3-1951

An Economic Study of the University of Tennessee Power Plant

Jack London Gamble
University of Tennessee - Knoxville

To the Graduate Council:

I am submitting herewith a thesis written by Jack London Gamble entitled "An Economic Study of the University of Tennessee Power Plant." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Mechanical Engineering.

W. R. Chambers, Major Professor

We have read this thesis and recommend its acceptance:

Russ Bauer, J. F. Bailey

Accepted for the Council:
Dixie L. Thompson

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

March 1, 1951

To the Graduate Council:

I am submitting herewith a thesis written by Jack London Gamble entitled "An Economic Study of the University of Tennessee Power Plant." I recommend that it be accepted for nine quarter hours of credit in partial fulfillment of the requirements for the degree of Master of Science, with a major in Mechanical Engineering.

W. R. Chambers
Major Professor

We have read this thesis and recommend its acceptance:

[signature]

J. F. Bailey

Accepted for the Council:

[signature]
Dean of the Graduate School

AN ECONOMIC STUDY OF THE UNIVERSITY OF TENNESSEE POWER PLANT

A THESIS

Submitted to
The Graduate Council
of
The University of Tennessee
in
Partial Fulfillment of the Requirements
for the degree of
Master of Science

by

Jack London Gamble

March 1951

TABLE OF CONTENTS

LIST OF TABLES

LIST OF ILLUSTRATIONS

FIGURE PAGE

CHAPTER I

THE PROBLEM

A history of the University of Tennessee Power Plant is helpful in that it serves to emphasize the importance of having a planned program for future operation based on sound economic and engineering principles. The present power plant is the result of the expansion over a period of years of the facilities and services offered by the University and is one of the finest University Power Plants in the South.

A 25 horsepower, Two pole, Edison engine driven generator installed in 1892 in an annex to what was then Reece Hall generated the first electricity produced on the University campus. Central heating was first employed on the campus with the installation in 1898 of a sixty horsepower Dallas horizontal return tubular boiler. This boiler was part of the equipment of Estabrook Hall which had just then been completed, and Estabrook, Blount, and Carrick Halls were connected to the boiler for heating. The boiler also supplied steam to the throttle of an American Ball Simple Steam Engine which was directly connected to a 25 kilowatt generator. All other buildings at that time were separately heated. The original boiler was later replaced by a larger unit of the Hawley Down Draft fire tube type, which in turn gave way to a conventional 150 horsepower horizontal return tubular boiler. The replacement of the boilers was accompanied by the installation of a 50 kilowatt generator driven by an American Ball Compound Steam Engine and a 35 kilowatt non-condensing turbogenerator unit which remained in service until 1924.

In 1924 the first major equipment addition was two cross drum box header boilers, two hundred pound designed pressure, manufactured by the Walsh and Weidner Company, each rated at 337 boiler horsepower. Taylor Stokers and forced draft completed the essential features of the steaming equipment. These boilers have since been rebuilt and are now in service at the University Farm. Installed concurrently was the 625 KVA Westinghouse turbogenerator unit, originally a non-condensing unit, which was converted into a condensing unit some two years later. This unit is now in service.

In 1928 two 350 horsepower Casey Hedges boilers of the bent tube type, each having five cross drums, were installed. These boilers are fired by Westinghouse four-retort stokers. Also installed and placed in service at this time was the General Electric Company 625 KVA turbogenerator and condenser.

In 1937 an extension was built to the west end of the original power plant for housing a new boiler. The boiler installed was constructed by the Combustion Engineering Company under the designation of type "VU". This is a completely water cooled furnace featuring pulverized coal firing, forced and induced draft, plate type air heater, and superheater, guaranteed to produce 60,000 pounds of steam per hour continuously and 75,000 pounds of steam per hour for a four hour period.

The first major addition to the electrical generation capacity was a Westinghouse 1875 KVA turbogenerator and condenser which went into service in March, 1942. This unit is of the bleeder type, supplying heating steam at a bleed pressure of 65 psig. Also installed at this time was a pumping station to supply cooling water to the condensers from the Tennessee River.

In 1949 installation of a new boiler was completed. This was a Combustion Engineering Company type "VU" water wall boiler with pulverized fuel firing, air heater, superheater, and hydraulic ash disposal. The boiler was designed for operation at 450 psig pressure, but is presently operating at 200 psig. This installation featured completely automatic combustion controls, manufactured by the Republic Flow Meters Company. This boiler is guaranteed to produce 80,000 pounds of steam per hour continuously and 100,000 pounds of steam per hour for a four hour period. For the past winter, this boiler has been loaded practically to the continuous guarantee on a number of days, and has given every indication that it will meet the four hour guarantee.

The phenomenal growth of the University power plant has resulted from ever increasing demands for steam and electricity. The University must supply heating steam for all buildings on the campus since no other supply in available, but, as has happened at times in the past, electric power can be purchased if that method is shown to be more advantageous. In passing, it might be mentioned for the record that the reverse is also true; that electrical energy can also be sold, as actually happened during the earlier periods of the late World War.

With increased coal costs and the low rates available for TVA power, there is some question in the minds of University officials as to whether it is economically advisable for the University to continue generation of its power. The purpose of this thesis is to answer that question, and also to determine the best and most economical operating schedule which will supply the University's present and future needs for electricity and steam.

In the chapters to follow, data for both steam and electric loads will be compiled and evaluated in connection with the University's present needs and planned building program. Data was taken from plant log sheets for the period since 1940. For the years preceeding this, figures were accepted from a study made in 1940 for a Master's Thesis by D. M. Nicholas.[1] Consideration will be given to the possibility of purchasing a new turbo-generator and increasing steam pressure in the light of increased efficiencies expected. An economic study will then be made to determine what the cost of generated and purchased power will be, both for present and future loads. In the final Chapter conclusions and recommendations will be presented in a summarized form.

---

[1]D. M. Nicholas, An Expansion Program for the University of Tennessee Power Plant, a Thesis, Knoxville, 1940.

CHAPTER II

ELECTRICAL DISTRIBUTION SYSTEM AND LOAD SURVEYS

A detailed study of the electrical distribution system is beyond the scope of this study, but the system will be described as it applies to the power plant.

Electricity is generated and distributed at 2400 volts over 10 three-phase feeders. In Table I the various feeders are listed with the connected transformer capacity and buildings served by each.

The Estabrook and Ferris Feeder leaves the plant at the front and parallels the front wall, underground to the Estabrook Substation, while a branch circuit leaves from the front of the plant and runs underground directly to the Ferris Hall substation through a pull box across Estabrook Road.

The Strong Hall, Melrose, and Farm Feeders are underground and parallel each other from the plant to the Fifteenth Street Entrance. The Farm line is then run with aerial cable along Rose Avenue across the Louisville and Nashville Railroad tracks to the University Farm, while the Strong Hall and Melrose Hall lines are overhead from Fifteenth Street, the Melrose line running along Rose Avenue to Melrose Hall, while the Strong Hall line leaves Rose Avenue at an alley between Fifteenth Street and Temple Avenue, follows the alley to a point at the rear of the University Hospital, where it turns west to Temple Avenue, and thence along Temple to Strong Hall. A separate parallel circuit of the overhead type, leaving at the rear of the plant and following a path behind Estabrook Hall to the Fifteenth Street Entrance is available and can be used to feed the three above mentioned feeders.

The Blount Feeder leaves at the northeast corner of the plant and crosses to a pull box across Estabrook Road. From here it proceeds to the Blount Hall substation and thence along Middle Drive to the Gymnasium, all of which is underground. An overhead feeder from the pull box at the front of the Gymnasium feeds a transformer on a pole at the old Athletic Association Building.

The Biology and Administration Feeder leaves the plant and parallels the Estabrook line to the Estabrook Substation. From this point the underground line proceeds directly to a pull box which it shares with the Blount Feeder on Middle Drive, thence along Middle Drive to the Biology Building and the Administration Building.

The Ayres Feeder leaves the plant with the Blount Feeder, proceeding directly up the hill beside Perkins Hall and the Physics Building to Ayres Hall. It is entirely underground.

The Home Economics Feeder follows an underground path behind Ferris Hall around the hill to a pull box in the Trailer Village which it shares with the Humes Hall Feeder. From this point it proceeds across West Cumberland Avenue to the Home Economics Building while a branch line serves the Library. The Humes Hall line follows a path in front of Ferris Hall to the above mentioned pull box and thence up the hill to the Humes Hall substation, all underground.

A 2000 kilowatt transformer bank at the corner of Main Avenue and Estabrook Road, installed by the City with switchgear, can be used to supply electricity to the plant busses whenever it is deemed advisable,

TABLE I

CONNECTED KVA TRANSFORMER CAPACITIES
BY FEEDERS AND SUBSTATIONS

Feeders	Substations	Transformers KVA Cap.	Transformers No.-Sizes	Bldgs. Fed
	Strong Hall	450	3-150	Strong Hall W. Strong Hall
	Henson Hall	40.5	2-1.5 1-37.5	Henson Hall
Strong Hall	Temple Prac. House	57.5	1-37.5 2-10	Temple Prac. H. Temple Court Hospital Aconda Court
	Transf. on Pole	25	1-25	X-Ray
	Law Building	112.5	3-37.5	Law Bldg.
	W. Stadium	25	1-25	W. Stadium Armory
	Transf. on Pole	60	1-50 2-5	E. Barracks
Melrose Hall	Melrose	375	3-50 3-75	Melrose Hall
	Transf. on Pole	15	1-15	Faculty Club
	Scoreboard	10	1-10	Scoreboard
Esta. and Ferris	Ferris	162.5	3-37.5 2-25	Ferris Hall Chem. Annex
	Estabrook	80	1-50 2-15	Esta. Hall
	Blount	70	1-50 2-10	Blount Physics & Geo.
Blount	Gymnasium	57.5	1-37.5 2-10	Gymnasium
	Transf. on Pole	37.5	1-37.5	Barracks
	Transf. on Pole	5	1-5	Old A. A. Bldg.
	Biology	210	2-100 1-10	Biology Student Center
Biol. and Adm.	Administration	112.5	1-100 2-10	Administration Ayres Annex
	E. Stadium	107.5	2-50 1-7.5	E. Stadium

TABLE I (cont.)

CONNECTED KVA TRANSFORMER CAPACITIES
BY FEEDERS AND SUBSTATIONS

Feeders	Substations	Transformers KVA Cap.	Transformers No.-Sizes	Bldgs. Fed
Ayres	Ayres	150	3-50	Ayres
	Perkins	200	1-200	Perkins
	Home Ec.	260	1-150	Home Economics
			1-100	
			2-5	
	Nursery	37.5	1-37.5	Nursery
Home Economics				Practice House
	Library	95	1-50	Library
			2-10	
			1-25	
	Transf. on Pole	25	1-25	Trailers
	Chem. Eng.	125	1-50	Chem. Eng.
			2-37.5	
Chem. Eng.	Berry Hall	75	3-25	Berry Hall
	N.S. Stadium	150	3-50	N.S. Stadium
	Humes Hall	160	1-150	Dabney Hall
Humes Hall			2-5	Science Hall
				South College
	Dairy Products	200	1-200	Dairy Products
	Foods Proc.	300	3-100	Foods Proc.
	New Ag. Eng.	112.5	3-37.5	New Ag. Eng.
	Cotton & Corn	20	2-10	Laboratory
	McCord Hall	225	3-75	McCord Hall
	Morgan Hall	125	1-50	Morgan Hall
			2-37.5	Temple Hall
Farm				Farm PP
				Ag. Eng.
				Greenhouses
	Transf. on Pole	10	1-10	Residences
				Beef Barn
	Transf. on Pole	15	1-15	Poultry Barn
	Transf. on Pole	100	2-50	Vet. Clinic
	Transf. on Pole	37.5	1-37.5	Barracks
	Transf. on Pole	10	2-5	Greenhouse
	Plant	450	3-150	Plant Aux.
Plant	Pumphouse	75	3-25	River Pumps
	Transf. on Pole	5	1-5	Outside Lights

or in case of emergency. A line proceeding along White Avenue from this transformer bank has recently been installed and is available to feed the buildings on the North side of West Cumberland when necessary or convenient while the rest of the system load is being taken by the Power Plant.

Whenever feasible transformer substations have been located in fire proof louvered door vaults on the ground floors of the buildings, but in some cases transformers are suspended from cross arms on poles located as near as possible to the points of utilization.

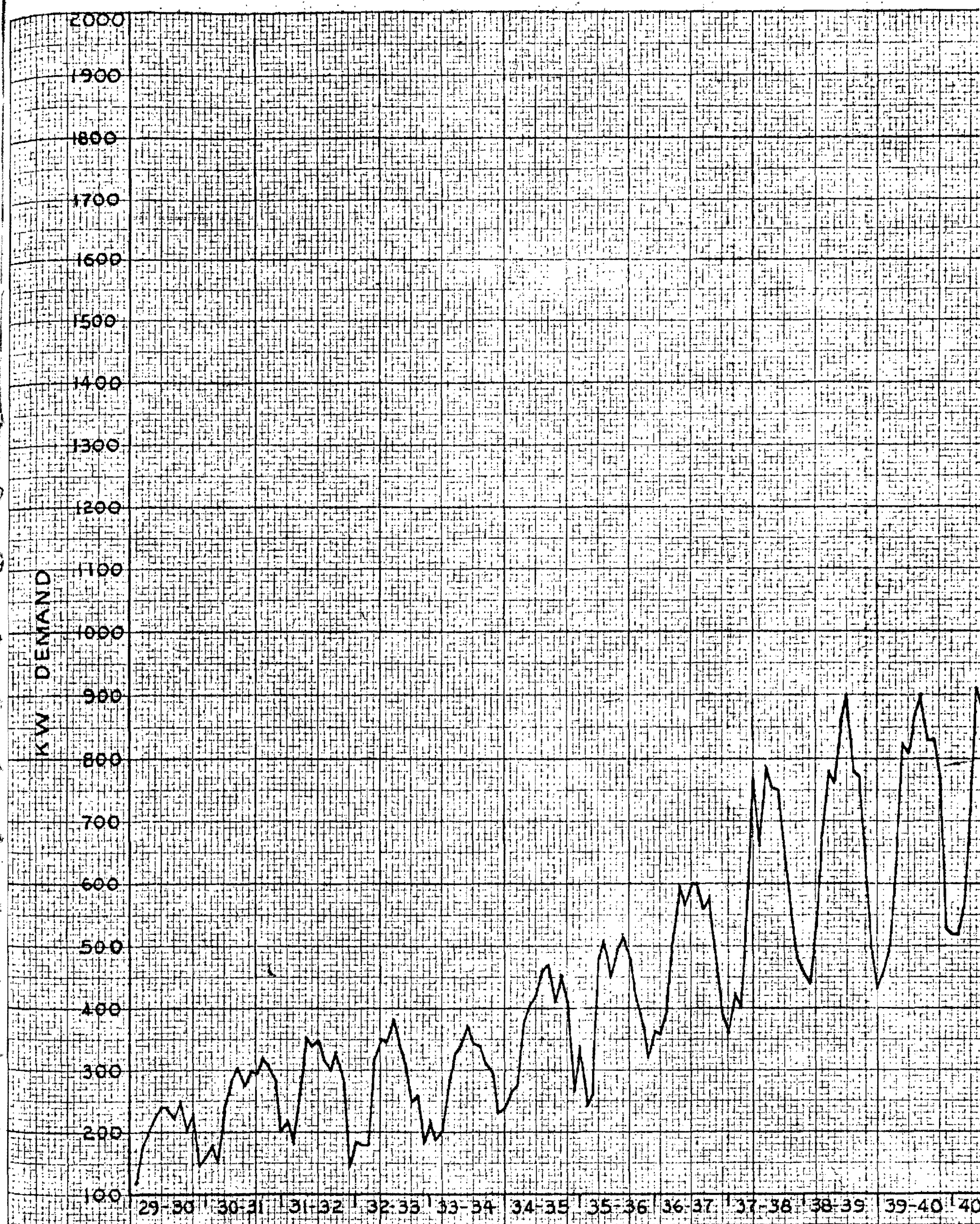
From Table I it can be seen that the total connected transformer capacity is 4,783.0 KVA. The total capacity in 1940 was 2,758.5 KVA. Thus there has been an increase of 73.0% in connected capacity in the past ten years. During the same period the maximum demand increased from 910 KW in 1940 to 2000 KW in 1950, representing an increase of 120%. In January 1940 326,800 KWH of electricity were consumed, while in January 1950 736,300 KWH were used, representing an increase of 125%. While complete data are not available for incremental increases, it is apparent that existing transformers are being loaded at a faster rate than new transformers are being provided, even with the University building program proceeding at a rapid rate.

All available pertinent data for a study of the electric load are tabulated in Table XI of the Appendix. In order to predict future loads, these data were plotted by months in Figure I to establish a load trend. From this load trend and the planned building program, it will be possible to predict future loads. While the upward trend in Figure I is unmistakable, it would be rather difficult to establish an accurate figure for this trend due to seasonal variations, therefore this curve has been replotted in Figure 2 on the basis of average monthly maximum demands per year. The dashed portions of these curves represent a period when the University was delivering power to city lines, and does not in any way represent actual demands by the University. In 1943, where figures are again represetive of University load, a drop in both demand and energy requirements is noticable. This was due to the decreased student enrollment and to curtailed facilities during the late war. It is significant, however, that a short time after the conclusion of the war the curve climbs rather steeply, and seems to return to the trend lines as established, as would be expected. The trend lines were drawn in such a manner as to represent the average slopes of the demand and energy curves.

Student enrollment has also been plotted on Figure 2, and while the curves are not exactly parallel, it is obvious that there is a general relationship existing.

Analysis of the trends over the twenty year period studied indicates an average increase in maximum demand of 64 KW per year and an increase in daily energy requirements of 720 KWH per year.

Discussion with responsible authorities indicates that within the next decade there will be a total of five new buildings, with installed transformer capacities of 150 KVA each plus 150 KVA installed in an addition to the Administration Building. Increases in capacities of present installations will probably amount to an additional 100 KVA. During this time a total of approximately 250 KVA in old transformers will be retired, leaving a net increase of approximately 750 KVA in connected load. The



KW DEMAND
2000
1900
1800
1700
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
29-30
30-31
31-32
32-33
33-34
34-35
35-36
36-37
37-38
38-39
39-40

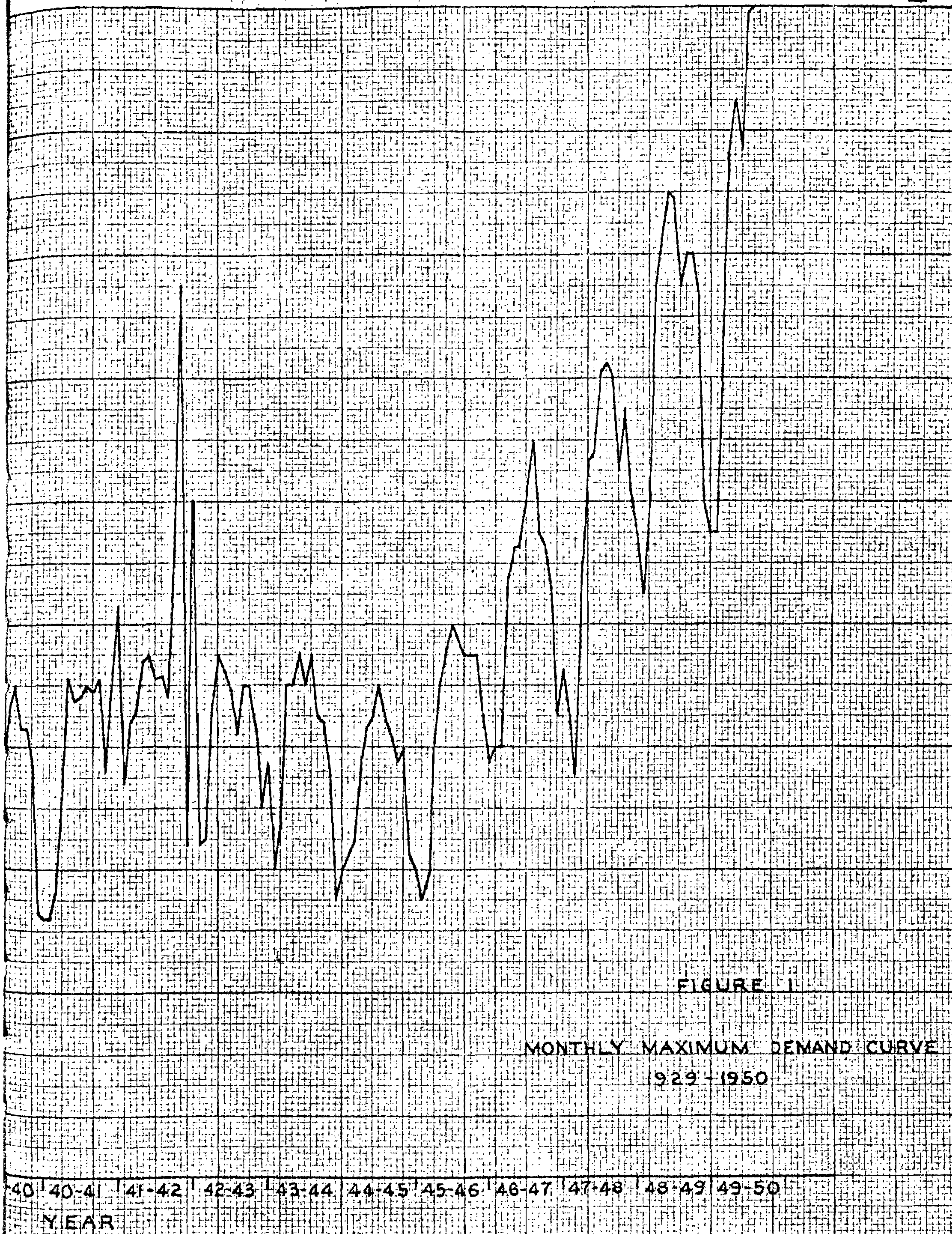


FIGURE 1

MONTHLY MAXIMUM DEMAND CURVE
1929 - 1950

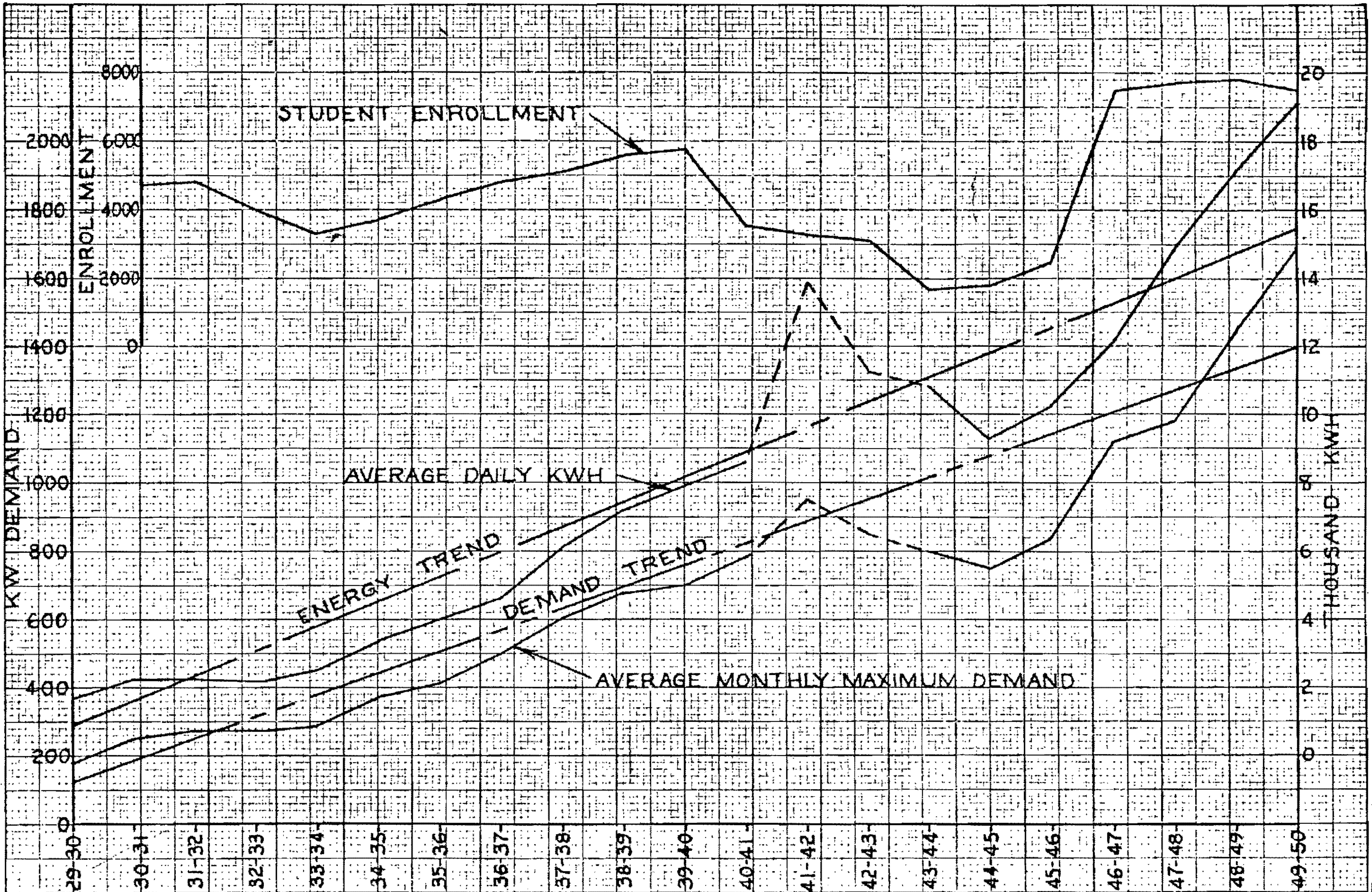


FIGURE 2
DEMAND AND ENERGY TRENDS

demand factor during the past has varied from 0.362 in 1933, the first year in which records were available, to 0.418 in 1949, so that a reasonable figure for the expected increase in maximum KW load for the next ten years would be 320 KW, making a maximum demand of 2320 KW in 1959-60. If the trend line is extended to 1959-60, the average monthly maximum demand is found as 2040 KW. The average monthly maximum demand has been approximately 80% of the maximum monthly demand, so that the maximum demand in 1959-60 from the trend line would be 2550 KW. This indicates that although the curve at present is somewhat above the trend line, it will level off and probably return to the trend line as established. Expressed as percentage, the increase in demand amounts to 2.25% based on 1949-50, if the maximum demand in 1959-60 is taken as the average of the two values established above, or approximately 2450 KW.

The corresponding energy increase, considering the planned building program, would amount to an increase in average daily requirements of 450 KWH per year. A figure of 720 KWH per year was established from the trend line, again indicating that the curve will return to the trend line as established. An average of the two above figures would be 585 KWH increase in daily energy requirements per year, or 3.0% based on 1949-50.

These figures, 2.25% for demand, and 3.0% for energy, will be used to construct daily load curves.

Before future load curves can be constructed, it must be determined that the general shape of the curve will not change significantly over a period of years. Accordingly, the data of Table XIII of the Appendix was gathered from plant log sheets and plotted as Figure 3. While it is noted that from year to year slight changes occur in the shape of the load curve, over a period of time the curve has not changed appreciably and the percentage change between curves is sufficiently steady that a constant rate of increase may be assumed to exist for purposes of this study.

Figures 4 through 9 on the following pages show the actual demand curves for the year 1949-50 and the expected load curves for the year 1959-60 for the peak day, typical summer, fall, winter and spring days, and winter weekends.

The data for the 1949-50 demand curves were taken from plant log sheets and compiled in Tables XIV and XVI in the Appendix. The peak day was taken not as the day on which the maximum demand was recorded, but as the day on which the most energy was used. The typical week days were chosen as days on which the energy consumed was closest to the average for the month excluding weekends. The weekend demand curves are all similar for any given season.

Data for the expected demand curves for 1959-60 were then computed using the percentage increase as already determined. For instance the demand at any time in 1959-60 was taken as 1.225 times the demand for that same time in 1949-50. The energy consumption for 1959-60 would be 1.3 times the energy consumption in 1949-50. These data are compiled in Tables XV and XVI of the Appendix.

The primary function of the University Power Plant is to supply heating steam to the buildings. The generation of electricity is a secondary function. Accordingly, the following Chapter presents a study of the steam distribution system and steam loads.

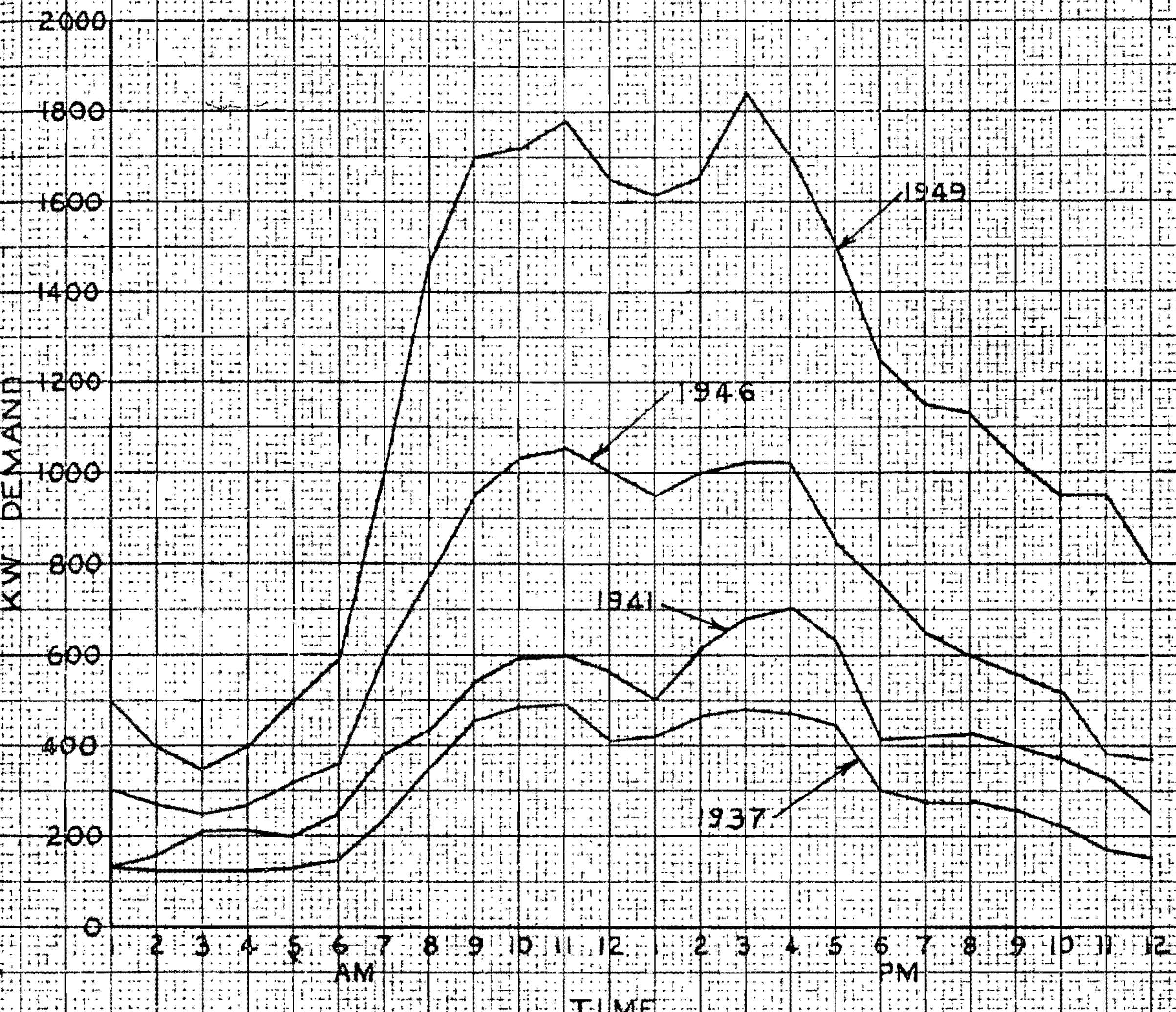


FIGURE 3

COMPOSITE HOURLY DEMANDS FOR SELECTED DAYS

IN NOVEMBER 937, 1941, 1946, 1949

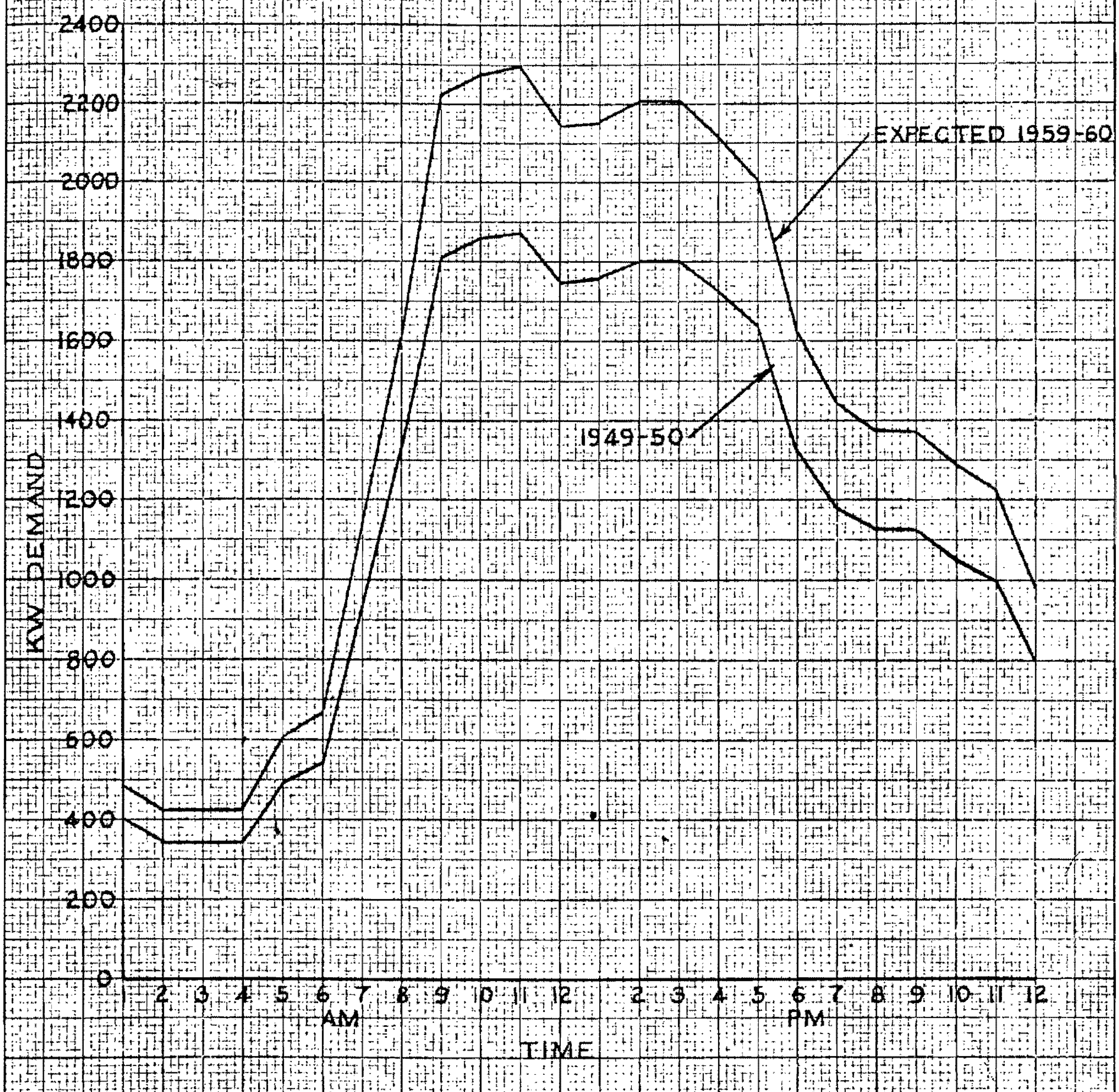


FIGURE 4

PEAK DAY DEMAND CURVES

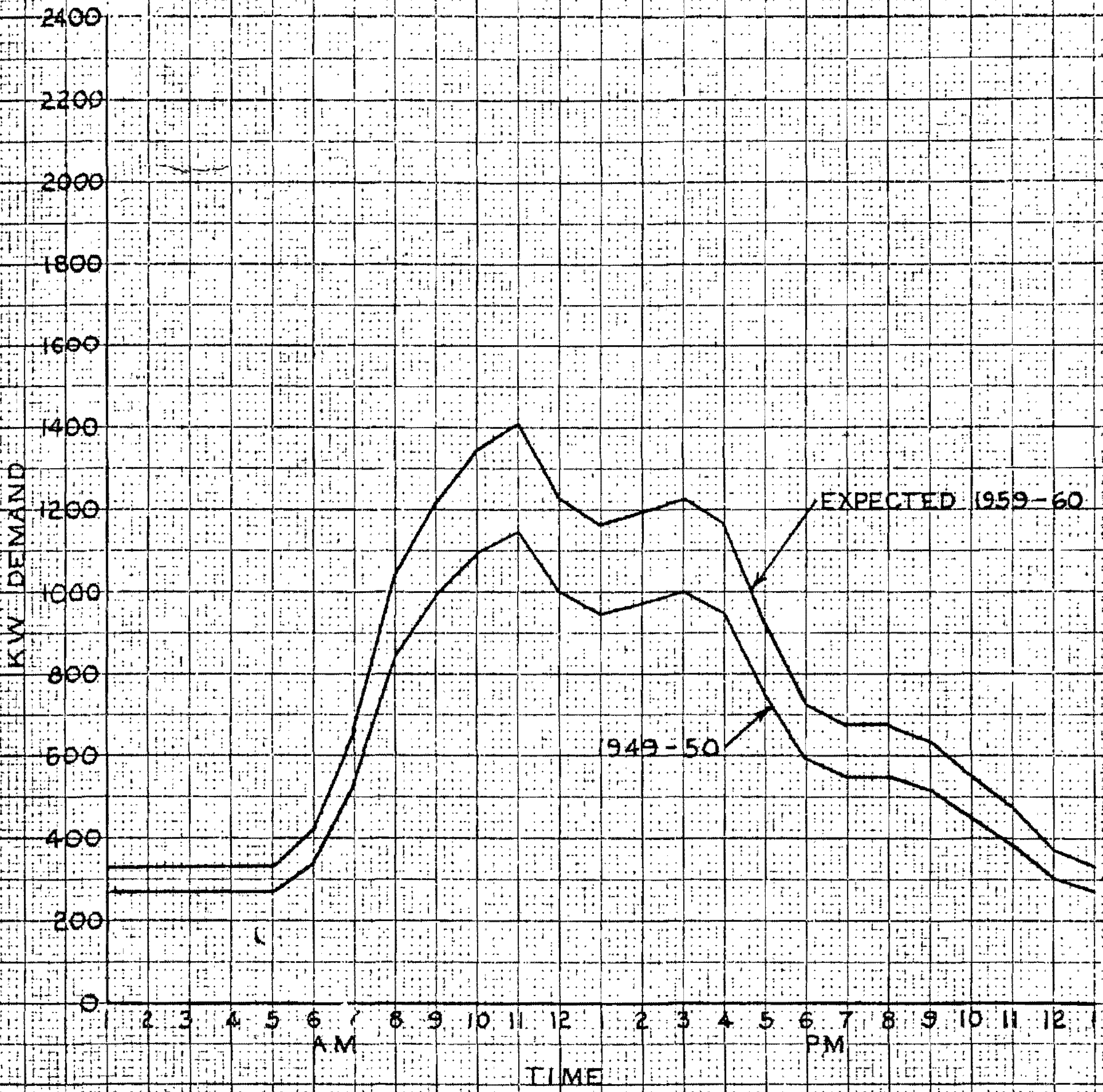


FIGURE 5

TYPICAL SUMMER LOAD CURVES

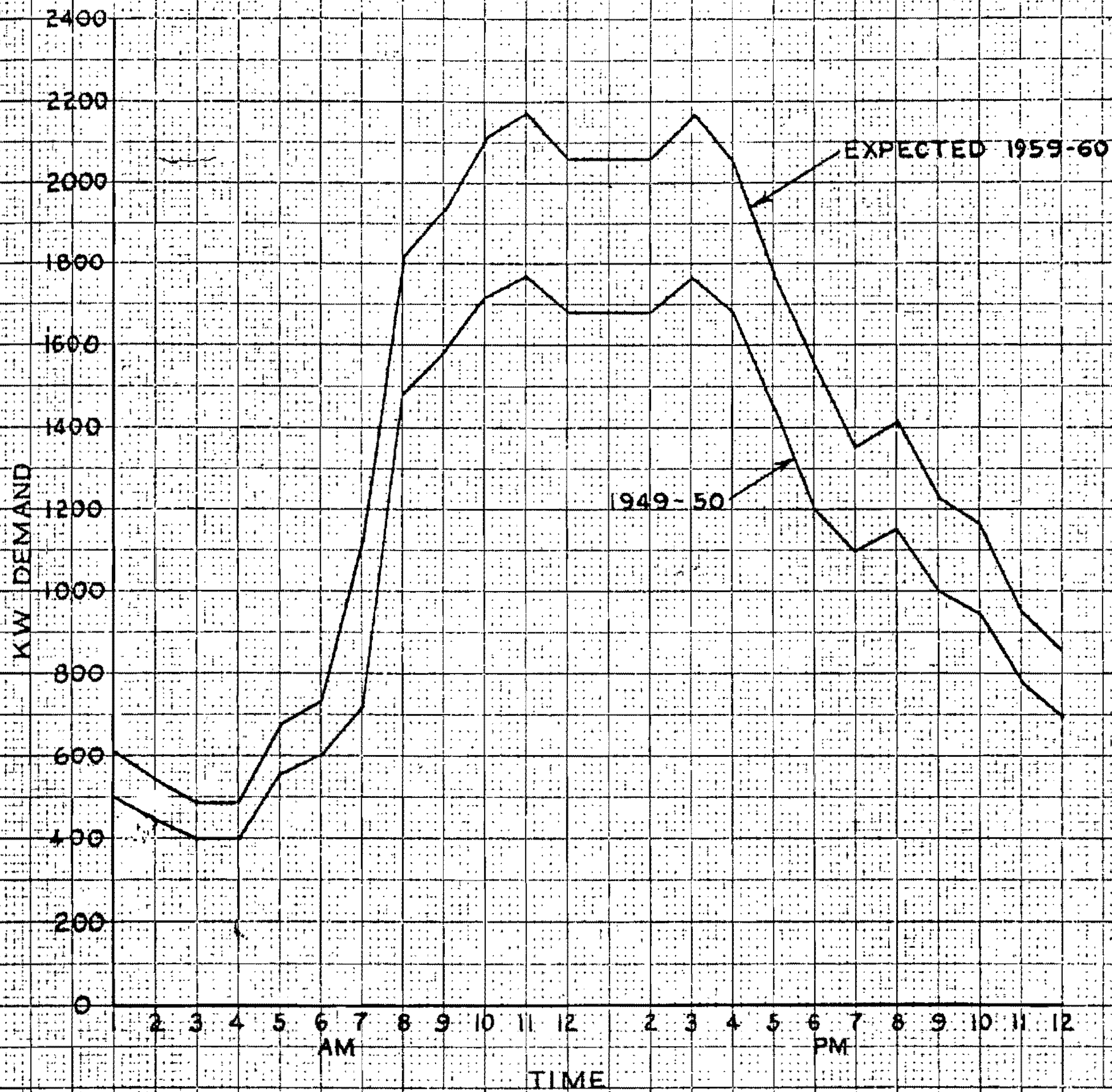


FIGURE 6

TYPICAL FALL LOAD CURVES

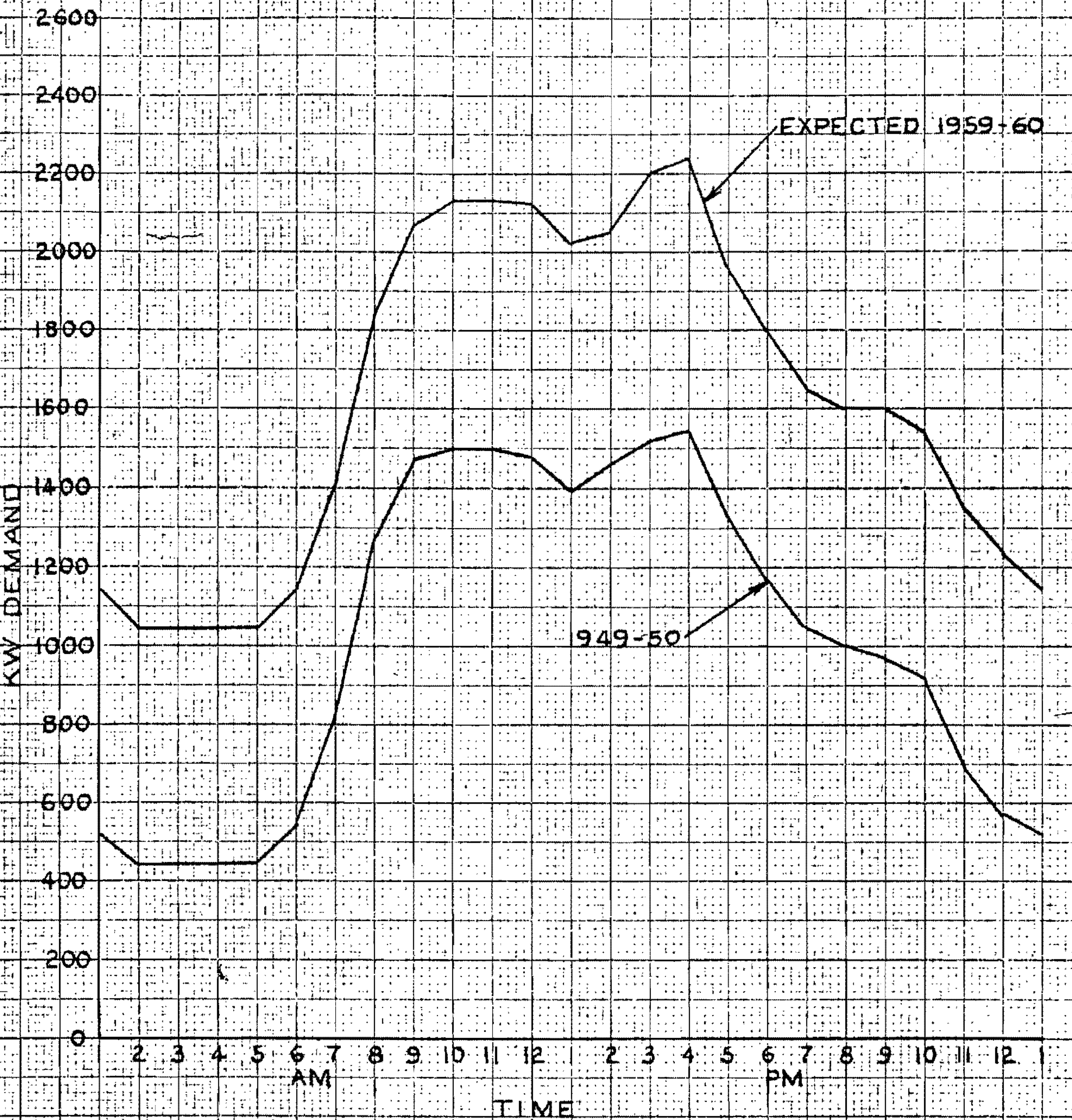


FIGURE 7

TYPICAL WINTER LOAD CURVES

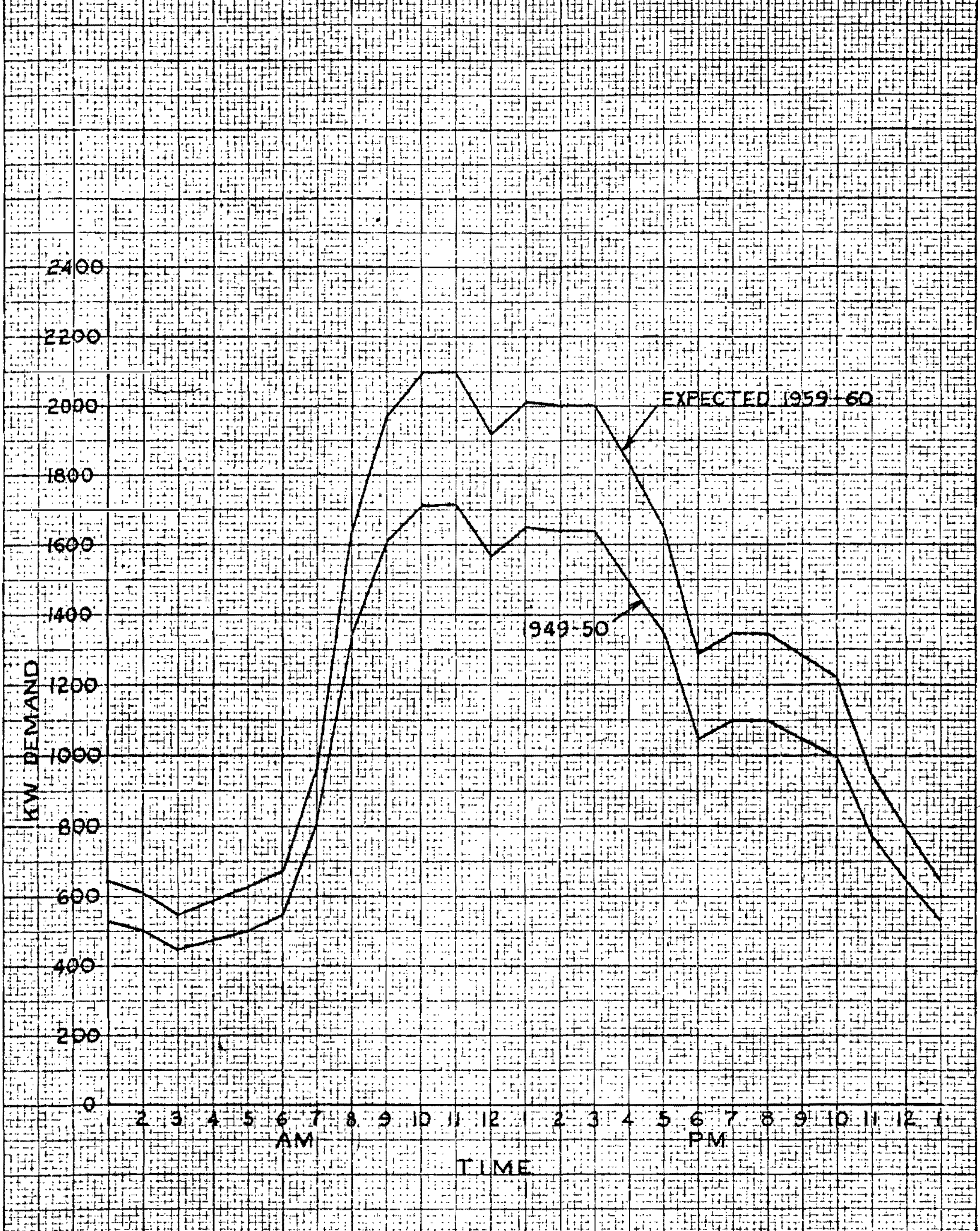


FIGURE 8
TYPICAL SPRING LOAD CURVES

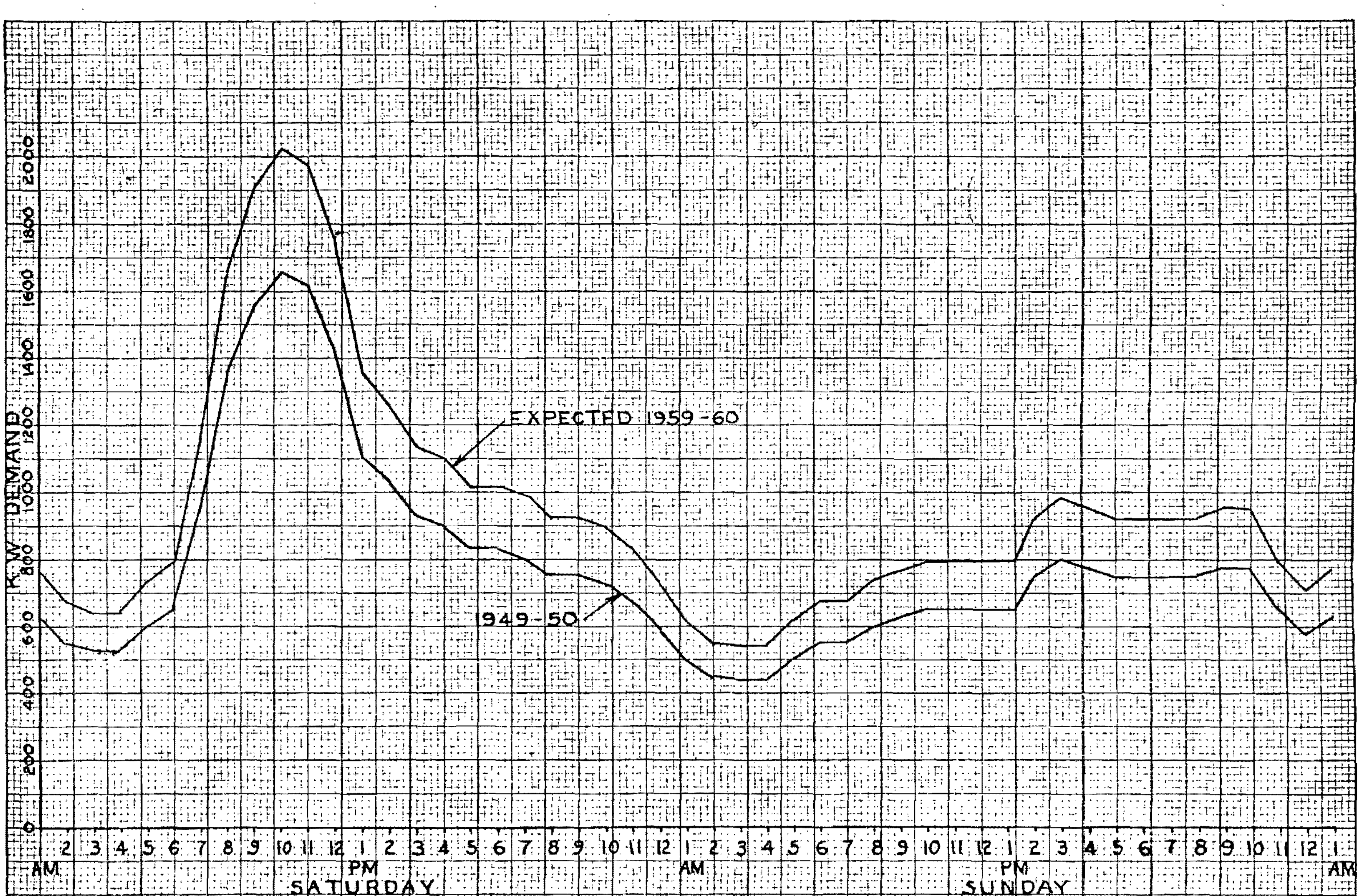


FIGURE 9

TYPICAL WINTER WEEKEND LOAD CURVES

CHAPTER III

STEAM DISTRIBUTION SYSTEM AND LOAD SURVEYS

A total of 38 buildings are connected to the University Power Plant for heating. 34 of these buildings are heated with steam extracted from the turbines, which in severe weather is augmented by steam reduced to a pressure of 60 psig through a reducing valve and desuperheater at the plant. Three buildings supplied by exhaust from plant auxiliaries and steam from plant heater reduced to distribution pressure at the plant. The remaining building, namely Berry Hall, is heated with steam distributed at plant pressure of 200 psig and reduced ahead of heating equipment with reducing valves located within Berry Hall.

With reference to Figure 10, the steam for 30 of the buildings is metered through the Strong Hall meter. Steam for four buildings is metered through the Humes Hall meter. The remainder of the heating steam is not metered.

The Strong Hall steam line, again referring to Figure 10, leaves the front of the plant where two branch lines leave, one proceeding up the hill terminating at Ayres Hall, the other running in front of Estabrook Hall to the East Stadium, and turning left along Stadium Drive to South Stadium. The Strong Hall main proceeds along Estabrook road through the back of the Memorial Auditorium to the 15th Street entrance, where a branch line feeds the Administration and Biology buildings, the Student Center and the SFOB office. The main proceeds up 15th Street to Temple, where another branch feeds steam to Melrose Hall. The main here turns right along Temple to W. Cumberland Avenue. Here two branches leave the

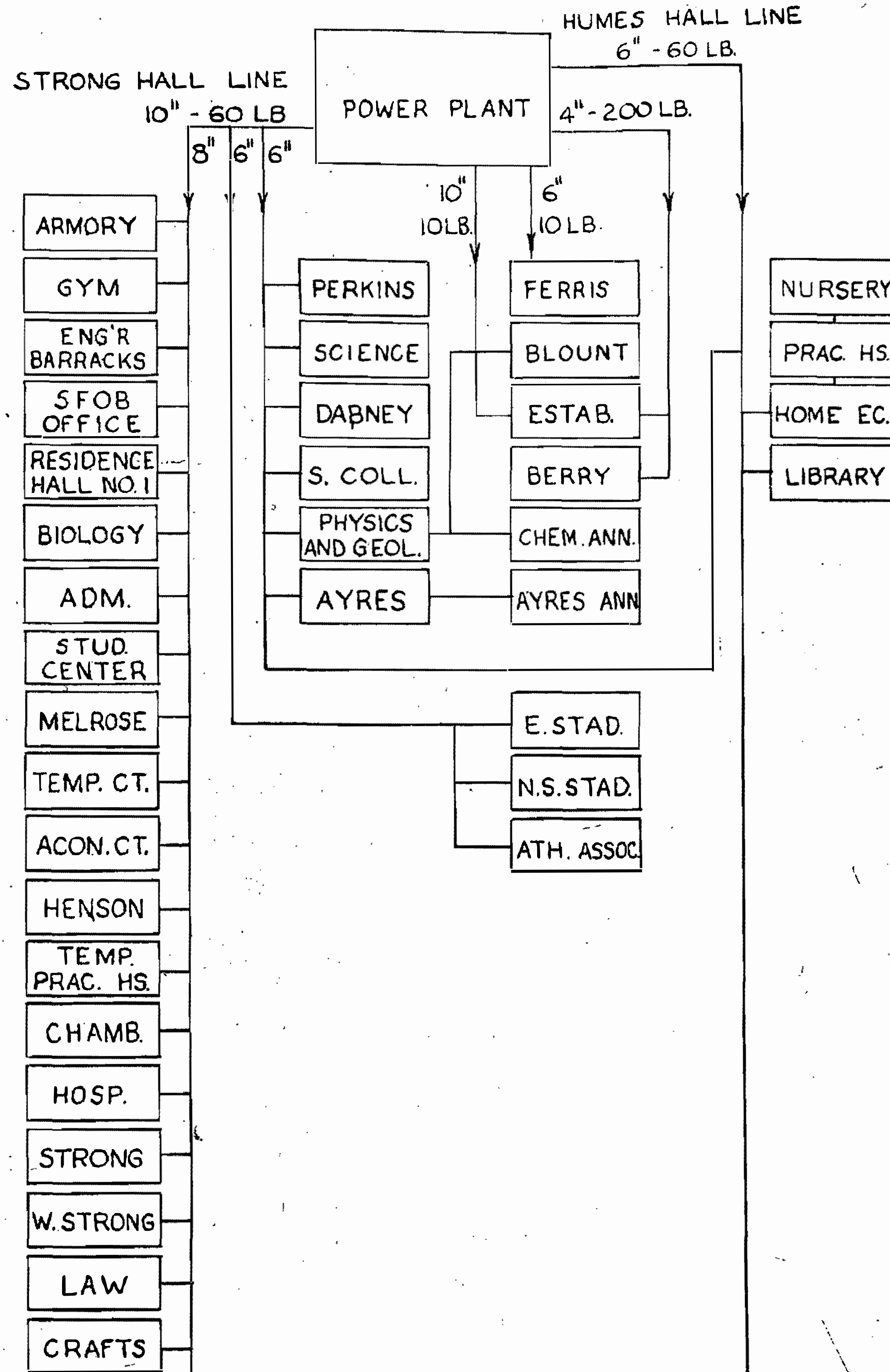


FIGURE 10
HEATING STEAM DISTRIBUTION DIAGRAM

main line, one feeding Henson Hall and Chamberlain Residence, the other crossing Temple to feed Aconda and Temple Courts, the Hospital, and Temple Practice House. The main then proceeds across W. Cumberland to a point East of Strong Hall. A branch here feeds Strong and West Strong Halls; the main then turns right and runs to the Law Building, and across 15th Street to a connection with the Humes Hall line in the Library.

The Humes Hall line leaves at the Northeast corner of the plant and runs to a point east of Dabney Hall above Estabrook Road where a connection is made to the Ayres Hall line. The line is here reduced from 6 inches to 4 inches and proceeds along the hill, across West Cumberland Avenue to the Home Economics building. A branch here runs through the Home Economics building to the Nursery and White Avenue Practice House. The main line proceeds along an alley to the above mentioned connection in the Library.

There are two low pressure lines. Ferris Hall is served exclusively by a 6 inch 10 psig line. The other line provides heat for Blount and Estabrook Halls.

In most cases, the steam mains are paralleled by a low pressure return line, but in some instances where it was necessary to provide gravity flow, the return line follows a separate path. In general, steam lines are insulated with 1½" of 85% Magnesia. The return lines on the Humes Hall line are not insulated.

Table II shows the cubic feet content of the buildings connected to the plant for heating during the 1949-50 heating season. It is proposed to show that within certain limits the steam demand for heating varies with

TABLE II

CUBICAL CONTENT OF BUILDINGS CONNECTED FOR HEATING

Building	Cubical Content		
Armory	119,622		
Memorial Auditorium	1,669,809		
Eng. Barracks	217,200		
SFOB Office	34,496		
Men's Res. Hall #1	49,280		
Biology	739,873		
Administration	446,467		
Student Center	44,208		
Melrose	667,755		
Temple Court	125,994		
Aconda Court	309,040		
Henson	298,100		
Temple Prac. House	59,713		
Chamberlain Residence	27,340		
Hospital	141,504		
Strong Hall	835,730		
W. Strong Hall	114,774		
Law	426,596		
Crafts Shop	33,600		
Subtotal		6,361,101	
E. Stadium	498,264		
N. S. Stadium	682,268		
Athletic Assoc.	71,453		
Subtotal		1,251,985	
Perkins	647,406		
Science	272,272		
Dabney	215,424		
Chem. Annex	179,600		
S. College	137,522		
Physics & Geol.	307,604		
Ayres	770,660		
Ayres Annex	47,200		
Subtotal		2,577,688	
Total on Strong Hall Meter			10,190,774
Nursery	77,160		
Practice House	31,050		
Home Economics	697,259		
Library	468,666		
Total on Humes Hall Meter			1,274,135
Ferris	479,776		
Blount	151,360		
Estabrook	583,137		
Subtotal		1,214,273	
Berry Hall		107,869	
Total Unmetered			1,322,142
GRAND TOTAL			12,787,051

the cubical content of the buildings, since all of the data which heating steam is normally based on, varies in some manner with the cubical content.

Tables XVII and XVIII of the Appendix lists the heating steam demand by years and by months for the 1949-50 season. Table XIX of the Appendix gives the degree days below 65 F per month as published by the U. S. Weather Bureau for the Knoxville area.

Figure 11 shows that the steam flow does vary with degree days, the points plotted being taken at random for the 1946-47 heating season. Figure 12 illustrates that the steam flow does vary with the student enrollment, the degree days per year being essentially constant.

According to the above ideas, any two periods to be chosen for comparison must have essentially the same number of degree days and the same student enrollment. The months of December 1946 and December 1949 were chosen for comparison, since the average temperatures were 44.2 F and 43.1 F, respectively, and the student enrollments were 7,442 and 7,506 respectively.

The total connected cubical content in December 1946 was 9,720,485 cubic feet. The steam demand for heating was 16,881,275 pounds. In December 1949 the connected cubical content was, from Table II, 12,787,051 cubic feet, while the steam demand was 23,229,859 pounds.

Thus the increase in cubical content was 31.6%, while the increase in steam demand was 37.6%. This difference can be attributed to the temporary nature of several of the buildings added during the period being studied, resulting in a greater heat loss than would have normally occurred, and hence a greater steam demand. It is safe to assume that had all of

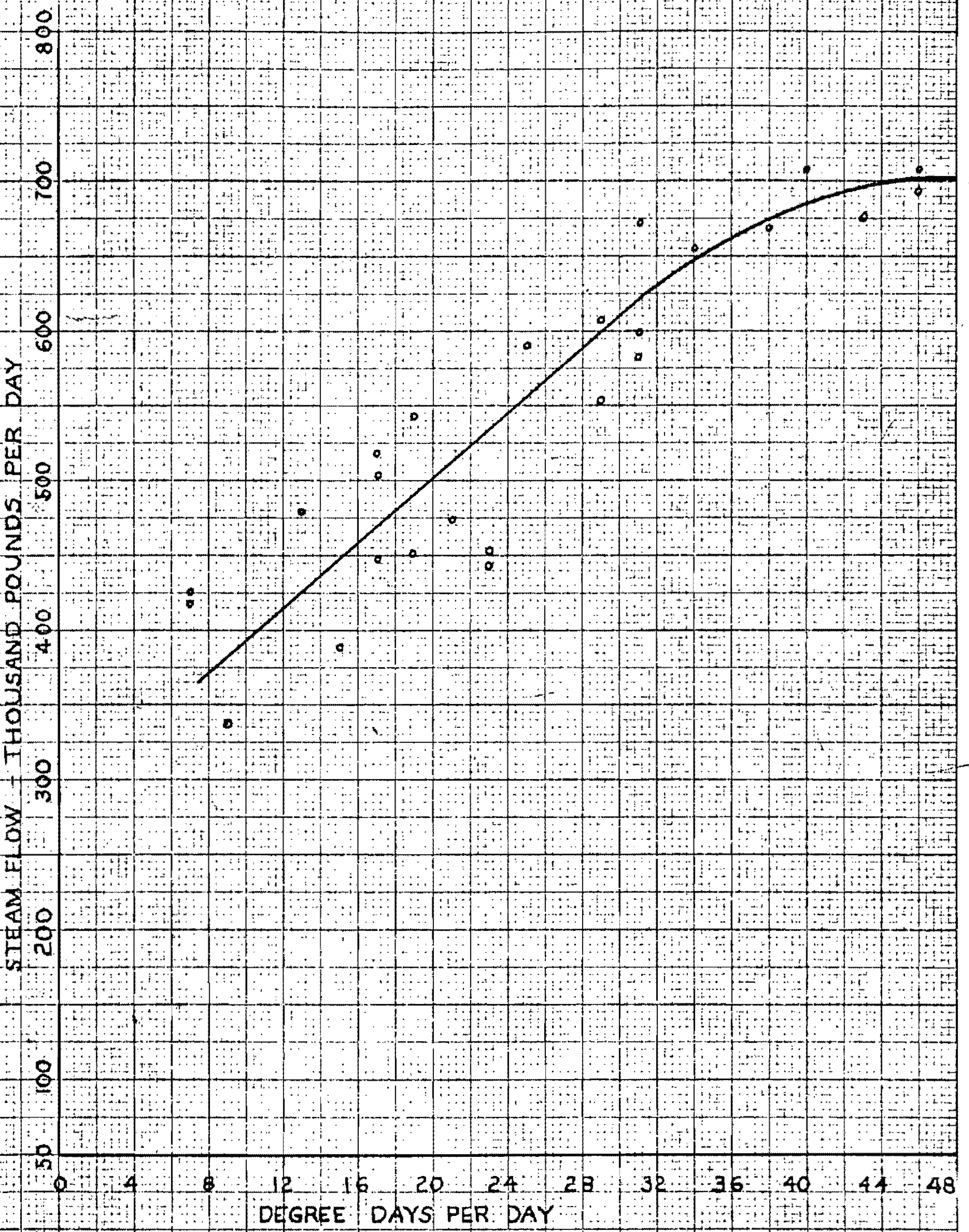


FIGURE 11

VARIATION IN STEAM FLOW WITH DEGREE DAYS

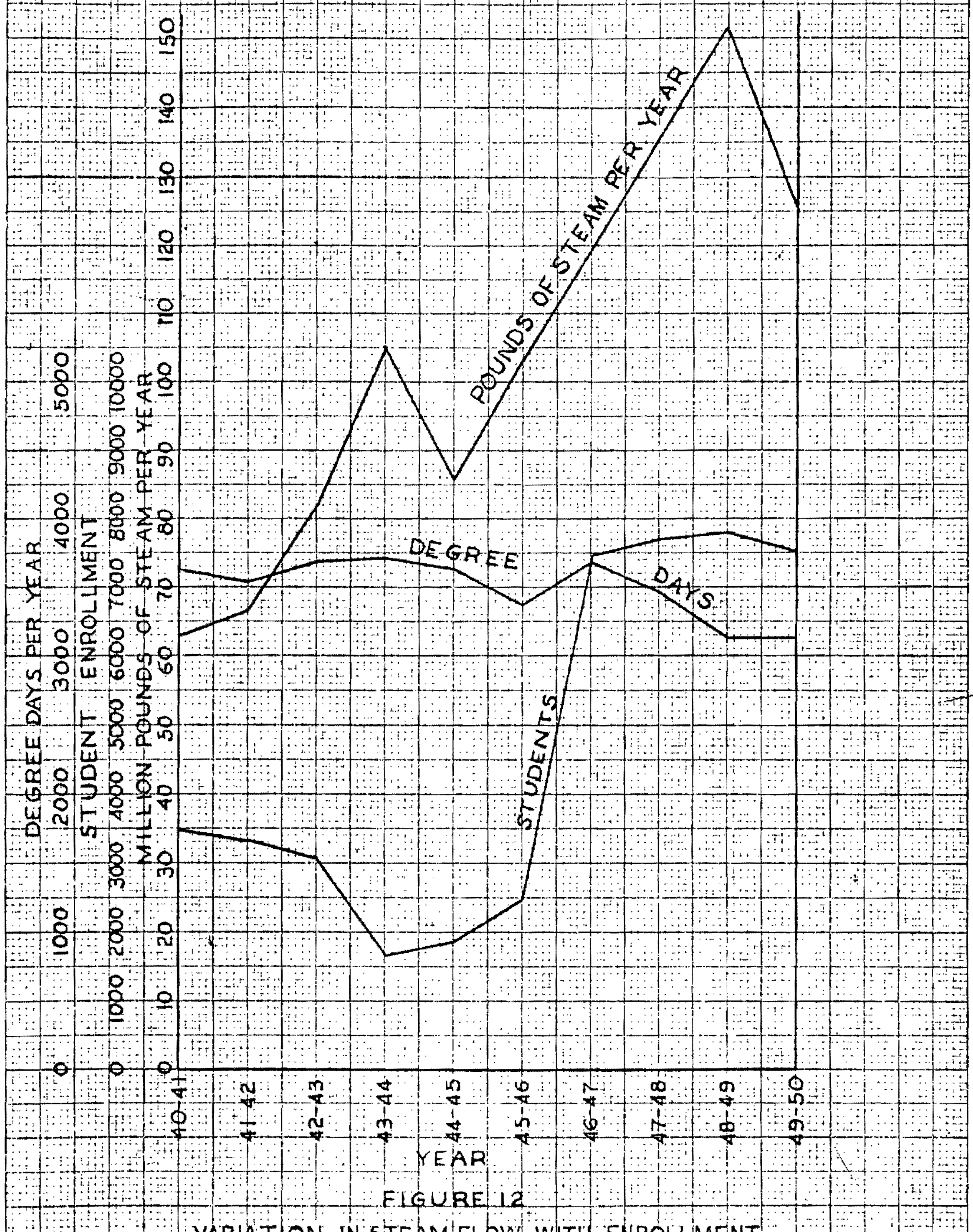


FIGURE 12

VARIATION IN STEAM FLOW WITH ENROLLMENT

the buildings been of a permanant type, the steam demand increase would have approached 31.6%, the increase in cubical content.

The increase in connected cubical capacity over the next ten years, to 1959-60, is expected to be about 3,850,000 cubic feet, or an increase of 30% over 1949-50. According to the above arguments, we can expect an increase in steam demand for heating of about 30%.

To apply this percentage increase to values of steam flow for 1949-50, Figure 13 was prepared from the data of Tables XVIII and XIV. This curve shows that with an increase in the number of degree days per month, there is a corresponding decrease in the pounds of steam per degree day, and that for high values of degree days per month the relationship can be assumed linear. This is to be expected since as the weather becomes colder, windows and doors which are normally left open are closed, less heat is wasted. The curve naturally approaches infinity at zero degree days, since a fixed amount of steam must go to heat water and for certain processes such as steam tables.

From Figure 13, a correction was found to convert the steam flow from what it actually was to what it would have been had the temperature been normal. Corrections were made only for those months for which the total degree days falls on the solid portion of the curve, the dashed portion being unreliable. The expected increase of 30% was then applied to the corrected steam demand.

The results of these calculations are tabulated in Table III.

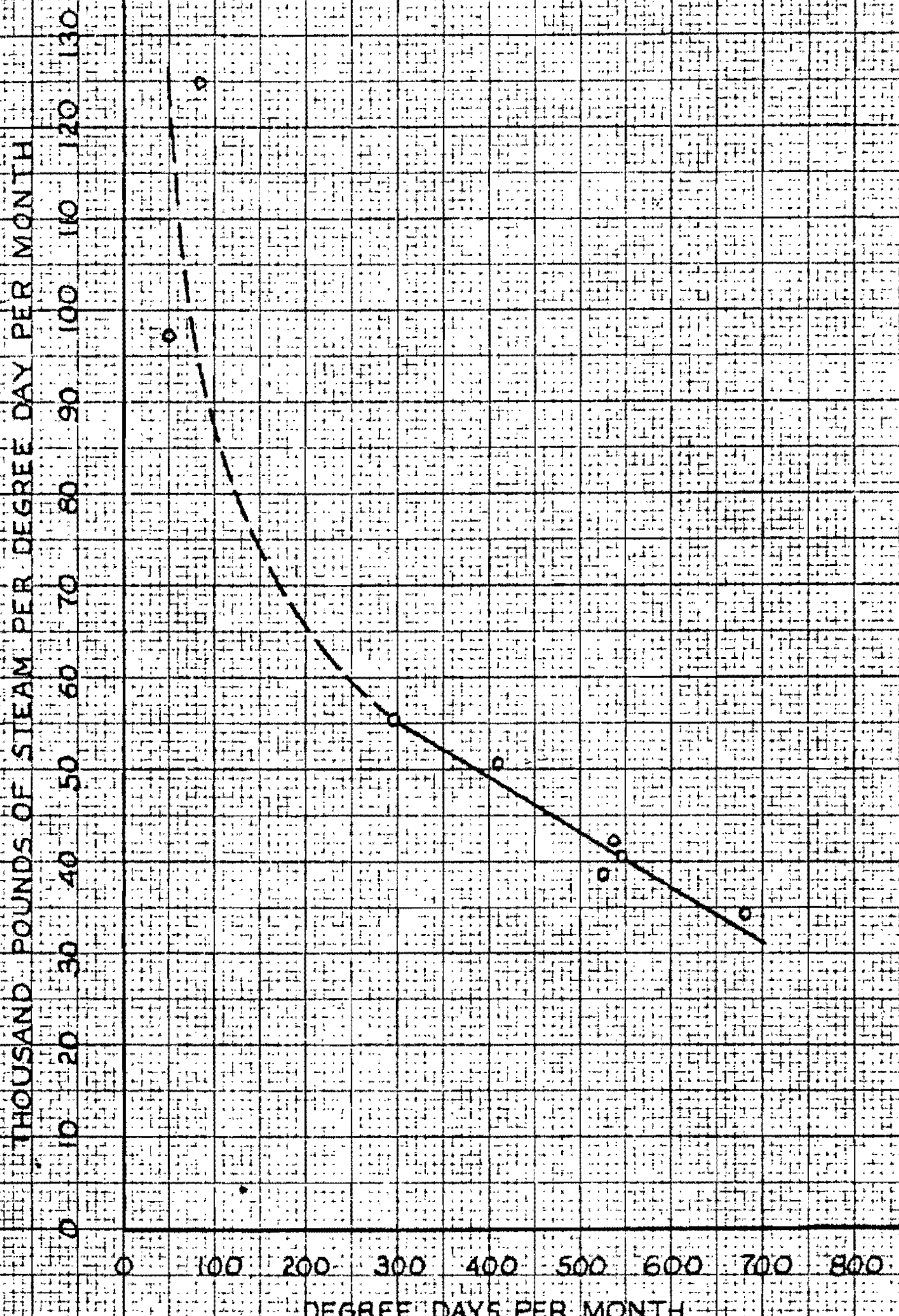


FIGURE 13

VARIATION IN POUNDS OF STEAM PER DEGREE DAY PER MONTH WITH DEGREE DAYS PER MONTH

TABLE III

STEAM DEMAND FOR HEATING ON 65 PSIG LINES

Month	1949-50	Corrected 1949-50	Expected 1959-60
July	4,261,950 lb.	4,261,950	5,550,000
Aug.	4,038,300	4,038,300	5,250,000
Sept.	4,854,000	4,854,000	6,310,000
Oct.	10,379,000	10,379,000	13,480,000
Nov.	22,010,000	20,849,500	27,104,000
Dec.	23,230,000	22,500,000	29,250,000
Jan.	20,730,000	22,743,000	29,550,000
Feb.	20,248,000	20,130,000	26,200,000
Mar.	22,708,000	21,430,500	27,900,000
Apr.	16,522,000	16,744,000	21,800,000
May	5,967,000	5,967,000	7,750,000
June	5,046,800	5,046,800	6,550,000
TOTAL			206,694,000

CHAPTER IV

SURVEY OF PRESENT EQUIPMENT AND SELECTION OF EQUIPMENT FOR FUTURE USE

The University of Tennessee must of necessity furnish its own heat. Central heating is without question the answer to the problem of how best to supply this heat, as has proven the case even with many institutions which must pay commercial rates for fuel.

The present steam generating equipment consists of two Combustion Engineering Boilers, one with a continuous rating of 80,000 lb per hr, and one of 60,000 lb per hr, both with considerable useful life left, as outlined in Chapter I. They will supply steam at 200 psig and 500 F. Also available to supply saturated steam at 200 psig are two Casey Hedges boilers rated at 350 boiler horsepower each. Experience indicates that together the two can be depended on to supply approximately 40,000 lb per hr continuously.

The maximum steam demand occurring in 1949-50 was 70,000 lb per hr, this for less than two hours during the early morning warm-up period. Applying an increase of 30%, as determined in Chapter III, to this figure, we can expect a maximum demand in 1959-60 of 91,000 lb per hr. This demand can easily be supplied by the new 80,000 lb per hr CE boiler as it has a four hour rating of 100,000 lb per hr.

For standby equipment, the 60,000 lb per hr CE boiler plus the two Casey Hedges boilers gives additional capacity of 100,000 lb per hr. It must be expected, however, that considering the age of the two Casey Hedges boilers of 22 years, and their corresponding lower efficiencies, that for anything other than emergency of standby use these boilers should be reconditioned and modernized, including the addition of waterwalls and superheaters. A detailed study of the costs and physical requirements of this work should be made, but is beyond the scope of this work.

For supplying the electric power requirements the University has three turbogenerators, as noted in Chapter I. One of these, the 1500 KW Westinghouse, can supply heating steam at 65 psig bleed pressure. The other two, one Westinghouse and one General Electric have capacities of 500 KW each, giving a total installed capacity of 2500 KW. The latter two units were originally designed to bleed steam at 10 psig, no provision being made for bleeding at the distribution pressure of 65 psig as now being used.

From a capacity standpoint, the expected maximum demand in 1959-60 of 2450 KW as determined in Chapter II can be supplied in four ways. These are:

1. Generate all power with present equipment.
2. Generate all power with new unit to be purchased.
3. Generate such power as the demand for heating steam will supply, purchase remainder.
4. Purchase all electric power.

In the selection of a new unit to be purchased under plan 2, it will be well to note at this point that by 1960 the newest unit now in service, the 1500 KW Westinghouse, will be 20 years old; the 500 KW Westinghouse and the 500 KW General Electric will be 36 and 32 years respectively. The dependability of units this old will be questionable, and could probably be depended on only for emergency or standby use. Most authorities state that it is necessary to provide spare capacity equal to that of the largest active unit. The University, however, has the previously mentioned city standby connection, eliminating the necessity of providing spare capacity. Moreover, experience has taught that parallel operation of two units requires a man to be in continuous attendance, while the occasional attention required by a single unit can be given by the boiler operator.

If then, a new unit is to be purchased it should be of sufficient capacity to handle the entire load in 1959-60. In Chapter II, it was determined that the maximum demand in 1959-60 will be 2450 KW. A turbo-generator size of 2500 KW would appear to be in order from these considerations.

Chapter V will consider the four above mentioned plans to determine the most economical.

CHAPTER V

ECONOMIC CONSIDERATIONS

Operating with Present Equipment

Figure 14 is the water rate curve for the 1500 KW turbogenerator as supplied by the Westinghouse Electric Company. Observation and tests on this unit indicate that the actual operation of this unit approach closely these curves. Figure 15 shows the water rates for the Westinghouse 500 KW turbogenerator. These curves were arrived at from actual operating conditions as taken from plant log sheets over a period of time. As noted on the curve, the average vacuum on this unit was 24 inches of mercury. This low vacuum was for the most part due to the lack of cooling water at low temperature, as the water for this condenser is supplied from a spray pond. If sufficient pump capacity is installed at the river pumphouse to supply river water to this unit, an increase in vacuum to 28 inches could be attained, and a decrease in throttle flow of approximately 8% expected. Actual operating data of recent date on the 500 KW G. E. unit are not available in sufficient quantity to be of use in setting up water rate curves, but such data as are available seem to indicate a slightly higher water rate than for the 500 KW Westinghouse.

In Chapter II an increase of 30% in KWH consumption was anticipated within the next decade. From Table I of the Appendix, the KWH consumption in 1949-50 was 6,961,800 KWH. In 1959-60 then, the expected power consumption will be 9,050,340 KWH per year. Due to the much higher water rates of the 500 KW units, as much as possible of this demand should be supplied by the 1500 KW unit, even at low loads.

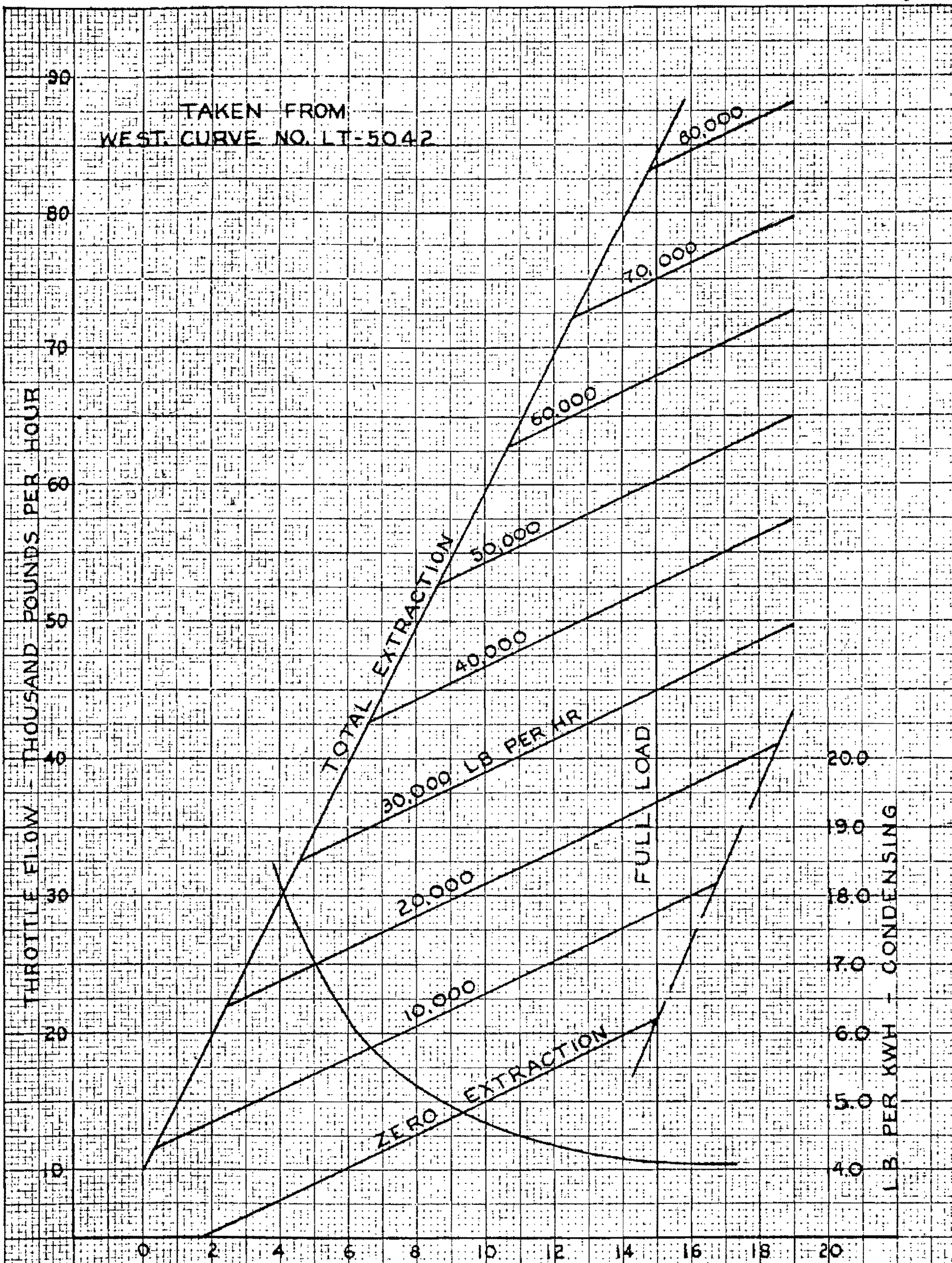


FIGURE 14
THROTTLE FLOW TO 1500 KW WESTINGHOUSE

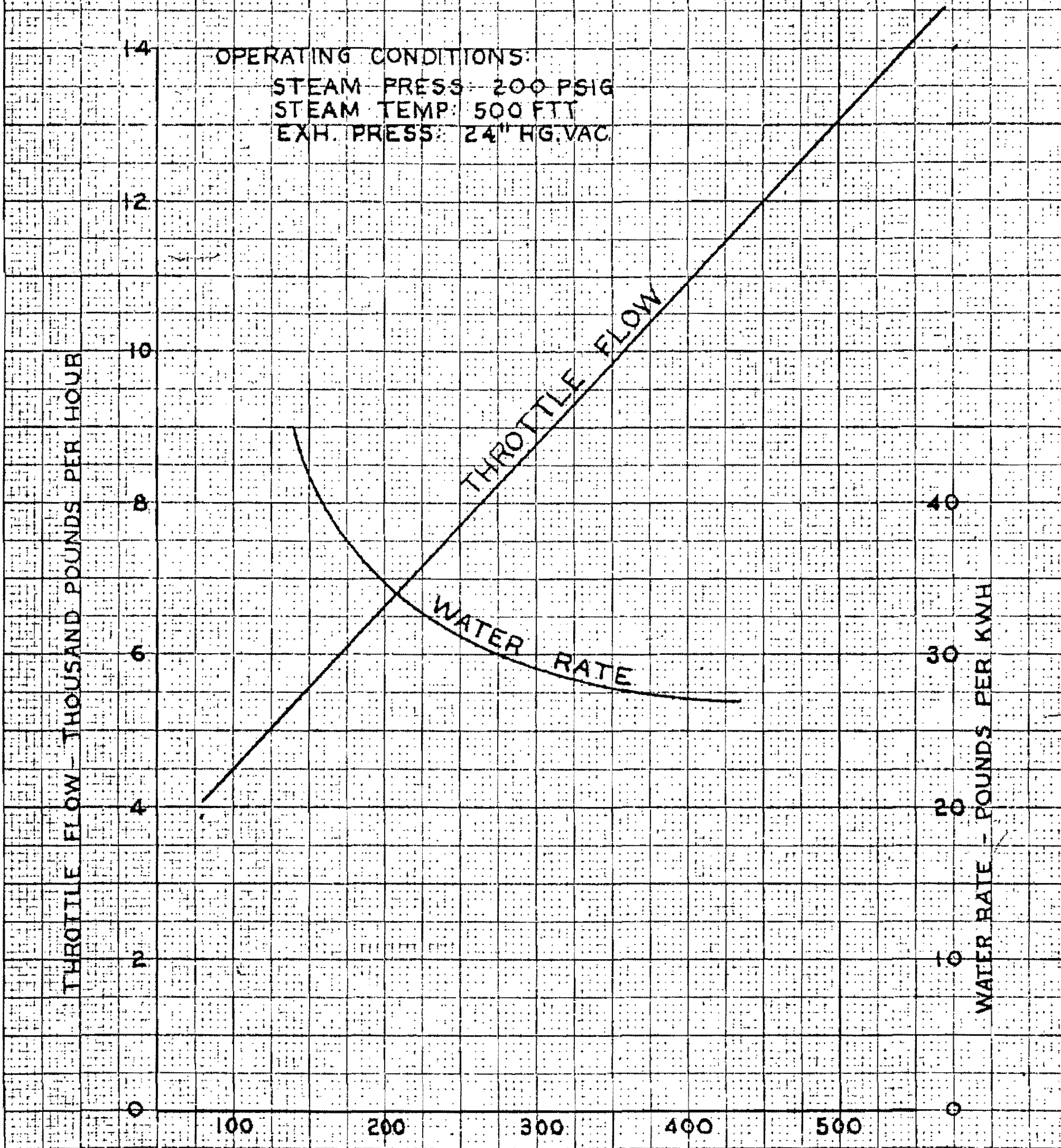


FIGURE 15

THROTTLE FLOW TO 500 KW WESTINGHOUSE

While exact load curves for any given day cannot be exactly constructed, it was shown in Chapter II that the shape of the average daily load curve is essentially constant. From Table I of the Appendix, the KW peak and KWH consumption were estimated using the rates of increase determined in Chapter II, and are tabulated in Table IV for each month of the year 1959-60. The monthly basis was chosen for computation since the City of Knoxville demand charges are based on monthly maximum demand, as will be later described. Average daily load curves were then constructed and a suggested schedule for operation of the three available units to supply the load based on these curves is tabulated in Table III. In setting up this schedule, preference was given to the most economical unit.

Table V tabulates the steam flows to the units as determined from the water rate curves at the average load on each unit, and show the total steam to the units for the months under consideration.

To arrive at a comparison of costs for each plan as described in Chapter IV, fixed charges on existing equipment will not be included, since no alterations planned will erase these costs. Fixed charges on new equipment plus actual operating expenses will be representative of the actual cost to the University of each plan.

It should be mentioned at this point that the Power Plant budget contains several items which are not actually chargeable to the Power Plant. Water and gas for all buildings are included in the Power Plant budget for want of a better place to include them. Also the items of fuel and labor at the University farm power plant are included in the budget, but will be excluded from this study.

Table VI is a tabulation taken from actual ledger sheets of the

TABLE IV

SUGGESTED OPERATING SCHEDULE FOR 1959-60
USING PRESENT UNITS

Month	KW Peak	Total KWH	KW Distribution 500KW GE Hrs.	500KW GE KWH	500KW West Hrs.	500KW West KWH	1500KW West Hrs.	1500KW West KWH
July	1410	434,000	0	0	0		744	434,000
Aug.	1410	516,000	0	0	0		744	516,000
Sept.	1890	476,000	0	0	130	24,000	720	452,000
Oct.	2160	823,000	180	18,000	315	141,750	744	663,250
Nov.	2270	910,000	240	24,000	300	105,000	720	781,000
Dec.	2170	755,000	180	18,000	315	141,750	744	595,250
Jan.	2440	958,000	240	36,000	330	148,500	744	773,500
Feb.	2450	916,000	240	40,000	330	150,000	672	736,000
Mar.	2340	951,000	220	30,000	330	140,000	744	781,000
Apr.	2250	874,000	200	20,000	330	130,000	720	724,000
May	2330	918,000	220	30,000	330	150,000	744	738,000
June	1710	519,000	0	0	240	48,000	720	471,000
Totals				216,000		1,179,000		7,665,000

TABLE V

STEAM DEMAND FOR GENERATION, PLAN I
FOR 1959-60

	500 KW G. E.			500 KW Westinghouse		
Month	Average KW Load	Average Thr. Flow lb per hr	Lb. Total Steam	Average KW Load	Average Thr. Flow lb per hr	Lb. Total Steam
July	0	0	0	0		
Aug.	0	0	0	0		
Sept.	0	0	0	185	6,300	820,000
Oct.	100	5,000	900,000	450	12,000	3,780,000
Nov.	100	5,000	1,200,000	350	9,900	2,970,000
Dec.	100	5,000	900,000	450	12,000	3,780,000
Jan.	150	6,500	1,560,000	450	12,000	3,960,000
Feb.	170	7,000	1,680,000	455	12,100	4,000,000
Mar.	135	6,000	1,320,000	425	11,500	3,800,000
Apr.	100	5,000	1,000,000	395	10,800	3,560,000
May	135	6,000	1,320,000	455	12,100	4,000,000
June	0	0	0	200	6,600	1,580,000
TOTAL			9,880,000			32,250,000

TABLE V (continued)

STEAM DEMAND FOR GENERATION, PLAN I
FOR 1959-60

	1500 KW Westinghouse				
Month	Average KW Load	Avg. Bleed lb per hr	Avg. TF, lb per hr	Steam to Cond. lb/hr	Total Steam to Cond., lb
July	584	7,470	15,000	7,530	5,600,000
Aug.	695	7,070	16,000	8,930	6,630,000
Sept.	630	8,780	16,500	7,720	5,560,000
Oct.	892	18,100	27,000	8,900	6,610,000
Nov.	1085	37,600	45,600	8,000	5,760,000
Dec.	800	39,300	43,500	4,200	3,125,000
Jan.	1040	39,700	46,800	7,100	5,280,000
Feb.	1045	38,900	46,500	9,600	6,450,000
Mar.	1050	37,500	45,000	7,500	5,575,000
Apr.	1005	30,250	39,500	9,250	6,660,000
May	993	10,400	23,500	13,100	9,730,000
June	655	9,100	17,500	8,400	6,050,000
TOTAL					73,030,000

power plant of the expenditures for the year 1949-50 with those items not properly chargeable to the power plant having been deducted. Column 1 contains those items which can be directly charged to electrical generation. Column 2 contains the items which can be charged to steam and electric distribution and steam generation. Of the total charged in Column 2, a total of $9,921.04 can be directly charged to upkeep on the distribution systems, leaving a total of $125,752.75 to be charged to steam generation. This represents a cost of $0.417 per thousand pounds of steam generated. This unit cost will of course be lower with increased steam load.

Figure 16 shows that the rate of increase per year of total water evaporated is approximately the same as the rate of increase in steam demand for heating, namely 30% as determined in Chapter III. In 1949-50 from Table XX of the Appendix, a total of 310,583,000 pounds of water were evaporated. In 1959-60 then, applying the increase of 30%, we can expect an increase of 93,175,000 pounds per year, or a total of 403,758,000 pounds per year. Fuel to supply this steam is coal from the State mines at Petros, for which the University pays $5.08 per ton at present freight rates. Recent coal analyses show a heating value of approximately 13,000 Btu per pound of coal. The efficiency of the 80,000 pound per hour CE boiler at normal loads is 86%. This figure is substantiated by daily records of performance kept at the plant. A heat balance shows that it will require 19,350 tons of coal to furnish total steam, or the fuel cost under Plan 1 will be $98,298.00 for the year 1959-60. This is of course assuming no increase in cost per ton of coal during this period.

It should be pointed out that throughout this study, costs for each

TABLE VI

EXPENDITURES IN 1949-50
CHARGEABLE TO POWER PLANT

Item	Directly Chargeable To Elec. Gen.	Chargeable to Dist. Systems and Steam Gen.	Total
Salaries	$ 2,500.00	$ 21,160.00	$ 23,660.00
Labor	1,000.00	19,991.52	20,991.52
Fuel		74,860.00	74,860.00
Water		2,586.44	2,586.44
Equipment		3,463.52	3,463.52
Rep. and Maint.	791.00	10,460.67	11,251.67
Supplies	316.63	1,990.71	2,307.34
Misc.	50.00	1,160.93	1,210.93
TOTALS	$ 4,657.63	$135,673.79	$140,331.42

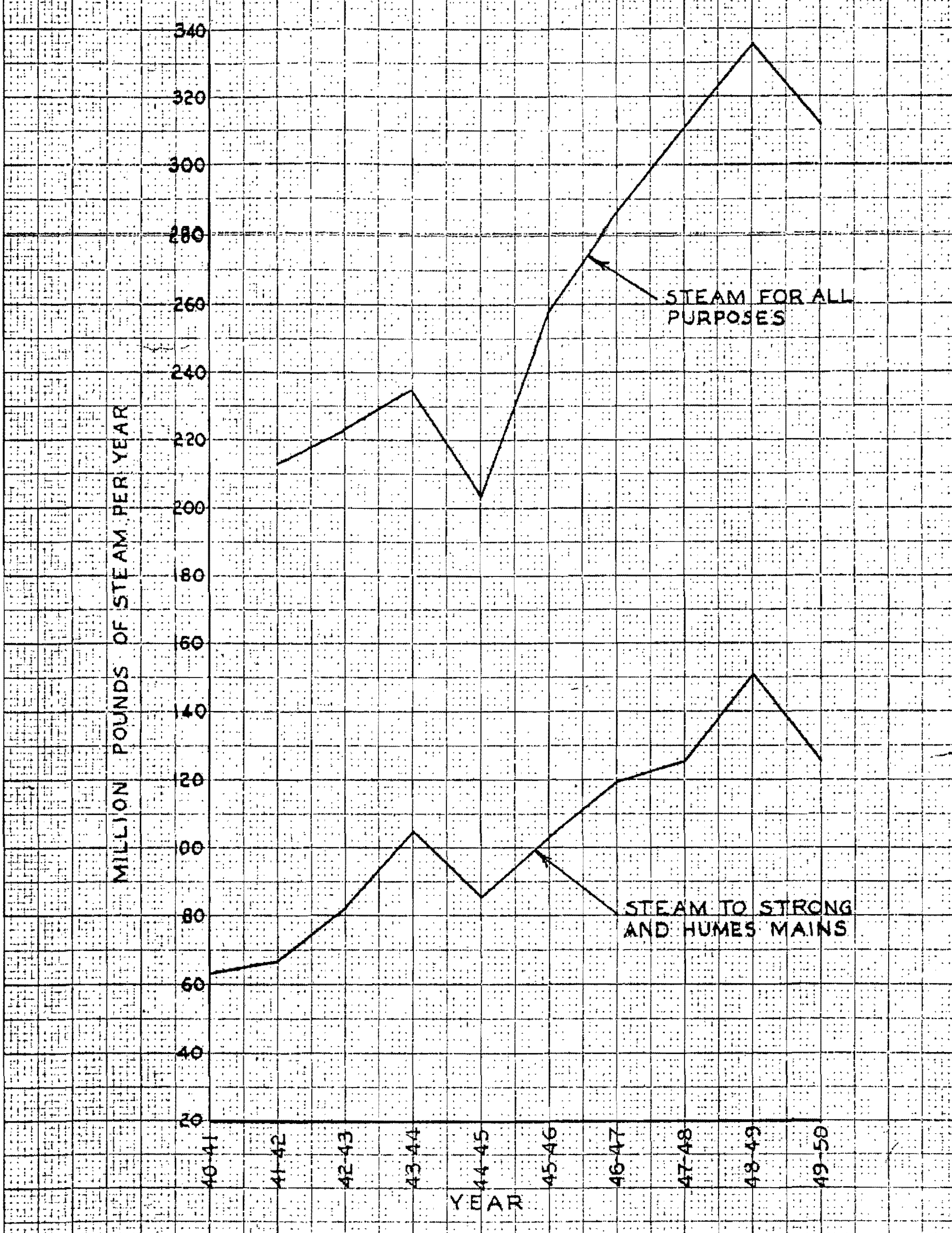


FIGURE 16

TOTAL STEAM EVAPORATED AND STEAM TO HEAT, YEARLY plan will be based on expenditures in the year 1949-50. The author knows of no method of predicting increases or decreases in the cost of supplies, labor, fuel, or purchased electricity, but the costs thus determined can be expected to be in the proper proportion for each plan.

To estimate the cost of salaries and labor under Plan 1 for 1959-60, the wages of a man in continuous attendance in the turbine room on at least two eight hour shifts is estimated to be $5,000.00 per year. This amount must be added to the cost in 1949-50, giving a total of $49,651.52 for salaries and labor in 1959-60.

The item of repairs and maintenance can be expected to increase in the same proportion as the loads on the equipment. From the total in Table VI of $10,460.67 as charged to steam generation and the distribution systems, an increase of 30% has been applied, giving a new total of $13,598.87. To this must be added the cost of maintenance and repairs on the electrical generating equipment. The total in 1949-50 of $791.00 was spent during a period in which for the most part only one unit was in operation. Under Plan 1, two units would be operating most of the time, and three for part of the time. It is safe to say that the cost of repairs and maintenance then is expected to be $15,971.87.

The cost of water, equipment, and miscellaneous expenses is not expected to change, while the cost of supplies can be expected to be proportional to the steam load. The cost of supplies will then be $2,999.54, and the cost of water, equipment, and miscellaneous will be $7,260.89.

The City of Knoxville provides standby service for the University, and for this service makes a minimum charge of $0.50 per kilowatt of installed standby transformer capacity. Under Plan 1, only 1500 KW standby capacity would be necessary, but as already outlined, 2000 KW standby capacity has recently been installed. It is not expected that this capacity would be changed, and so the minimum charge would be $1,000.00 per month, or $12,000.00 per year.

Since the University must provide spare steam capacity within the Power Plant, and to do this would require reconditioning and modernizing boilers number 3 and 4, some fixed charge must be included for this. The total cost of this work would probably be around $30,000 for the two boilers.

"Fixed charges usually consist of interest on investment, depreciation, taxes, and insurance."[1] Being a state institution, the University pays no taxes. Boiler insurance is carried on the boilers, but this would continue whether or not they are reconditioned. The useful life of a boiler has been estimated at 20 years.[2,3] The useful life of these boilers if reconditioned could be expected to be the same as a new boiler, or 20 years. Depreciation will then be calculated at 5% per year. Interest of investment has been computed at 4½% in the past by several officials of the University, and the author will not depart from this policy. Thus the total fixed charges will amount to 9½% of the investment, or $2,850.00 for this work.

The total cost of power and heat for the University in 1959-60 is

---

[1]Gaffert, G. A., Steam Power Stations (New York: McGraw Hill, 1946), p.462.

[2]*Ibid.*, p.464.

[3]Marks, L. S., Mechanical Engineers Handbook (New York: McGraw Hill, 1941), p. 1373.

then the total of the various costs determined in this section, or $189,031.82. The reader is referred to Chapter VI for a summary of these calculations.

Operating with New Unit to be Purchased

In giving consideration to a new unit, it will be well to note that the new boiler at the power plant is designed for a maximum pressure of 450 psig. Due to higher unit efficiencies at higher pressures and temperatures then, if a new unit is to be installed it should be able to use steam at these higher pressures and temperatures. It is the author's opinion that to allow for a considerable margin of safety and considering the inherent maintenance difficulties in a small power plant, that 400 psig would be a desirable operating pressure. The size of the unit has been determined in Chapter IV as 2500 KW. Figure 16 on the following page is a curve supplied by Westinghouse Electric Company of the steam consumption of such a unit.

If such a unit is to be installed, it must result in savings high enough to justify the cost of installation. Westinghouse has estimated the cost of the turbine-generator and erection at $154,000.00. The additional cost of foundations, piping, etc. is expected to run the cost to $200,000.00. With the removal of the two 500 KW units, space would be available for the installation without having to add to the building. It is expected that the salvage value of the two old units would pay for their removal. With fixed charges figured at 9½% per year, the fixed charges on the new unit would amount to $19,000.00.

Boilers number 3 and 4 would still have to be reconditioned, the

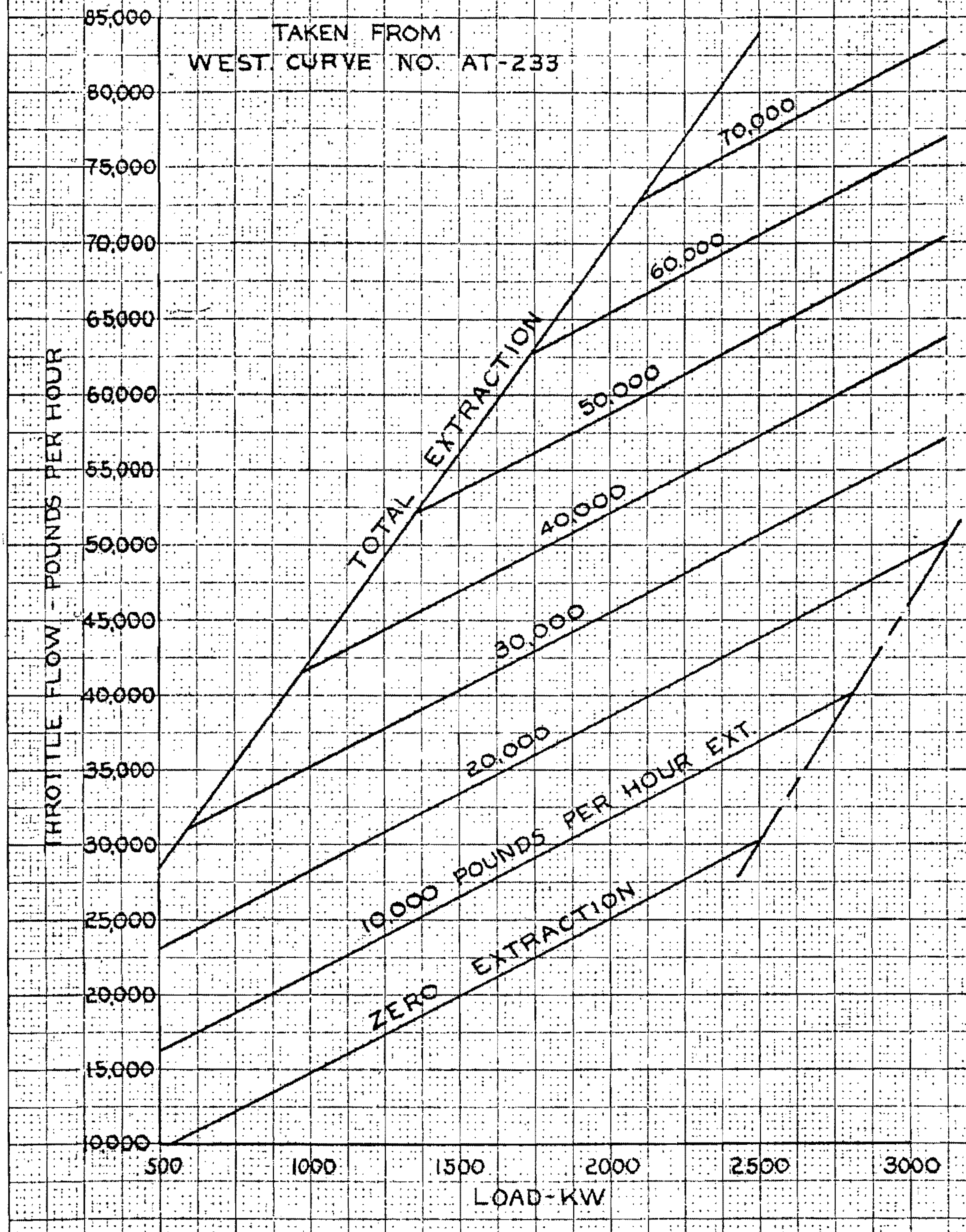


FIGURE 17
THROTTLE FLOW TO 2500 KW UNIT
TO BE PURCHASED

fixed charges for this being $2,850.00. The total fixed charges for Plan 2 would then be $21,850.00.

From the performance curves and average values for KW load and bleed, the steam to the condenser is calculated as 113,000,000 pounds for 1959-60. Under Plan 1 the total steam to the condensers was 115,160,000 pounds. A savings then of 2,160,000 pounds of steam could be expected. This steam, however, will be supplied at 400 psig and 600 F, therefore the cost per thousand pounds will increase due to the increased energy which must be added. The Btu added at present is approximately 913 Btu per pound of steam. At 400 psig and 600 F it will be 981 Btu per pound of steam, or an increase of 7.45%. From a heat balance similar to that for Plan 1, the cost of coal for Plan 2 is estimated to be $97,942.00 for 1959-60.

A decrease in cost of repairs and maintenance could be expected under this plan, especially from the electrical generating facilities. Repairs and maintenance on the steam generating equipment would be the same as for Plan 1, or $13,598.87. Repairs and maintenance on the electrical generating equipment would not be over that for 1949-50, or $791.00. The total cost of repairs and maintenance under Plan 2 would then be $14,389.87.

The cost of supplies would be $2,921.00, determined as in Plan 1, and the cost of water, equipment and miscellaneous would be $7,260.89.

The size of the City standby connection could be reduced since the University would have its own standby capacity of 1500 KW. Only 1000 KW would then be needed from the city, representing a minimum charge of $6,000.00.

The amount of labor needed under Plan 2 would not be different from that in 1949-50, or the cost would be $44,651.52.

The total cost of power and heat then will be, under Plan 2, $195,015.28 in 1959-60.

Generating Such Power as Heating Steam Demand Will Supply

For various reasons the Knoxville Utilities Board refuses to let the University synchronize with their power lines, and therefore if part of the load is carried by the city and part by the power plant, it must be a fixed connected load, electrically isolated.

From the expected increase in steam demand for heating in 1959-60, as determined in Chapter III, we find that the average extraction for the year will be 18,600 pounds per hour. From the water rate curve for the 1500 KW Westinghouse unit we find that this will supply 1,927,200 KWH in 1959-60, leaving approximately 7,123,140 KWH to be supplied by the city. Thus under this plan the University would supply approximately 21.3% of its electrical requirements. From Table I it can be seen that if the Plant, Estabrook and Ferris, and Chemical Engineering Feeders were isolated they would amount to approximately 23.5% of the total installed capacity. These feeders were chosen because of their proximity to the plant as well as for the fact that the percentages correspond to the theoritical amount which could be supplied.

Under this plan the University would supply some 2,130,000 KWH and purchase 6,920,000 KWH. The steam to the condensers for the periods when electrical requirements exceed heating steam demand, and to supply cooling steam for the turbine at other periods is estimated from the performance curves of the 1500 KW unit to be 21,050,000 pounds.

Under this Plan then, the maximum steam demand would be, in 1959-60, only 75,000 pounds per hour. This can be supplied by either of the two pulverized coal boilers for a four hour period, ample to warm up the lines. Boilers 3 and 4 would not have to be reconditioned and this item of fixed charges would be removed. The cost of putting this plan into operation, considering electric lines which would have to be erected and making the required switching stations would not exceed $10,000.00, giving a fixed charge of $950.00.

Table VII is the expected cost of city power for 76.5% of the expected load in 1959-60. These costs were figured under the City B-3 rate as follows:

Demand Charges per month:
- 1st 1000 KW----------$1.00 ea.
- Above 1000 KW-------- 0.90

Energy Charges per month:
- 1st 15,000 KWH-------$0.008 ea.
- Next 25,000 KWH------ 0.006
- Next 60,000 KWH------ 0.004
- Above 100,000 KWH---- 0.003

The other costs for Plan 3 were determined as in Plan 1, and are tabulated in Table IX, Chapter VI. It is not expected that any change in the amount of labor required would be needed under this plan. The other items are as already determined, making the total cost of power and heat in 1959-60 $183,512.60.

Purchasing All Electricity

Table VIII on the following page 51 is a tabulation of the cost under the City B-3 rate of supplying the University's electrical requirements in 1959-60. The cost of putting this plan into operation could very

TABLE VII

COST OF ELECTRICITY PURCHASED UNDER PLAN III

Month	KW Max. Demand	KWH Total for Month	Total Cost
July	1080	331,000	$ 2,275.00
Aug.	1080	394,000	2,464.00
Sept.	1445	365,000	2,705.50
Oct.	1650	629,000	3,682.00
Nov.	1730	696,000	3,955.00
Dec.	1670	576,000	3,541.00
Jan.	1865	731,000	4,201.50
Feb.	1870	701,000	4,096.00
Mar.	1790	728,000	4,105.00
Apr.	1725	669,000	3,869.50
May	1780	704,000	4,024.00
June	1310	396,000	2,677.00
TOTAL		6,920,000	$41,594.50

well cost $12,000.00 for lines, meters, etc., or a fixed charge of $1,140.00 per year.

Since the electric generators would not be operating under this plan, it is believed that an assistant operator on the day shift would not be needed, saving approximately $2,500.00 per year. It is considered advisable to have an assistant operator on the other shifts, since it is necessary for the operator to leave the operating floor at times for necessary work.

The other costs under this plan were determined as for Plan 1, and are tabulated in Table IX. The total cost of power and heat under this plan would be $185,320.18.

TABLE VIII

COST OF ELECTRICITY PURCHASED UNDER PLAN IV

Month	KW Max. Demand	KWH Total for Month	Total Cost
July	1410	433,000	$ 2,878.00
Aug.	1410	515,000	3,124.00
Sept.	1890	477,000	3,442.00
Oct.	2160	823,000	4,723.00
Nov.	2265	910,000	4,988.50
Dec.	2180	754,000	3,634.00
Jan.	2440	957,000	5,377.00
Feb.	2450	916,000	5,263.00
Mar.	2340	951,000	5,269.00
Apr.	2255	875,000	4,964.50
May	2325	920,000	5,162.50
June	1710	519,000	3,406.00
TOTAL		9,050,000	$52,231.50

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

Table IX on the following page presents in summarized form the results of the calculations in Chapter V. The determination of each item was described there. These costs, as already explained, include only operating expenses and fixed charges on those items of equipment for which new investment would be required, as no changes contemplated would affect fixed charges on existing equipment. This tabulation is for the fiscal year 1959-60, but for present operating conditions the relative costs would not be appreciably different. These costs were based on actual expenditures in 1949-50, but regardless of any increased costs, the relative costs are expected to remain the same. If, however, the cost of fuel, labor, and supplies increases or decreases faster than the cost of purchased power, it would be well to check closely to determine that these relative positions do remain the same.

For two reasons the author will recommend that Plan 3 be placed in operation. The first is the obvious reason that the cost of power and heat will be less. The cost of purchasing all power is sufficiently close to this that one might well ask, why go to all the trouble of generating power when it can be purchased for practically the same cost? The value of an active generating plant to an engineering college is the answer to this question. Its value is one which cannot be calculated in dollars and cents, but never the less it is present. The author would like to take this opportunity to recommend to the engineering college that if schedules

TABLE IX

SUMMARY OF CALCULATIONS

			Cost in Year 1959-60					
Plan No.	Salaries and Labor	Repairs and Maintenance	Fuel	Supplies	Water, Equip. and Misc.	Purchased Power	Fixed Costs	Total
1	$49,651.52	$15,971.87	$98,298.00	$2,999.54	$7,260.89	$12,000.00	$ 2,850.00	$189,031.82
2	44,651.52	14,389.87	97,942.00	2,921.00	7,260.89	6,000.00	21,850.00	195,015.28
3	44,651.52	11,251.67	75,438.00	2,366.00	7,260.89	41,594.50	950.00	183,512.60
4	42,151.52	10,460.67	70,205.60	1,870.00	7,260.89	52,231.50	1,140.00	185,320.18
Cost in 1949-50	44,651.52	11,251.67	74,860.00	2,307.34	7,260.89	9,094.22	--	149,425.64

will permit they should make more use of the power plant as a laboratory in order to recognize this intrinsic value.

In accordance with the above ideas, it is the author's recommendation that the University generate only such power as can be generated with steam which can be extracted and used as heating steam, and that procedure be instituted to do such necessary work as will allow the City of Knoxville to supply the remainder of the load.

In order to supply standby steam capacity, it is also recommended that a study of Boilers 3 and 4 be started to determine the costs and physical requirements of reconditioning and modernizing these boilers.

BIBLIOGRAPHY

BIBLIOGRAPHY

Gaffert, G. A., Steam Power Stations, Third Edition. New York: McGraw Hill, 1946.

Kleinsassar, T. W., compiled under direction of, Local Climatological Summary with Comparative Data. Chattanooga, Government Printing Office, 1950.

Marks, L. S., Mechanical Engineers Handbook, Fourth Edition. New York: McGraw Hill, 1941.

Nicholas, D. M., An Expansion Program for the University of Tennessee Power Plant, a Thesis, Knoxville, 1940.

APPENDIX

TABLE X

THE UNIVERSITY OF TENNESSEE POWER PLANT
CAPITAL EXPENDITURES

Item	Cost
Costs Chargeable to Steam Generation	
Building	$ 50,000.00
Boilers 3 and 4, settings and stokers	28,000.00
Stack and Breeching	10,787.00
Boiler #5, Comb. Equipment, fans, etc.	50,243.00
Fuel Handling Equipment	29,490.00
Ash Handling, No. 5 Boiler	22,379.00
Piping, Auxiliaries, Metering Equip., Feedwater Heating and Treating Equipment	32,767.00
Coal Yard and Recovery Equipment	26,282.00
Boiler No. 1, C. E. Contract	165,168.00
Boiler No. 1, Installation	282,847.00
Engineering Fees	36,400.00
TOTAL FOR STEAM GEN.	$734,363.00
Costs Chargeable to Electrical Generation	
Building	$ 20,000.00
Two 500 K. W. Turbine Generators with Switchboard and Auxiliaries	73,030.00
1500 K. W. Westinghouse Turbine Generator, Condenser, Installation and Auxiliaries	74,613.00
Switchboard Additions	3,196.00
Pumphouse, Equipment and Transite Pipe Line	13,464.00
Voltage Regulators, Temperature Recorder	1,200.00
Frequency Controller	788.00
Engineering Fees	3,240.00
TOTAL FOR ELECTRIC GENERATION	$189,531.00
Distribution System - Electric	
Ayres Hall Underground Line	$ 12,387.00
Aerial Cable to Farm and Underground to Gate	29,357.00
White Avenue Aerial Line	29,065.00
Balance of Distribution System	20,000.00
Engineering Fees	4,248.00
TOTAL ELEC. DIST. SYSTEM	$ 95,057.00
Distribution System - Steam	
Ayres Line	$ 32,951.00
Strong Hall Line	137,658.00
Strong Hall Line, Library Extension	39,357.00
Humes Hall Line	30,000.00
Balance of Distribution System	20,000.00
Engineering Fees	12,598.00
TOTAL STEAM DIST. SYSTEM	$272,564.00

TABLE XI

ELECTRIC LOAD AND PEAKS BY MONTHS

Month	Kilowatt Hours Generated	Kilowatt Hours Purchased	Total	KW Peak
		1929-30		
July	51900	0	51900	120
Aug.	36800	100	36900	175
Sept.	20200	3400	23600	200
Oct.	56900	200	57100	225
Nov.	58200	0	58200	240
Dec.	44900	200	45100	240
Jan.	60800	100	60900	220
Feb.	56500	0	56500	250
Mar.	59500	700	60200	200
Apr.	48800	1300	50100	230
May	64600	100	64700	145
June	37000	300	37300	
TOTAL	596100	6400	602500	
		1930-31		
July	49900	0	49900	160
Aug.	39100	1900	41000	180
Sept.	22300	12000	34300	150
Oct.	60400	200	60600	235
Nov.	72100	100	72200	280
Dec.	72500	100	72600	305
Jan.	83200	200	83400	275
Feb.	74400	0	74400	300
Mar.	69000	900	69900	295
Apr.	88400	0	88400	320
May	87700	800	88500	310
June	55500	0	55500	185
TOTAL	774500	16200	790700	
		1931-32		
July	66500	0	66500	200
Aug.	55400	0	55400	220
Sept.	19700	21800	41500	180
Oct.	66000	0	66000	265
Nov.	76300	200	76500	355
Dec.	70600	0	70600	340
Jan.	90000	200	90200	350
Feb.	90300	0	90300	315
Mar.	76500	600	77100	300
Apr.	79500	0	79500	330
May	78200	0	78200	285
June	46900	0	46900	145
TOTAL	815900	22800	838700	

TABLE XI (continued)

ELECTRIC LOAD AND PEAKS BY MONTHS

Month	Kilowatt Hours Generated	Kilowatt Hours Purchased	Total	KW Peak
		1932-33		
July	44800	0	44800	185
Aug.	45400	4400	49800	180
Sept.	17900	11300	29200	180
Oct.	66700	1200	67900	310
Nov.	89000	0	89000	350
Dec.	71000	100	71100	345
Jan.	105300	200	105500	385
Feb.	91700	0	91700	350
Mar.	88600	300	88900	310
Apr.	64200	300	64500	250
May	67000	0	67000	260
June	49500	0	49500	180
TOTAL	801100	17800	818900	
		1933-34		
July	56800	600	57400	220
Aug.	47800	6100	53900	190
Sept.	20100	22500	42600	200
Oct.	78300	100	78400	280
Nov.	89700	100	89800	325
Dec.	76100	0	76100	340
Jan.	101200	400	101600	375
Feb.	90700	200	90900	345
Mar.	92300	0	92300	340
Apr.	89300	0	89300	310
May	94300	0	94300	295
June	83600	0	83600	230
TOTAL	920200	30000	950200	
		1934-35		
July	79700	0	79700	240
Aug.	62000	14000	76000	265
Sept.	19200	27800	47000	275
Oct.	92000	11600	103600	375
Nov.	116900	800	117700	405
Dec.	101600	0	101600	420
Jan.	132100	400	132500	460
Feb.	121700	0	121700	470
Mar.	118300	0	118300	410
Apr.	127700	0	127700	455
May	118600	0	118600	410
June	98900	0	98900	265
TOTAL	1188700	54600	1243300	

TABLE XI (continued)

ELECTRIC LOAD AND PEAKS BY MONTHS

Month	Kilowatt Hours Generated	Kilowatt Hours Purchased	Total	KW Peak
		1935-36		
July	109300	0	109300	340
Aug.	91600	0	91600	240
Sept.	26900	33100	60000	260
Oct.	126300	300	126600	480
Nov.	139200	1000	140200	510
Dec.	115000	500	115500	450
Jan.	150900	0	150900	495
Feb.	139100	2600	141700	520
Mar.	135900	2200	138100	480
Apr.	137000	1400	138400	425
May	142100	0	142100	375
June	106600	400	107000	320
TOTAL	1419900	41500	1461400	
		1936-37		
July	124200	0	124200	365
Aug.	112500	0	112500	360
Sept.	65000	27500	92500	400
Oct.	147200	0	147200	505
Nov.	158100	600	158700	600
Dec.	136000	0	136000	565
Jan.	174600	0	174600	600
Feb.	149900	1300	151200	600
Mar.	156800	0	156800	560
Apr.	153300	0	153300	580
May	160400	900	161300	470
June	120200	1000	121200	395
TOTAL	1658200	31300	1689500	
		1937-38		
July	129600	0	129600	360
Aug.	140400	0	140400	425
Sept.	43300	47400	90700	400
Oct.	175200	3800	179000	600
Nov.	197300	18100	215400	770
Dec.	171800	24800	196600	660
Jan.	259000	2400	261400	790
Feb.	243800	400	244200	755
Mar.	223000	0	223000	750
Apr.	213300	400	213700	640
May	192200	0	192200	560
June	147300	0	147300	480
TOTAL	2136200	97300	2233500	

TABLE XI (continued)

ELECTTIC LOAD AND PEAKS BY MONTHS

Month	Kilowatt Hours Generated	Kilowatt Hours Purchased	Total	KW Peak
		1938-39		
July	159600	0	159600	460
Aug.	147000	0	147000	440
Sept.	141900	2100	144000	540
Oct.	218800	0	218800	680
Nov.	271400	0	271400	780
Dec.	217800	0	217800	760
Jan.	289500	0	289500	860
Feb.	276600	0	276600	900
Mar.	272400	0	272400	780
A pr.	256100	0	256100	770
May	209000	0	209000	630
June	164400	0	164400	500
TOTAL	2624500	2100	2626600	
		1939-40		
July	162200	0	162200	430
Aug.	162500	0	162500	460
Sept.	147700	0	147700	500
Oct.	230200	0	230200	630
Nov.	280500	0	280500	825
Dec.	255900	0	255900	810
Jan.	326800	0	326800	870
Feb.	315700	0	315700	900
Mar.	301600	0	301600	830
Apr.	289200	0	289200	830
May	254600	0	254600	770
June	178200	0	178200	530
TOTAL	2905100	0	2905100	
		1940-41		
July	192300	0	192300	520
Aug.	181000	0	181000	520
Sept.	166300	0	166300	560
Oct.	254700	0	254700	720
Nov.	313900	0	313900	910
Dec.	254700	0	254700	875
Jan.	329300	0	329300	880
Feb.	325400	0	325400	900
Mar.	328400	0	328400	890
Apr.	318600	0	318600	910
May	269000	0	269000	760
June	203400	0	203400	900*
TOTAL	3137000	0	3137000	

*Feeding City Feeder.

TABLE XI (continued)

ELECTRIC LOAD AND PEAKS BY MONTHS

Month	Kilowatt Hours Generated	Kilowatt Hours Purchased	Total	KW Peak
		1941-42		
July	525700	0	525700	1030*
Aug.	395900	0	395900	740*
Sept.	368600	0	368600	840*
Oct.	543700	0	543700	860*
Nov.	557100	0	557100	940*
Dec.	462000	0	462000	950*
Jan.	274100	0	274100	910*
Feb.	314800	0	314800	915*
Mar.	308300	0	308300	880*
Apr.	314500	0	314500	1120*
May	741400	0	741400	1550*
June	257900	0	257900	640*
TOTAL	5064000	0	5064000	
		1942-43		
July	386800	0	386800	1200*
Aug.	585200	0	585200	640
Sept.	202400	0	202400	650
Oct.	325300	0	325300	850
Nov.	327600	0	327600	950
Dec.	302000	0	302000	925
Jan.	322200	0	322200	895
Feb.	277100	0	277100	820
Mar.	362600	0	362600	900
Apr.	357200	0	357200	900
May	346100	0	346100	825
June	301200	0	301200	700
TOTAL	4095700	0	4095700	
		1943-44		
July	305900	0	305900	775
Aug.	248300	0	248300	600
Sept.	263300	0	263300	675
Oct.	361000	0	361000	900
Nov.	380000	0	380000	900
Dec.	387000	0	387000	950
Jan.	396000	0	396000	900
Feb.	367000	0	367000	950
Mar.	376000	0	376000	850
Apr.	337000	0	337000	840
May	316000	0	316000	750
June	214000	0	214000	550
TOTAL	3951500	0	3951500	

*Feeding City Feeder.

TABLE XI (continued)

ELECTRIC LOAD AND PEAKS BY MONTHS

Month	Kilowatt Hours Generated	Kilowatt Hours Purchased	Total	KW Peak
		1944-45		
July	210000	0	210000	600
Aug.	210000	0	210000	620
Sept.	201700	0	201700	650
Oct.	292000	0	292000	775
Nov.	325200	0	325200	830
Dec.	312000	0	312000	850
Jan.	346000	0	346000	900*
Feb.	324000	0	324000	840
Mar.	309000	0	309000	815
Apr.	294000	0	294000	775
May	307800	0	307800	800
June	246000	0	246000	
TOTAL	3377700	0	3377700	
		1945-46		
July	226000	0	226000	600
Aug.	265800	0	265800	550
Sept.	180400	0	180400	600
Oct.	322000	0	322000	800
Nov.	330000	0	330000	900
Dec.	310000	0	310000	950
Jan.	375000	0	375000	1000
Feb.	355000	0	355000	975
Mar.	359000	0	359000	950
Apr.	363000	0	363000	950
May	349000	0	349000	950
June	291500	0	291500	850
TOTAL	3726700	0	3726700	
		1946-47		
July	290000	0	290000	775
Aug.	262000	0	262000	800
Sept.	221000	0	221000	800
Oct.	414000	0	414000	1075
Nov.	399000	0	399000	1125
Dec.	362400	0	362400	1125
Jan.	452000	0	452000	1200
Feb.	437000	0	437000	1300
Mar.	450000	0	450000	1150
Apr.	413000	0	413000	1125
May	422000	0	422000	1050
June	316000	0	316000	850
TOTAL	4438400	0	4438400	

*Load Reached 1350 on test.

TABLE XI (continued)

ELECTRIC LOAD AND PEAKS BY MONTHS

Month	Kilowatt Hours Generated	Kilowatt Hours Purchased	Total	KW Peak
		1947-48		
July	317000	0	317000	925
Aug.	318200	0	318200	850
Sept.	222000	0	222000	755
Oct.	401000	0	401000	1100
Nov.	457000	0	457000	1265
Dec.	416000	0	416000	1280
Jan.	550000	0	550000	1405
Feb.	523000	0	523000	1425
Mar.	519000	0	519000	1400
Apr.	495000	0	495000	1250
May	500000	0	500000	1350
June	386000	0	386000	1200
TOTAL	5104200	0	5104200	
		1948-49		
July	403000	0	403000	1150
Aug.	363300	0	363300	1050
Sept.	308000	0	308000	1200
Oct.	577700	0	577700	1550
Nov.	601100	0	601100	1625
Dec.	511500	0	511500	1700
Jan.	539600	0	539600	1690
Feb.	700600	0	700600	1550
Mar.	629000	0	629000	1600
Apr.	605700	0	605700	1600
May	591000	0	591000	1525
June	408000	0	408000	1200
TOTAL	6238500	0	6238500	
		1949-50		
July	55000	280500	333500	1150
Aug.	0	396500	396500	1150
Sept.	194500	172500	367000	1540
Oct.	634100	0	634100	1760
Nov.	699800	0	699800	1850
Dec.	579800	200	580000	1770
Jan.	736300	0	736300	1990
Feb.	705100	0	705100	2000
Mar.	731400	0	731400	1910
Apr.	672500	0	672500	1840
May	706600	0	706600	1900
June	148300	250700	399000	1395
TOTAL	5861400	1100400	6961800	

TABLE XII

UNIVERSITY OF TENNESSEE STUDENT ENROLLMENT
KNOXVILLE DEPARTMENTS

Years	Students
1929-30	4463
1930-31	4709
1931-32	4847
1932-33	4038
1933-34	3241
1934-35	3736
1935-36	4294
1936-37	4810
1937-38	5087
1938-39	5542
1939-40	5730
1940-41	3478
1941-42	3305
1942-43	3091
1943-44	1651
1944-45	1871
1945-46	2477
1946-47	7442
1947-48	7690
1948-49	7790
1949-50	7506

TABLE XIII

KW COMPOSITE HOURLY DEMANDS FOR SELECTED DAYS
IN NOVEMBER 1937, 1941, 1946, 1949

Hour		1937	1941	1946	1949
1	AM	131	130	300	500
2		124	160	270	400
3		124	210	250	350
4		122	210	270	400
5		131	200	310	500
6		148	250	360	600
7		237	380	600	1000
8		351	425	775	1455
9		454	540	950	1700
10		486	590	1025	1725
11		489	600	1050	1780
12		406	560	1000	1650
1	PM	417	500	950	1620
2		466	610	1000	1660
3		483	680	1025	1850
4		477	700	1025	1700
5		442	630	850	1500
6		303	410	760	1250
7		277	420	650	1150
8		276	430	600	1125
9		253	400	560	1025
10		222	370	500	950
11		169	330	380	950
12		152	250	375	800

TABLE XIV

1949-50 LOAD DATA

Hour	Peak Day Jan.16,1950 30,300 KWH	TYPICAL DAYS Summer Day Aug.3,1949 15,000 KWH	Fall Day Nov.18,1949 26,300 KWH	Winter Day Jan.23,1950 28,300 KWH	Spring Day May 11,1950 25,300 KWH
1 AM	400	275	500	450	525
2	350	275	450	450	500
3	350	275	400	425	450
4	350	270	400	425	475
5	500	275	550	495	500
6	550	350	600	600	550
7	950	550	925	950	800
8	1350	850	1485	1420	1350
9	1810	1000	1580	1720	1610
10	1860	1100	1720	1840	1710
11	1875	1150	1770	1850	1715
12	1750	1000	1680	1770	1570
1 PM	1760	950	1685	1800	1650
2	1800	975	1685	1810	1640
3	1800	1000	1775	1850	1640
4	1725	950	1675	1750	1500
5	1640	750	1450	1575	1350
6	1325	590	1200	1325	1050
7	1180	550	1100	1125	1100
8	1125	550	1150	1100	1100
9	1125	520	1000	1075	1050
10	1050	450	950	975	1000
11	1000	390	775	750	775
12	800	305	700	600	650

TABLE XV

EXPECTED 1959-60 LOAD DATA

Hour		Peak Day 39,390 KWH	Summer Day 19,500 KWH	TYPICAL DAYS Fall Day 34,190 KWH	Winter Day 36,790 KWH	Spring Day 32,890 KWH
1	AM	490	338	613	551	643
2		429	338	551	551	613
3		429	338	490	521	551
4		429	331	490	521	582
5		613	338	674	606	613
6		674	429	735	735	674
7		1164	674	1133	1164	980
8		1654	1041	1819	1740	1654
9		2217	1225	1936	2107	1972
10		2278	1348	2107	2252	2095
11		2297	1409	2168	2266	2101
12		2144	1225	2058	2168	1923
1	PM	2156	1164	2065	2205	2021
2		2205	1194	2065	2217	2009
3		2205	1225	2174	2266	2009
4		2113	1164	2052	2144	1838
5		2009	919	1776	1929	1654
6		1623	723	1570	1623	1286
7		1446	674	1348	1378	1348
8		1378	674	1409	1348	1348
9		1378	637	1225	1317	1286
10		1286	551	1165	1194	1225
11		1225	478	949	919	949
12		980	374	858	735	796

TABLE XVI

LOAD DATA FOR 1949-50 AND EXPECTED 1959-60
WINTER WEEKENDS

Hour	Saturday Jan 21,1950 20,300 KWH	Expected 1959-60 26,390 KWH	Sunday Jan. 22,1950 15,000 KWH	Expected 1959-60 19,500KWH
1 AM	625	765	500	615
2	550	675	450	550
3	525	640	440	540
4	525	640	440	540
5	600	735	500	615
6	650	795	550	675
7	950	1165	550	675
8	1345	1650	600	735
9	1550	1900	625	765
10	1650	2020	650	795
11	1610	1970	650	795
12	1420	1740	650	795
1 PM	1100	1350	650	795
2	1025	1255	750	920
3	925	1130	800	980
4	900	1100	775	950
5	825	1010	750	920
6	825	1010	750	920
7	800	980	750	920
8	750	920	750	920
9	750	920	775	950
10	725	890	775	950
11	675	825	650	795
12	600	735	575	705

TABLE XVII

YEARLY STEAM AS METERED THROUGH
STRONG AND HUMES METERS

Year	Strong	Humes	Total
1940-41	35,558,000 lb.	27,325,000 lb.	62,883,000 lb.
1941-42	44,805,000	21,876,000	66,681,000
1942-43	58,081,000	23,521,000	81,606,000
1943-44	77,193,000	27,104,000	104,297,000
1944-45	60,649,000	24,449,000	85,098,000
1945-46	73,165,000	29,490,000	102,655,000
1946-47	86,264,000	33,110,000	119,374,000
1947-48	87,901,000	36,221,000	124,122,000
1948-49	137,937,000	13,474,000	151,411,000
1949-50	113,355,000	12,313,000	125,668,000

TABLE XVIII

MONTHLY HEATING STEAM FOR
HEATING SEASON OF 1949-50

Month	Strong	Humes	Total
Sept.	4,753,000 lb.	101,000 lb.	4,854,000 lb.
Oct.	10,073,000	306,000	10,379,000
Nov.	20,031,000	1,979,000	22,010,000
Dec.	20,909,000	2,321,000	23,230,000
Jan.	19,111,000	1,619,000	20,730,000
Feb.	18,841,000	1,907,000	20,748,000
Mar.	20,331,000	2,377,000	22,708,000
Apr.	14,992,000	1,530,000	16,522,000
May	5,872,000	95,000	5,967,000

TABLE XIX

MONTHLY DEGREE DAYS[a]

Month	1940-41	1941-42	1942-43	1943-44	1944-45
July	0	0	0	0	0
Aug.	0	0	0	0	0
Sept.	50	0	75	46	1
Oct.	137	82	170	259	222
Nov.	493	506	414	548	541
Dec.	583	610	809	782	863
Jan.	756	850	701	748	830
Feb.	792	807	640	548	598
Mar.	649	465	586	482	224
Apr.	119	171	267	257	178
May	42	47	33	42	137
June	0	0	0	1	22
TOTAL	3621	3538	3695	3713	3616

Month	1945-46	1946-47	1947-48	1948-49	1949-50	Mean
July	0	0	0	0	0	0
Aug.	0	5	0	0	0	0
Sept.	6	12	38	12	50	20
Oct.	217	153	41	249	83	183
Nov.	433	350	513	395	542	491
Dec.	929	647	748	701	680	750
Jan.	768	668	1014	513	407	722
Feb.	592	891	594	486	526	660
Mar.	228	738	360	491	539	471
Apr.	145	115	105	260	298	322
May	36	89	40	19	3	57
June	8	3	0	0	1	3
TOTAL	3362	3671	3453	3126	3129	3629

[a]Source: Compiled under direction of T. W. Kleinsassar, Local Climatological Summary with Comparative Data (Chattanooga: Government Printing Office, 1950).

TABLE XX

TOTAL WATER EVAPORATED BY YEARS

Year	Total Water Evaporated
1930-31	111,783,000 lb.
1931-32	135,140,500
1932-33	114,293,400
1933-34	108,696,700
1934-35	134,265,800
1935-36	143,728,900
1936-37	156,824,200
1937-38	188,000,100
1938-39	223,300,000
1939-40	234,749,000
1940-41	269,806,000
1941-42	213,769,000
1942-43	223,247,000
1943-44	234,696,000
1944-45	203,521,000
1945-46	257,818,000
1946-47	285,763,000
1947-48	309,381,000
1948-49	334,159,000
1949-50	310,583,000