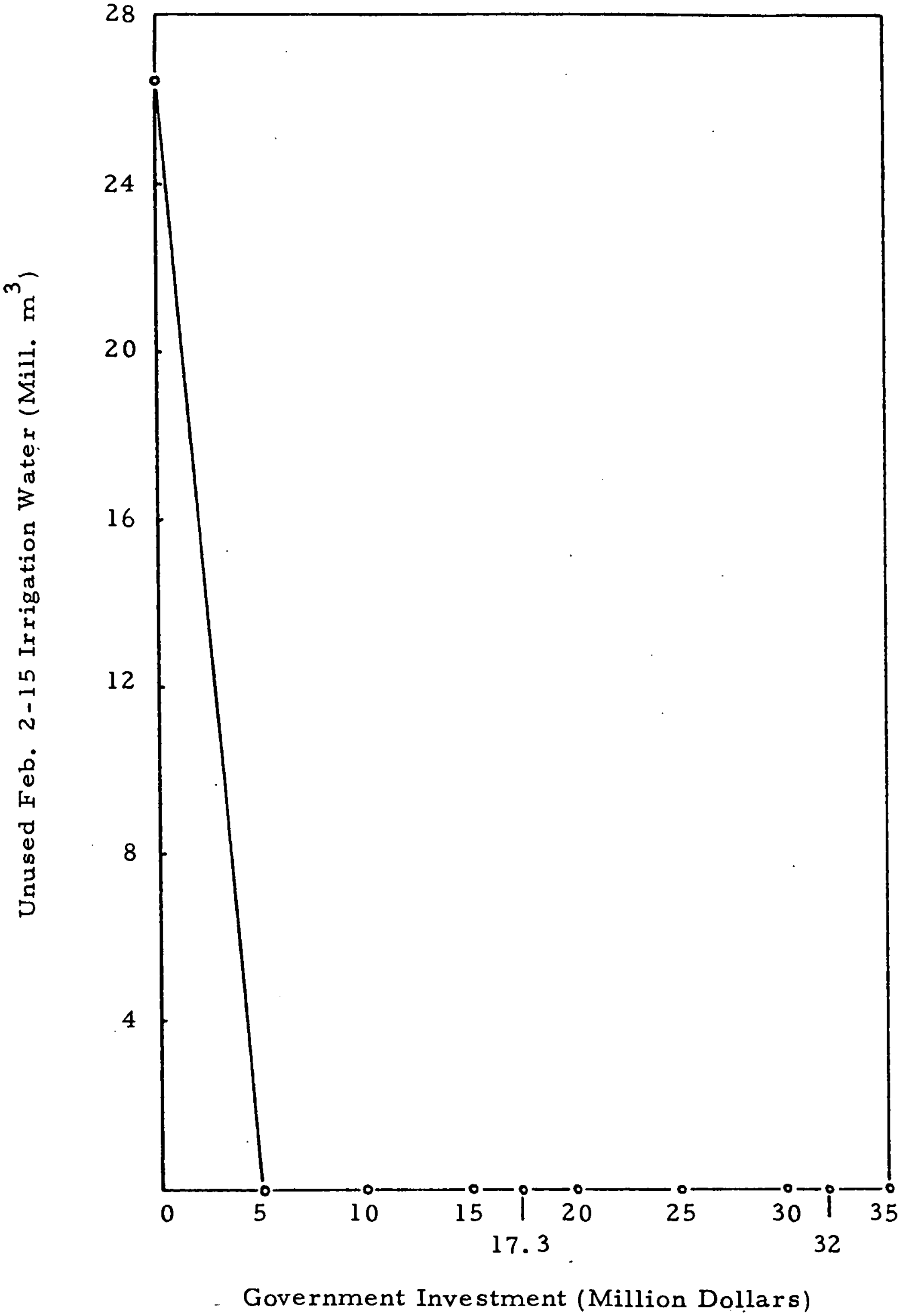

Figure A-15. Relationship between government investment in irrigation development and unused February 2-15 irrigation water.

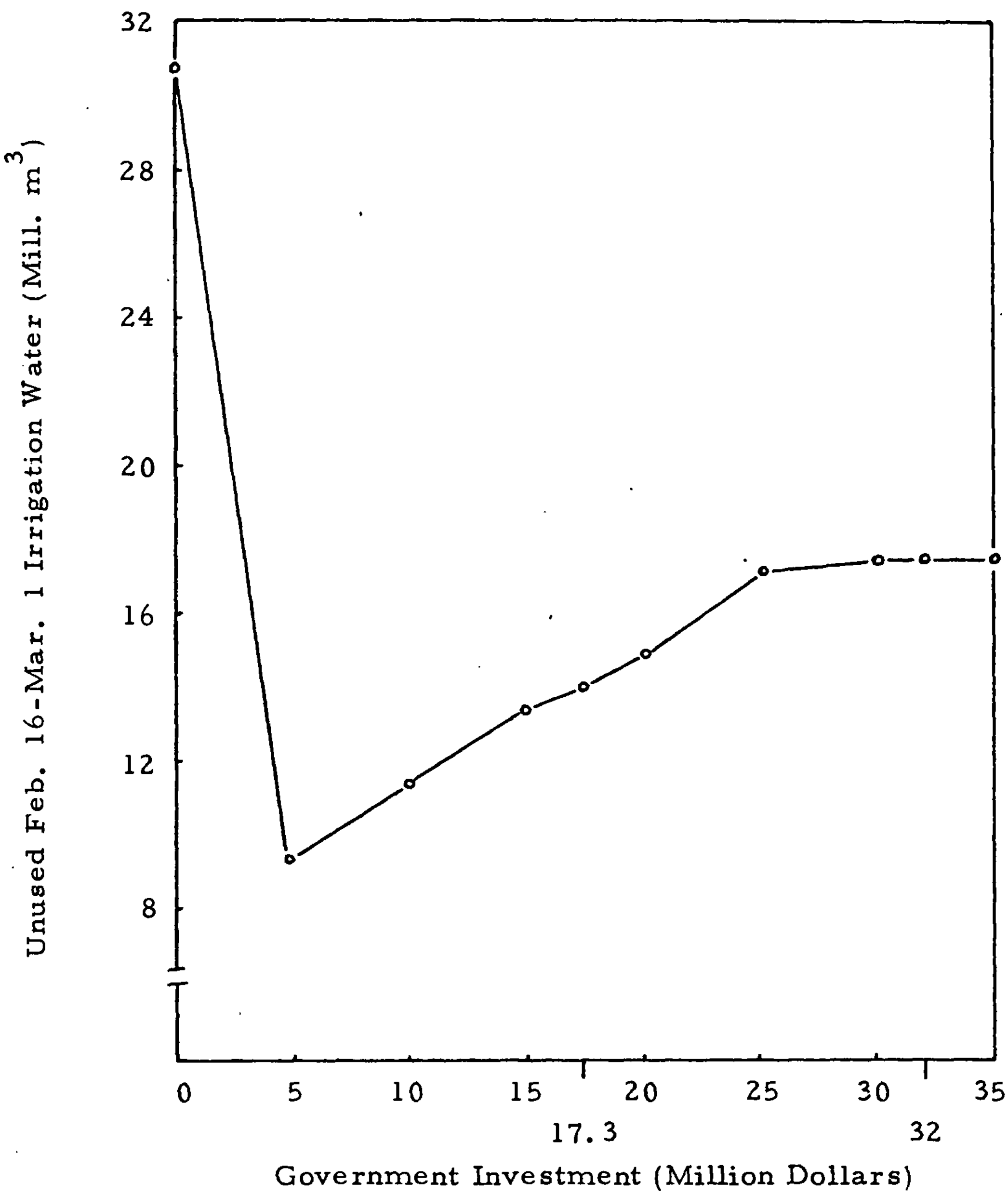

Figure A-16. Relationship between government investment in irrigation development and unused February 16-March 1 irrigation water.

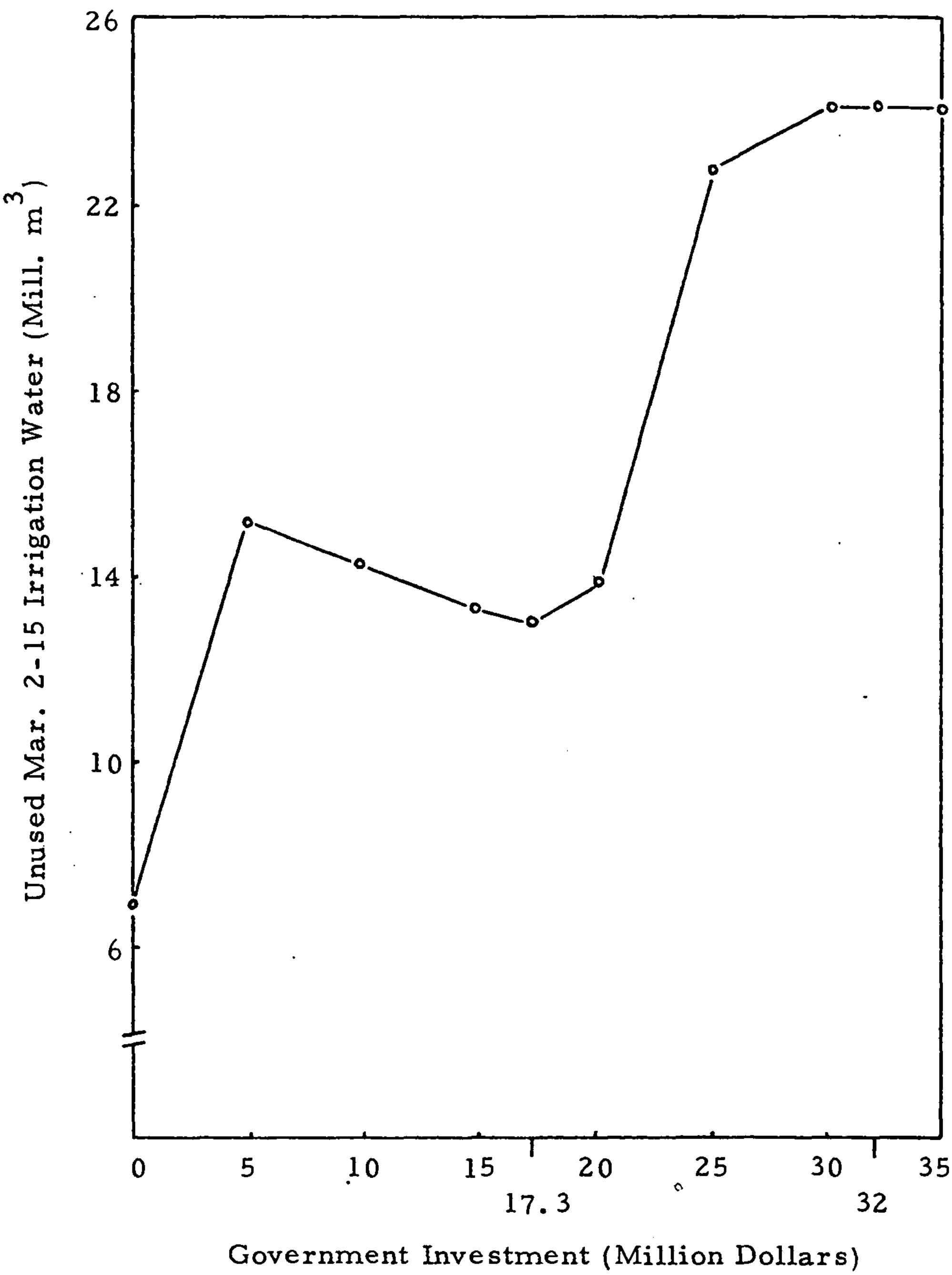

Figure A-17. Relationship between government investment in irrigation development and unused March 2-15 irrigation water.

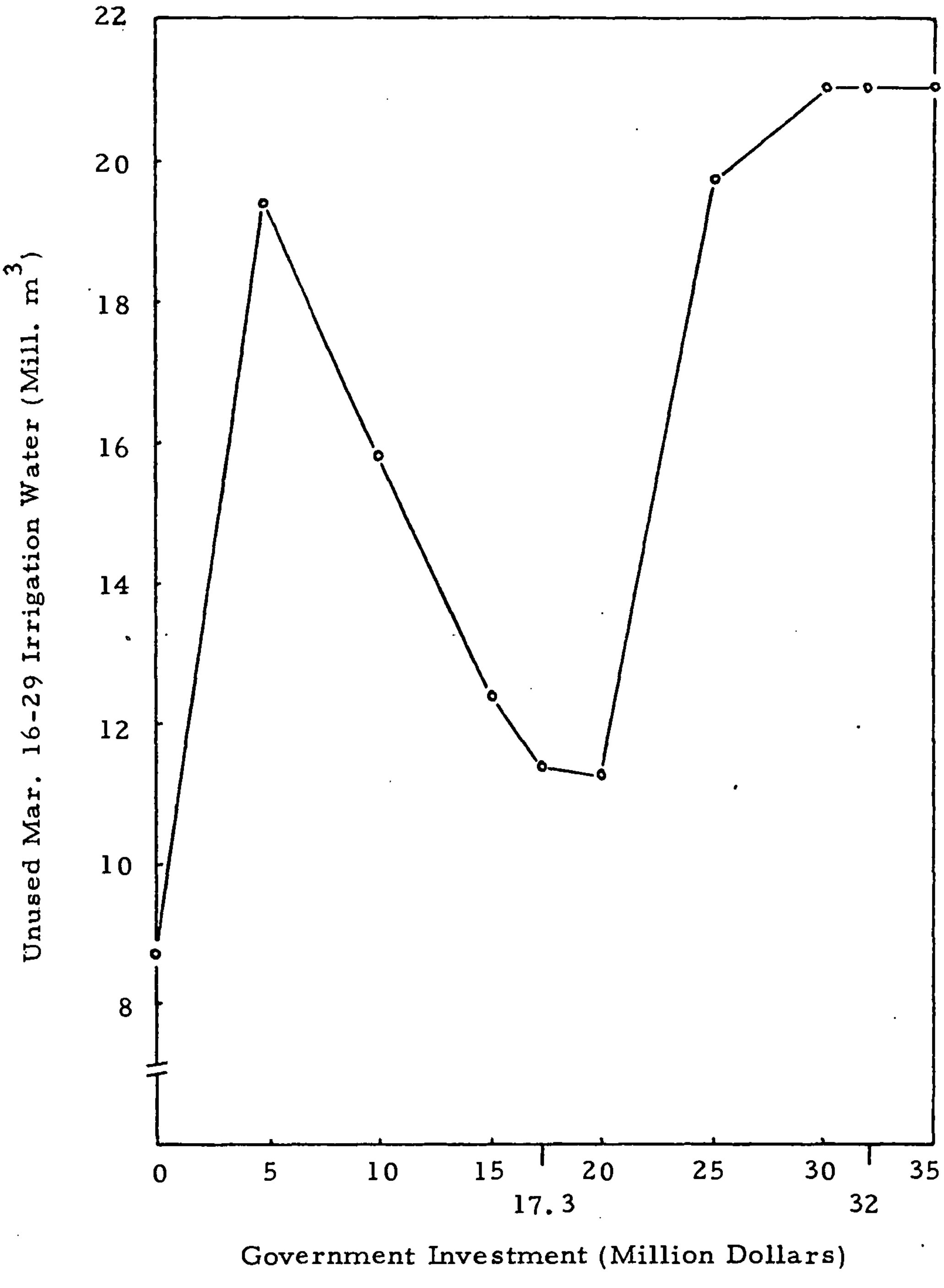

Figure A-18. Relationship between government investment in irrigation development and unused March 16-29 irrigation water.

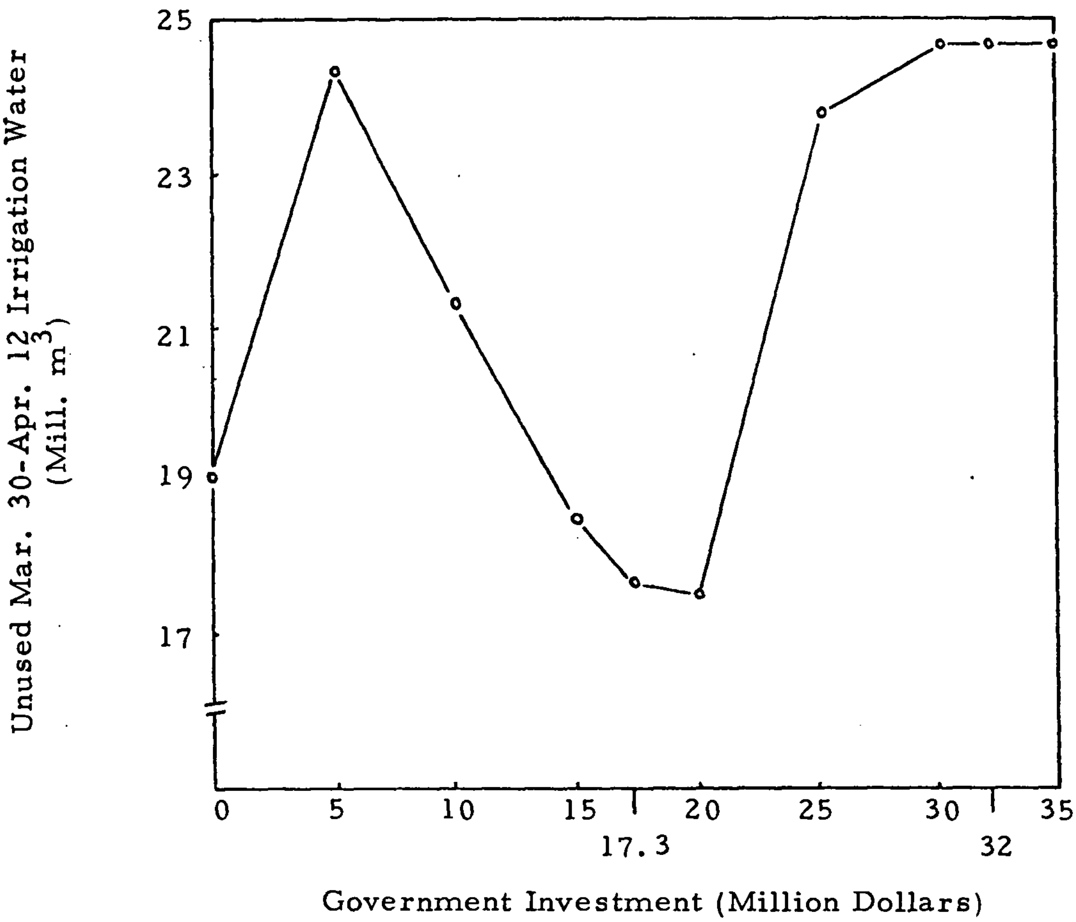

Figure A-19. Relationship between government investment in irrigation development and unused March 30-April 12 irrigation water.

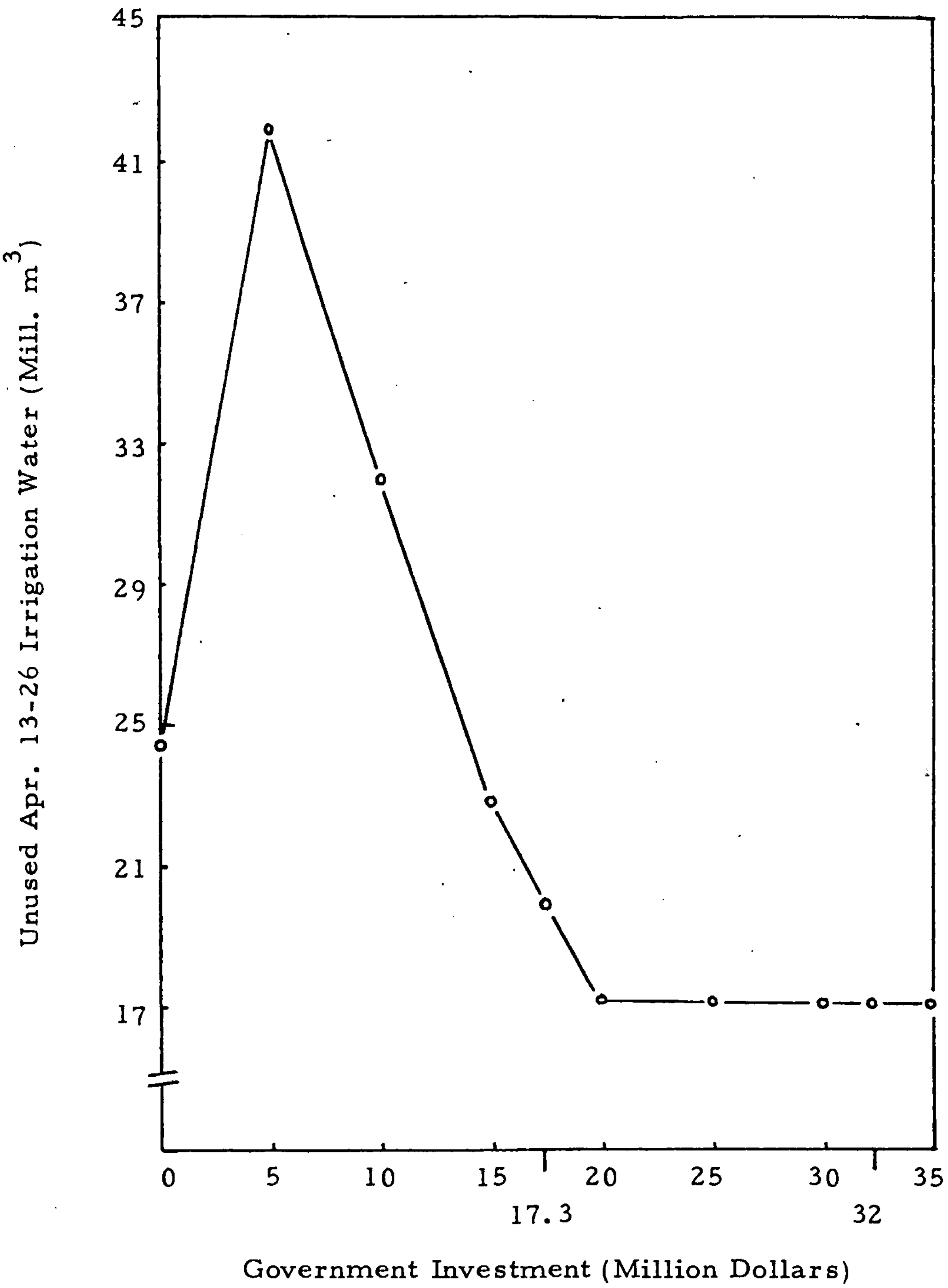

Figure A-20. Relationship between government investment in irrigation development and unused April 13-26 irrigation water.

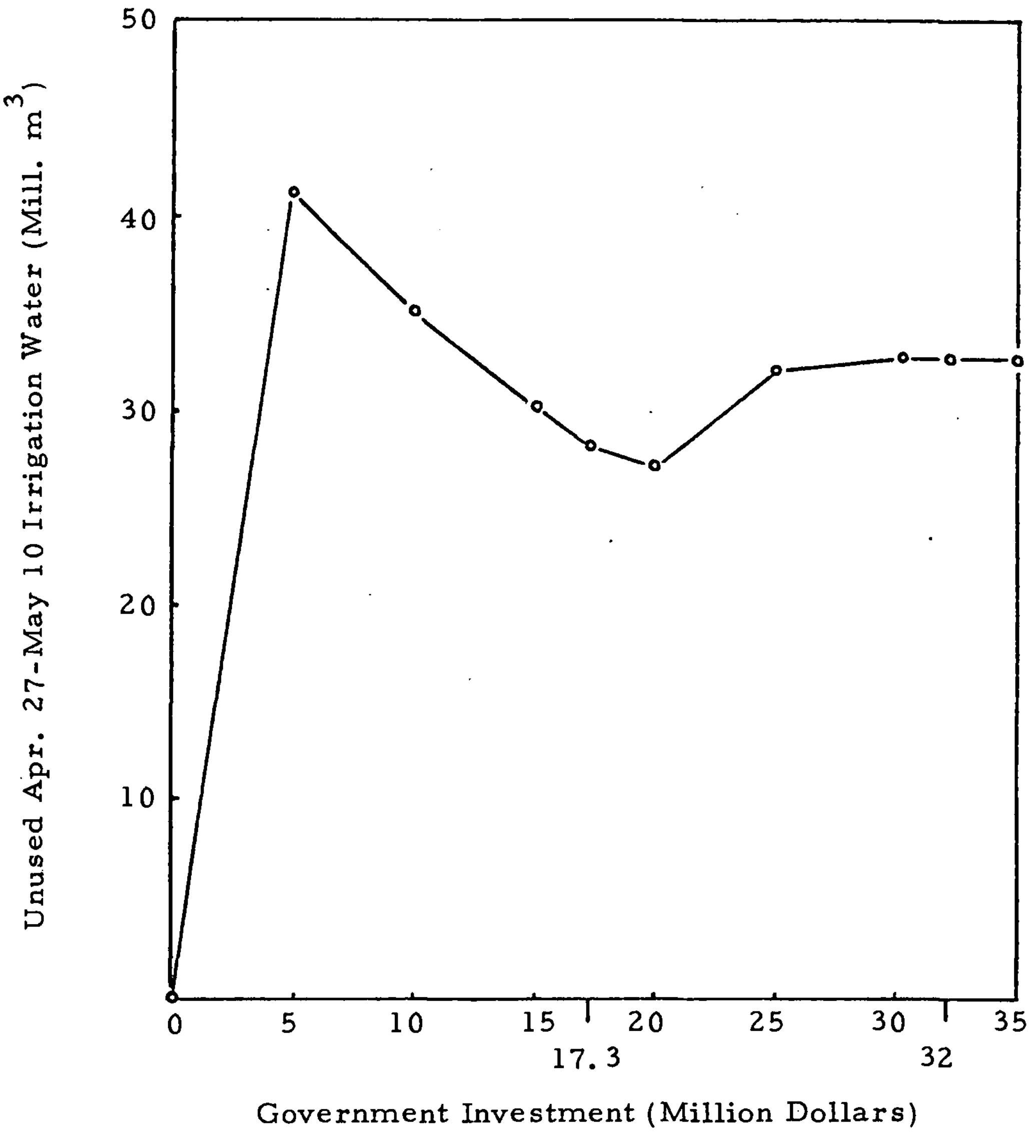

Figure A-21. Relationship between government investment in irrigation development and unused April 27-May 10 irrigation water.

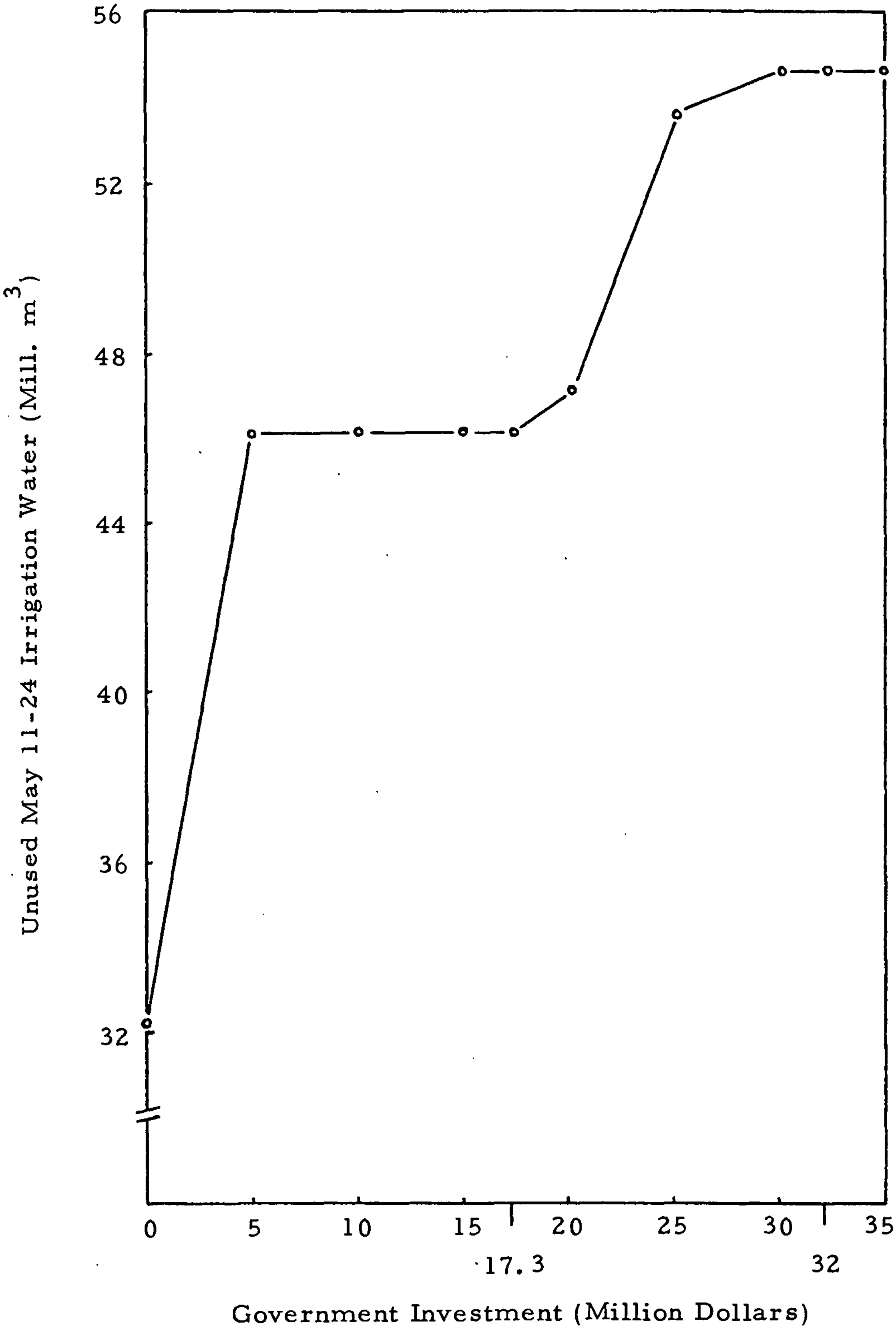

Figure A-22. Relationship between government investment in irrigation development and unused May 11-24 irrigation water.

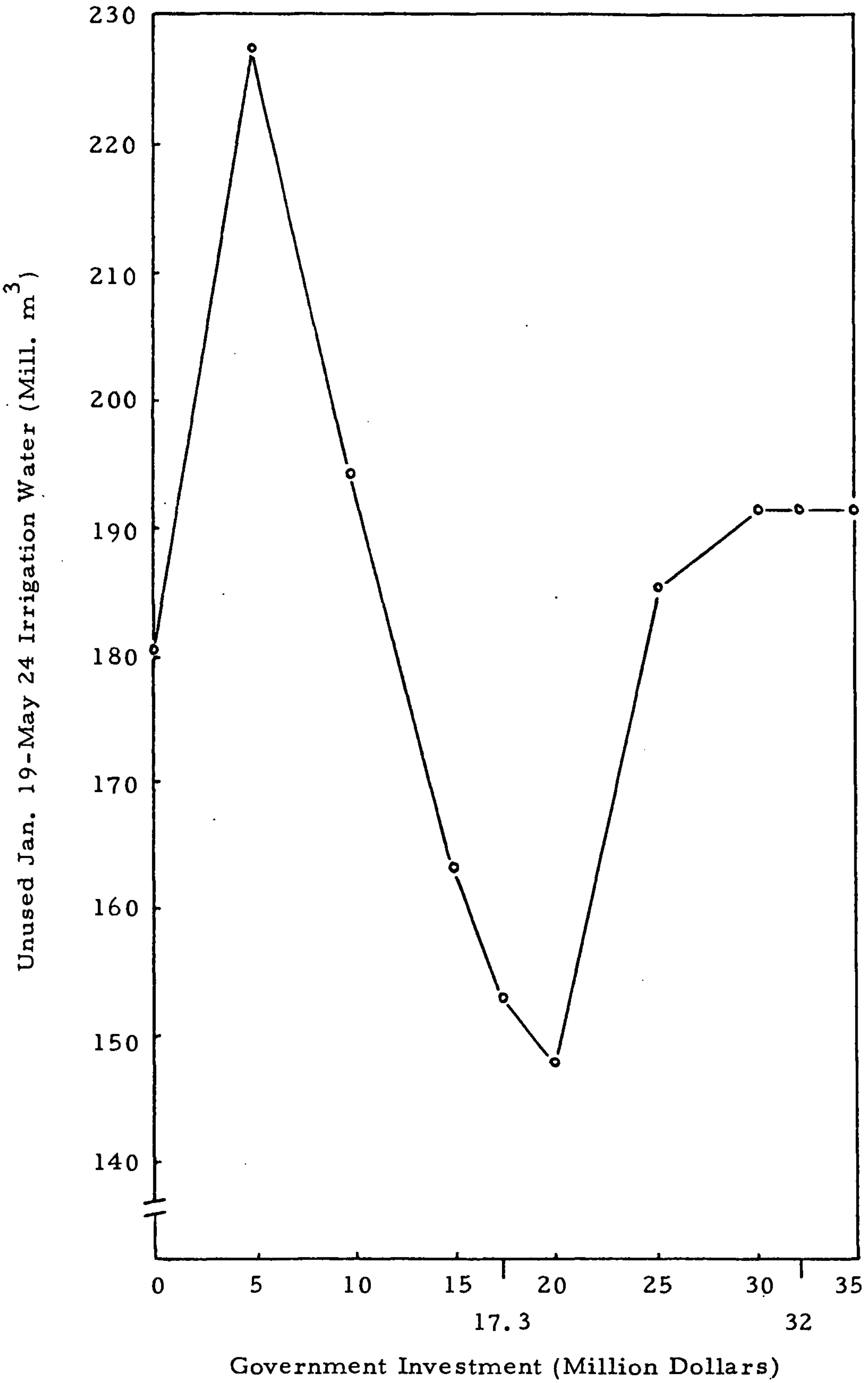

Figure A-23. Relationship between government investment in irrigation development and unused January 19-May 24 irrigation water.

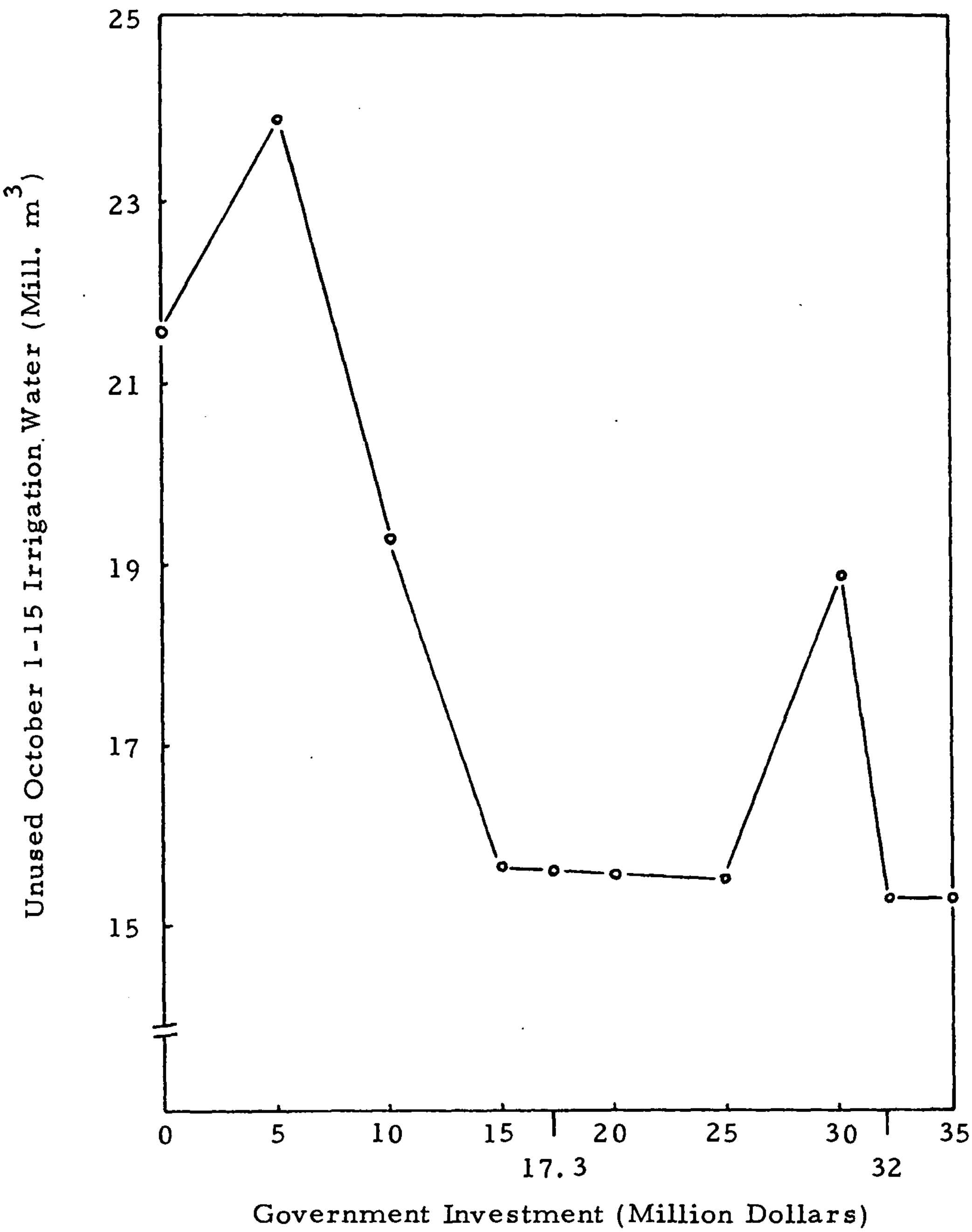

Figure A-24. Relationship between government investment in irrigation development and unused October 1-15 irrigation water.

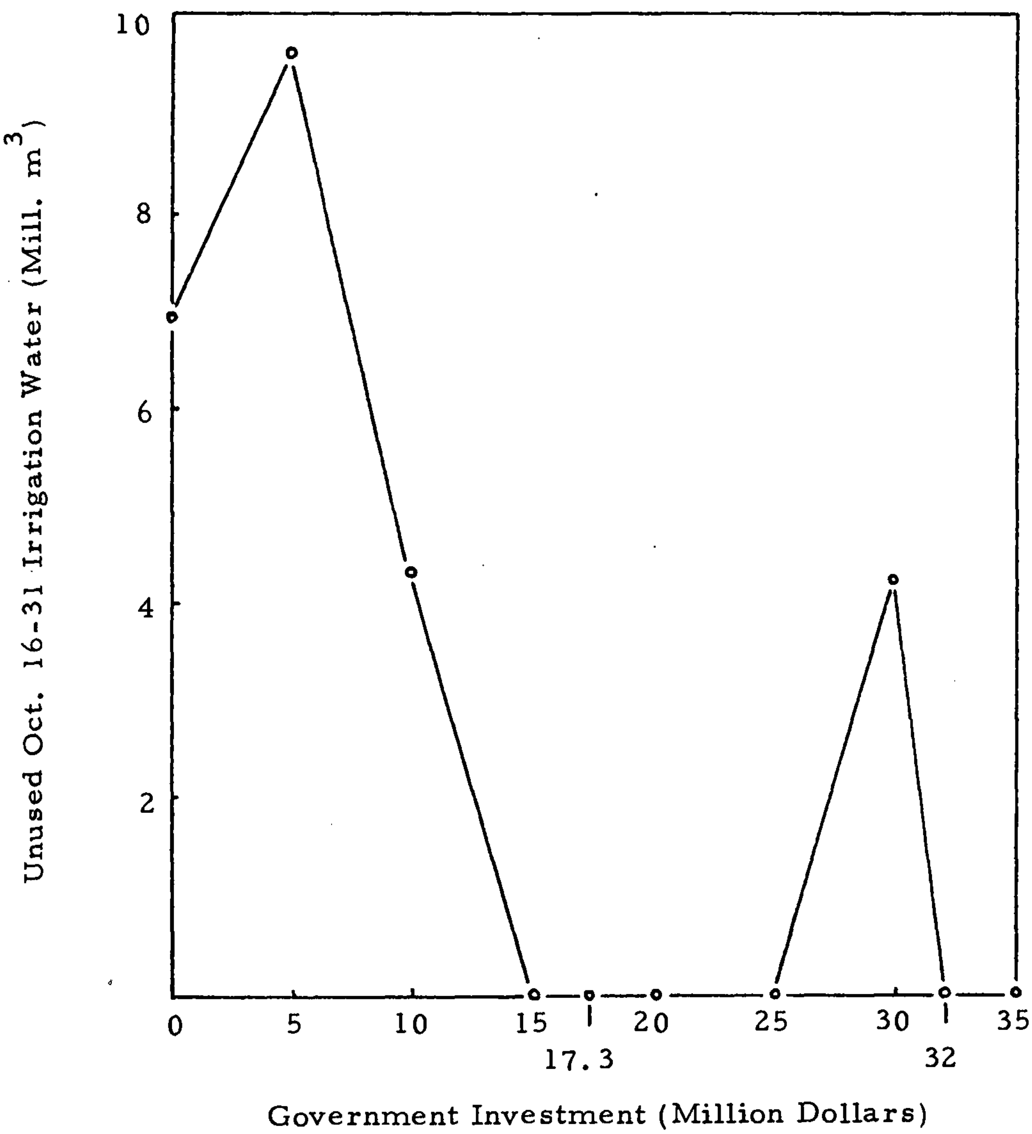

Figure A-25. Relationship between government investment in irrigation development and unused October 16-31 irrigation water.

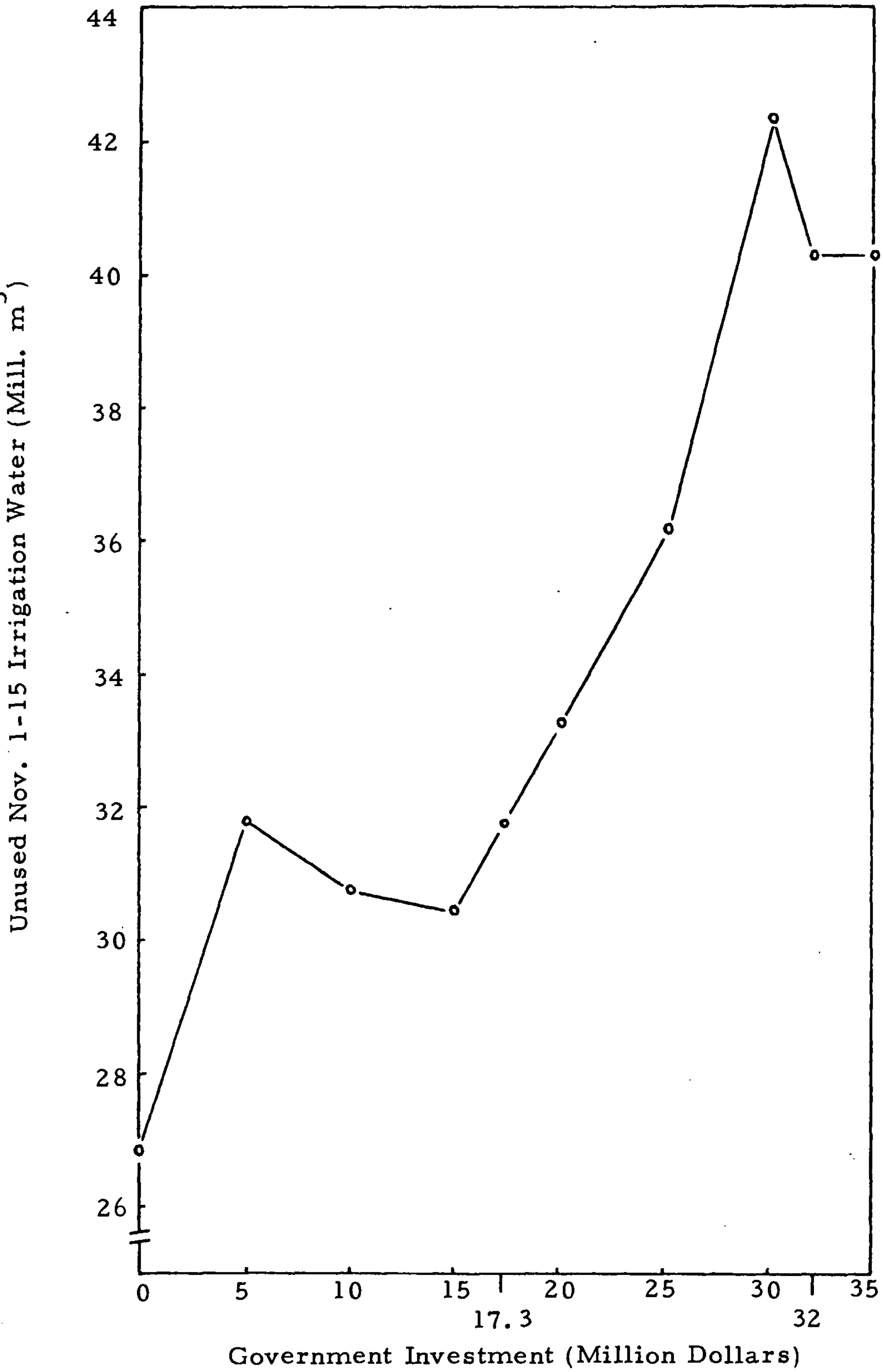

Figure A-26. Relationship between government investment in irrigation development and unused November 1-15 irrigation water.

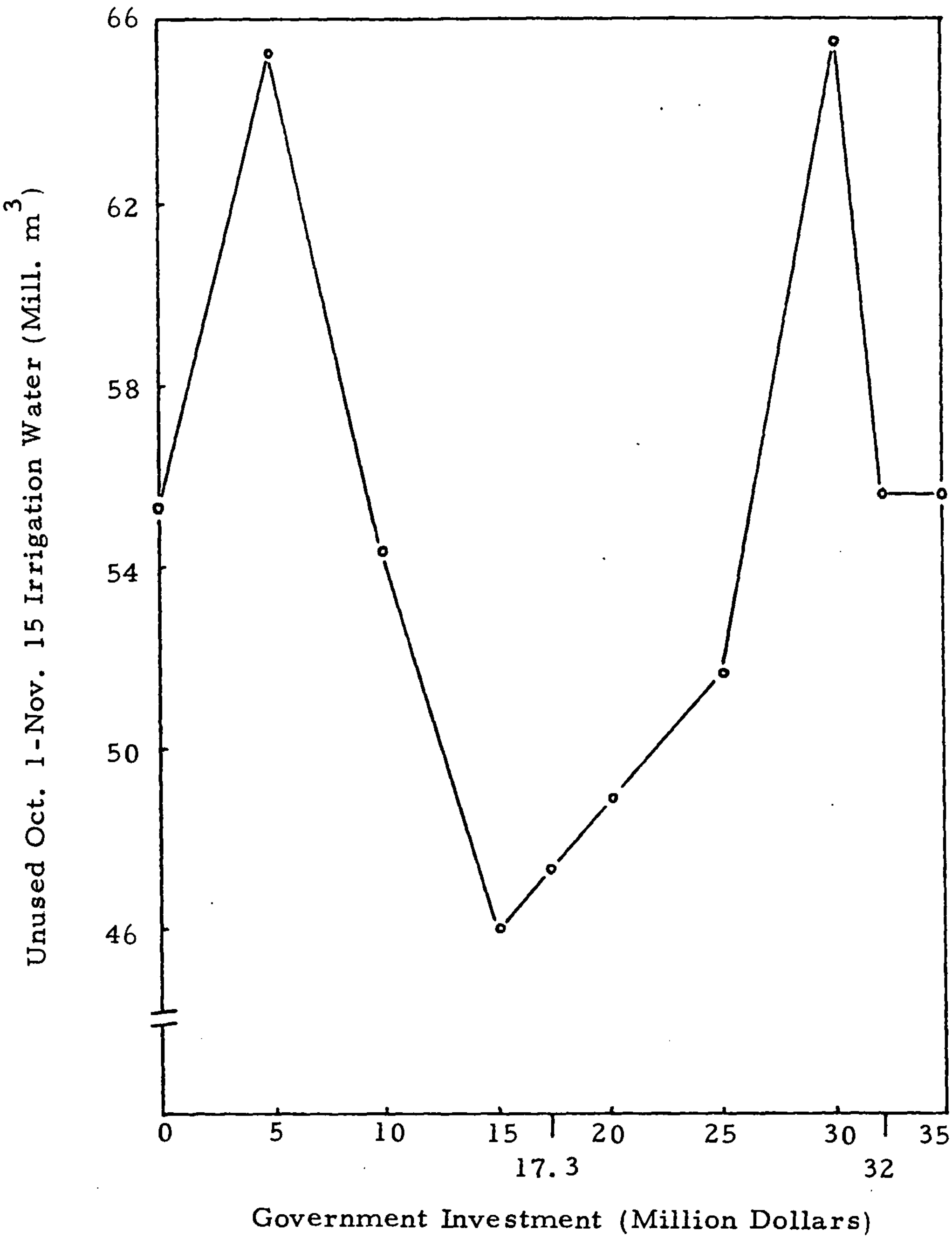

Figure A-27. Relationship between government investment in irrigation development and unused October 1-November 15 irrigation water.