GEOTHERMAL DEVELOPMENT PLAN: PIMA COUNTY

by

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INTRODUCTION

Alternative sources of energy will have to be developed as the availability of traditional energy resources continues to diminish. Arizona is supplied with geothermal reserves which could potentially supplement the existing energy supplies. Consequently, planning efforts have concentrated on estimating the potential of geothermal energy utilization in Arizona and in providing information necessary for its prospective commercialization.

Geothermal commercialization plans were prepared for seven distinct intrastate subdivisions. The geothermal resource prospect and the potential geothermal uses for each area are discussed in separate Area Development Plans (ADPs). The major objective of the ADP is to provide information for the prospective development and commercialization of geothermal energy in the specified area. Attempts are made to match the available geothermal resources to potential residential, commercial, industrial and agricultural users.

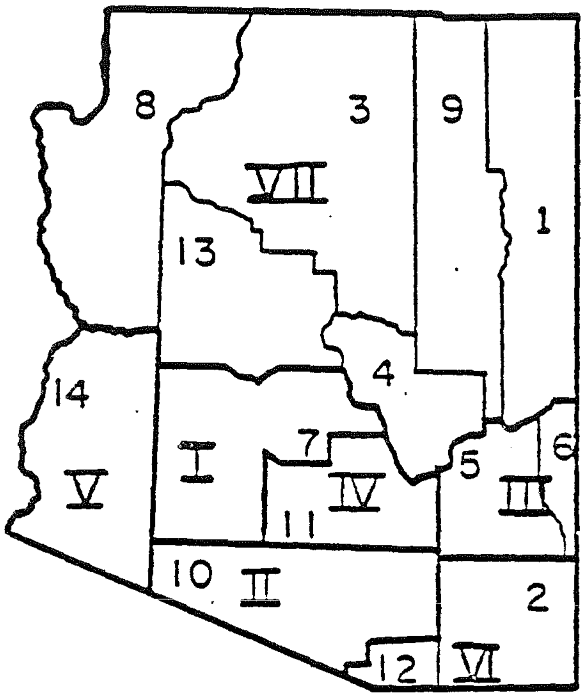
Pima County is located entirely within the Basin and Range physiographic province in which geothermal resources are known to occur. Continued growth as indicated by such factors as population growth, employment and income will require large amounts of energy. It is believed that geothermal energy could provide some of the energy that will be needed. Potential users of geothermal energy within the county are identified.

AREA DEVELOPMENT PLANS

Arizona has been divided into seven distinct single or multicounty subdivisions for which Area Development Plans (ADPs) for geothermal commercialization have been developed. A map of Arizona presented in Figure 1 shows these areas which are numbered in order of planning priority.

Priorities

I) Maricopa
II) Pima
III) Graham/Greenlee
IV) Pinal
V) Yuma
VI) Cochise/Santa Cruz
VII) Northern Counties (1,3,4,8,9,13)



County Names

1. Apache
2. Cochise
3. Coconino
4. Gila
5. Graham
6. Greenlee
7. Maricopa
8. Mohave
9. Navajo
10. Pima
11. Pinal
12. Santa Cruz
13. Yavapai
14. Yuma

Figure 1: Area Development Plans for Arizona.

This ADP is concerned with Pima County. Both metric and English units are provided in the text. However, only metric units appear in the tables and figures. For convenience, some common conversion factors are listed in Table 1. In this report, one million Btu = MBtu.

TABLE 1: SOME COMMON CONVERSION FACTORS

Length and Volume Conversions:

To Convert:	Multiply By:	To Obtain:
meters	3.281	feet
kilometers	0.6214	miles
cubic kilometers	0.2399	cubic miles
liters	0.2642	gallons

Temperature Conversions: $^{o}F = (1.8 \times {}^{o}C) + 32$

GEOTHERMAL RESOURCES

Pima County lies entirely within the Basin and Range physiographic province which is characterized by numerous mountain ranges arising abruptly from broad valleys. At least four areas known to store thermal water at relatively shallow depths of less than 1200 m (3940 ft) are located within Pima County. Numbered boxes in Figure 2 identify these areas; Table 2 gives the location of each of these areas along with rough estimates of depth, volume and temperature.

The Tucson metropolitan area is located in the Santa Cruz Valley, a broad, sediment-filled basin surrounded by mountains. A deep oil test well near the center of the basin had a bottom hole temperature of 147^{o}C (297^{o}F) at a depth of 3600 m (11,810 ft). Five miles northeast of the oil test well are water wells in which thermal water has been encountered. The highest measured temperature was 52.2^{o}C (126^{o}F) at a depth of 762 m (2500 ft).

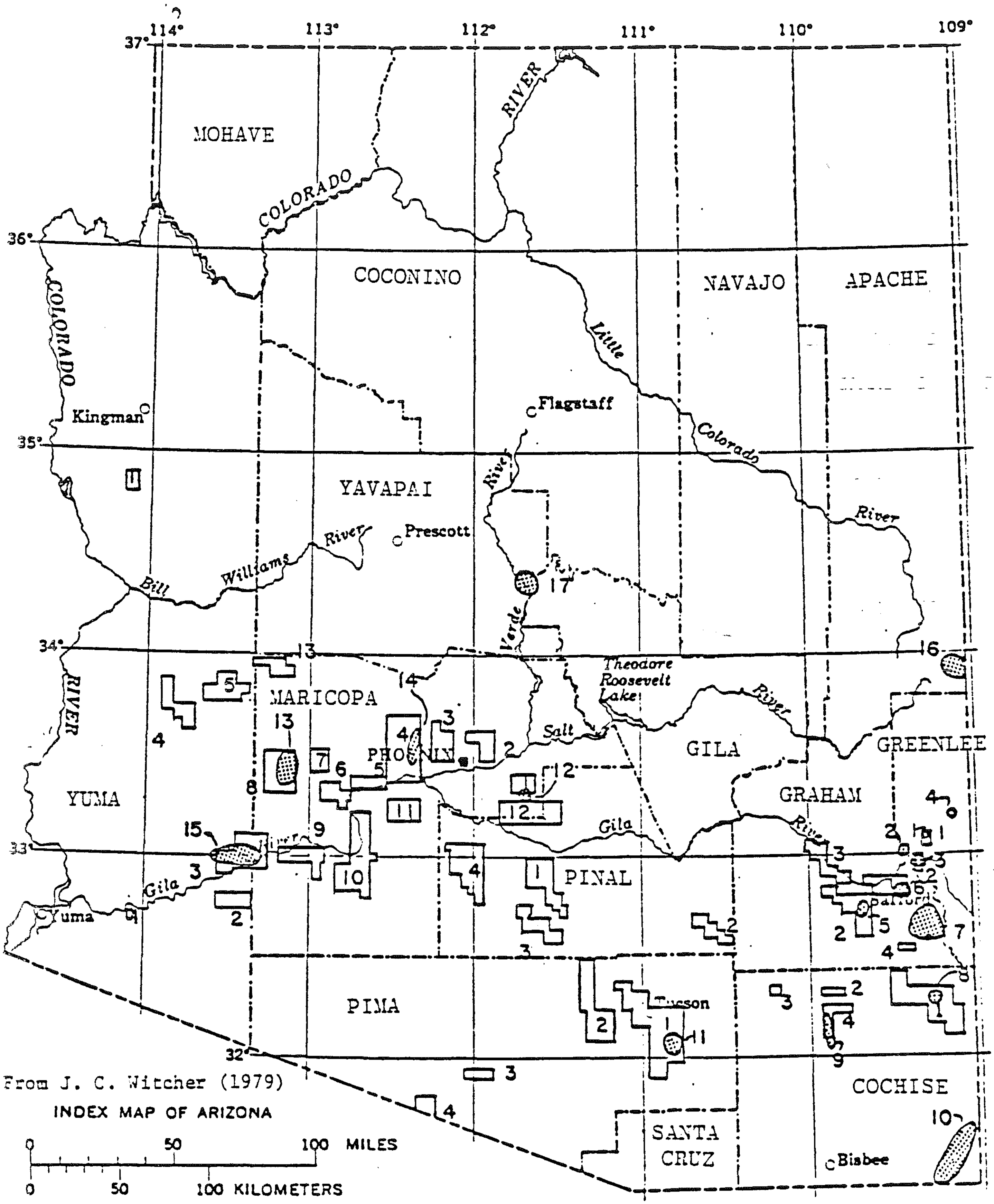


Figure 2: Arizona's Proven, Potential and Inferred Resources.

TABLE 2: PROVEN AND POTENTIAL RESERVOIRS OF PIMA COUNTY OF LESS THAN 1.2 KM DEPTH

Modified from Witcher (1979)   Tr - Average Reservoir Temperature

Area	Location	Volume (km^3)	Measured (^oC) Temperature	Depth (km)	Tr - ^oC	Geothermometry Temperature ^oC	Method
1	T12-17S, R12-15E	287.9	30-50	<0.76	60	50-65	Chalcedony, Na-K-Ca
2	T12-15S, R10-11E	157.9	30-45	<0.61	60	30-60	Chalcedony
3	T17S, R3-5E	30.9	35-40	<0.21	55	50-60	Chalcedony
4	T19-20S, R31E	40.3	30-45	<0.30	65	50-80	Chalcedony

Warm water from wells on the Papago Indian Reservation indicates the existence of low temperature (<90°C; <194°F) geothermal potential in Pima County. Much of the reservation is unexplored, but several water wells on the Papago Farms southwest of Sells have encountered 45°C (113°F) to 47°C (117°F) water at depths of less than 200 m (656 ft) (Stone, 1980).

Intermediate temperature geothermal potential is inferred from presently available geological, geochemical and geophysical information (Witcher, 1979). The location of one inferred potential reservoir in Pima County and rough estimates of its depth, volume and temperature are presented in Table 3.

A forthcoming state geothermal map compiled by the Arizona Bureau of Geology and Mineral Technology and published by the National Oceanographic and Atmospheric Administration will provide a complete and updated listing of data concerning thermal well and spring locations as well as temperature and depth estimates, flow rates and total dissolved solids. This map will be available in late 1981.

ECONOMY

Population

Pima County was chosen for the second Area Development Plan since it contains the state's second largest population center, namely Tucson. With a 1980 population of 531,263 and an area of 9,240 square miles, Pima County has a population density of 57.5 persons per square mile. This figure can be misleading since the population is not uniformly distributed throughout the county but is concentrated in the Tucson area. The 1980 urban area population of Tucson was 487,263 giving it a population density of 1392 persons per square mile. Other major cities in the county are South Tucson, Ajo, Green Valley/Continental and Catalina. They are listed in Table 4 along with their populations.

TABLE 3: INFERRED INTERMEDIATE TO HIGH TEMPERATURE (>90°C) GEOTHERMAL RESERVOIRS OF PIMA COUNTY OF LESS THAN 2.5 KM DEPTH

Tr - Average reservoir temperature

Name	Location	Depth km	Volume km^3	Tr - °C
Tucson Basin	T14-15S, R14-15E	2.5	2.5	130

Inferences based on:

(1) Deep well tests

(2) Geophysics/heat flow

(3) Structure

TABLE 4: MAJOR CITIES IN PIMA COUNTY AND THEIR POPULATIONS

Town	Population
Tucson	467,200
South Tucson	6,576
Green Valley	8,551
Papago Indian Reservation	7,970
Ajo	6,096
Catalina	3,468
Tucson Estates	3,331
Marana	1,982
Others	16,138
	521,302

Of the 521,301 persons in Pima County, 69 percent are white, 24 percent are Hispanic, 3 percent are Indian and 3 percent are black.

Growth

Over the last 40 years, the population of Pima County has grown at an annual rate of 5.2 percent. Future projections place population growth at 2.3 percent per year until the year 2000. However, many persons within Tucson believe these projections underestimate population growth. Many feel that the population of Tucson alone will exceed 1,000,000 people before 2000. Figure 3 shows projected population for Pima County at the 2.3 percent growth rate and at various other growth rates as well. It is almost certain that the 2.3 percent figure is too low for Pima County.

The majority of growth is expected to occur in and around Tucson since it is the only major city in the county. Southwest Tucson is growing most rapidly followed by the northeast and northwest sections. Figure 4 shows the growth rates for areas of Tucson as measured by increases in school enrollment.

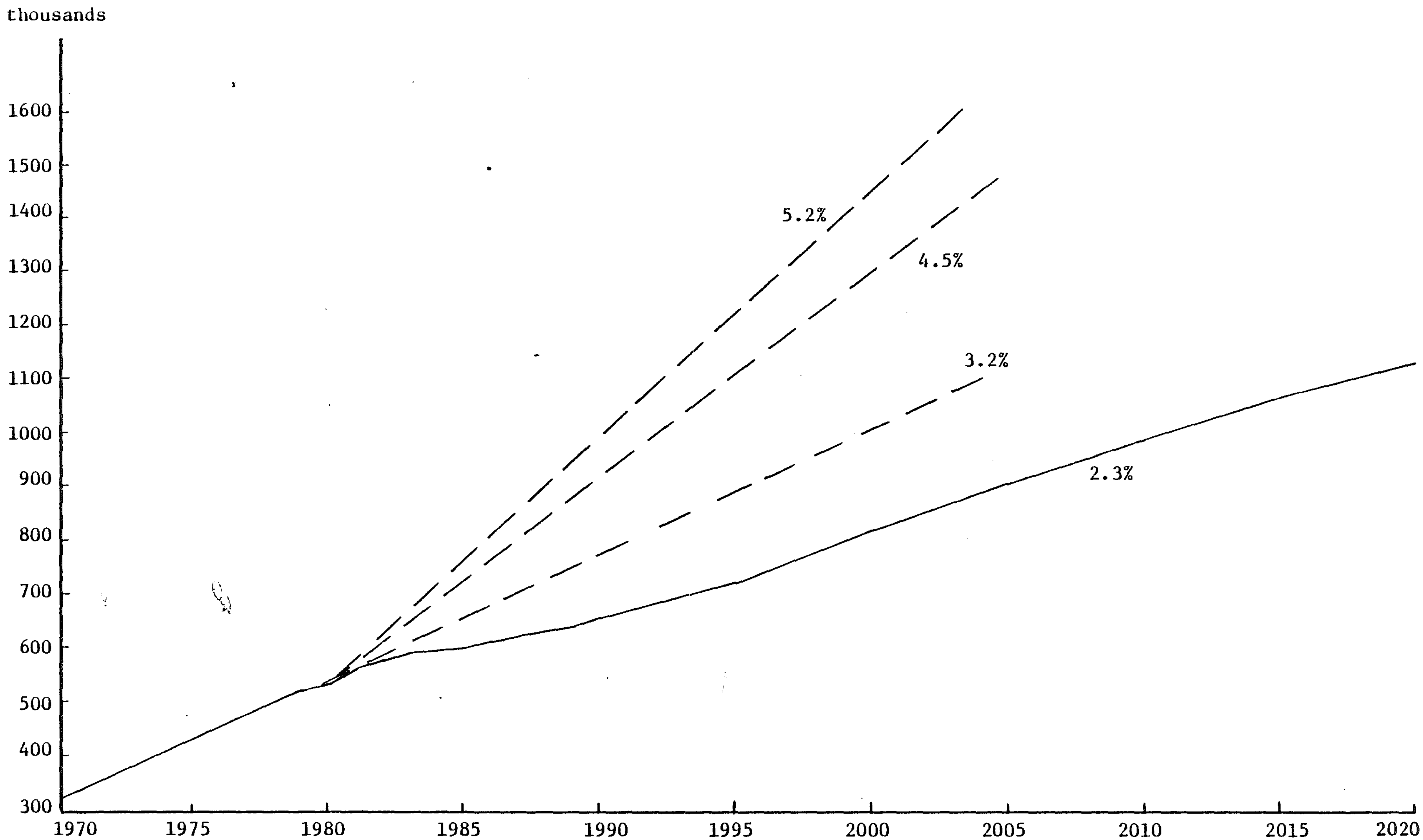


Figure 3: Population Projections for Pima County to 2020.
Source: Technical Advisory Committee (DES)

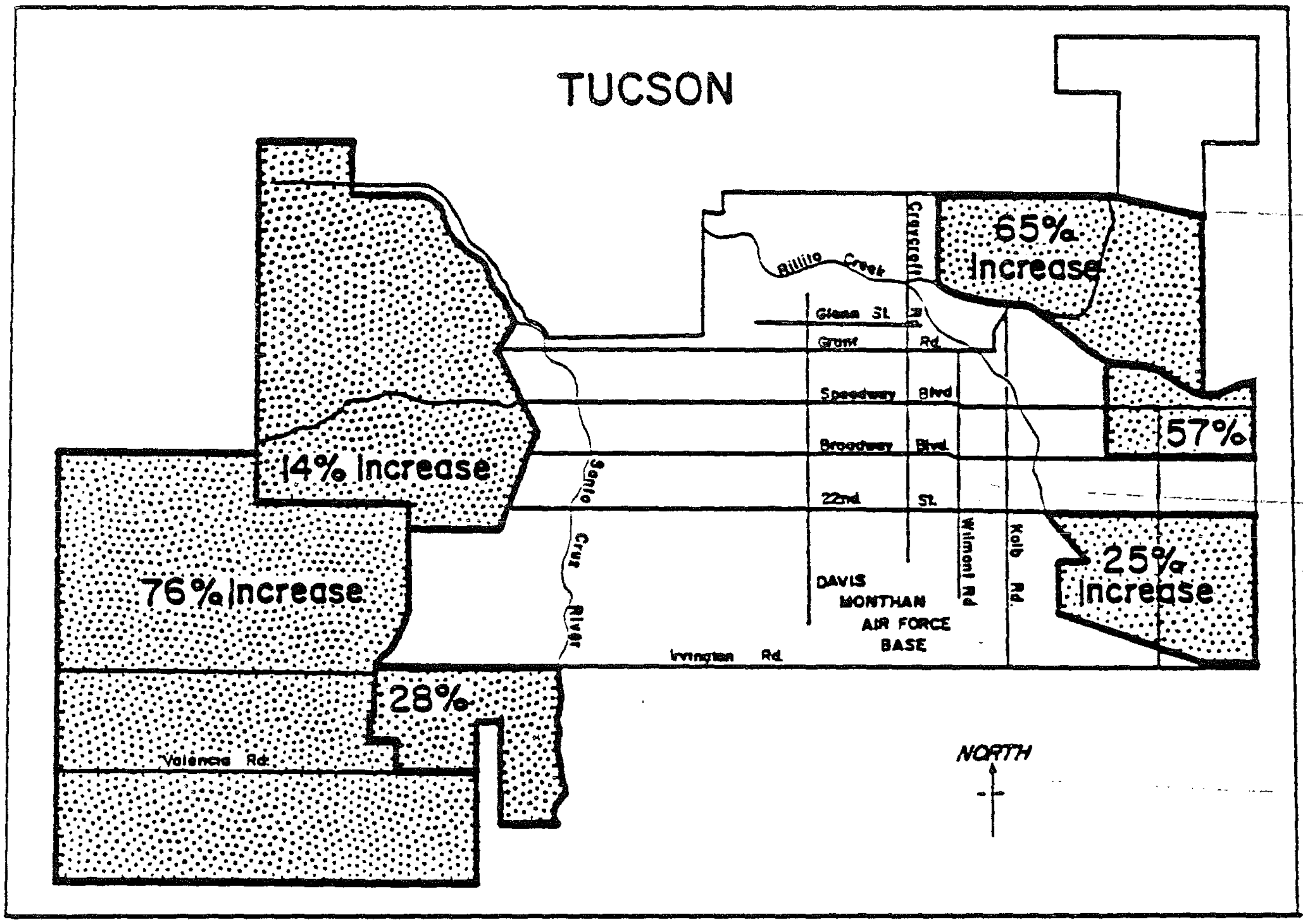


FIGURE 4: Fastest Growing Areas of Tucson.

Industry and Employment

The principal contributor to Pima County's income is tourism, accounting for $900 million in fiscal 1978 - 1979. This figure represents a 25-percent increase from the previous year. Although tourism in the county has shown rapid growth over the years, energy shortages may slow the growth in travel to Arizona and to Pima County.

The second largest contributor to the county's economy is manufacturing, specifically of aircraft and electronics products. Manufacturing accounted for an estimated 17,000 jobs in 1979 and contributed over $300 million to the Pima County economy in 1977. The Department of Economic Security estimates that manufacturing employment will grow at an annual rate of over 5 percent, mostly in the Tucson metropolitan area.

The third largest contributor to the Gross County Product of Pima County is mining, specifically copper mining. Copper mining in Pima County accounted for about 40 percent of total production in Arizona in 1970. However, the copper industry fluctuates wildly depending upon the market price of copper and is only recently recovering from a 1977 slump.

Agriculture is also an important segment of the Pima County economy, accounting for over $44 million in income in 1977. In 1978, a total of 46,000 acres was planted in Pima County, the majority of which were planted in cotton followed by grains, vegetables and alfalfa. The Department of Economic Security estimates that approximately 1500 persons were employed in agriculture in 1979. However, due to critical water problems, employment in agriculture is expected to decline 2.2 percent per year through the year 2000.

Figures 5 and 6 give 1978 employment levels for various sectors as well as the expected levels in the year 2000. Overall employment in the

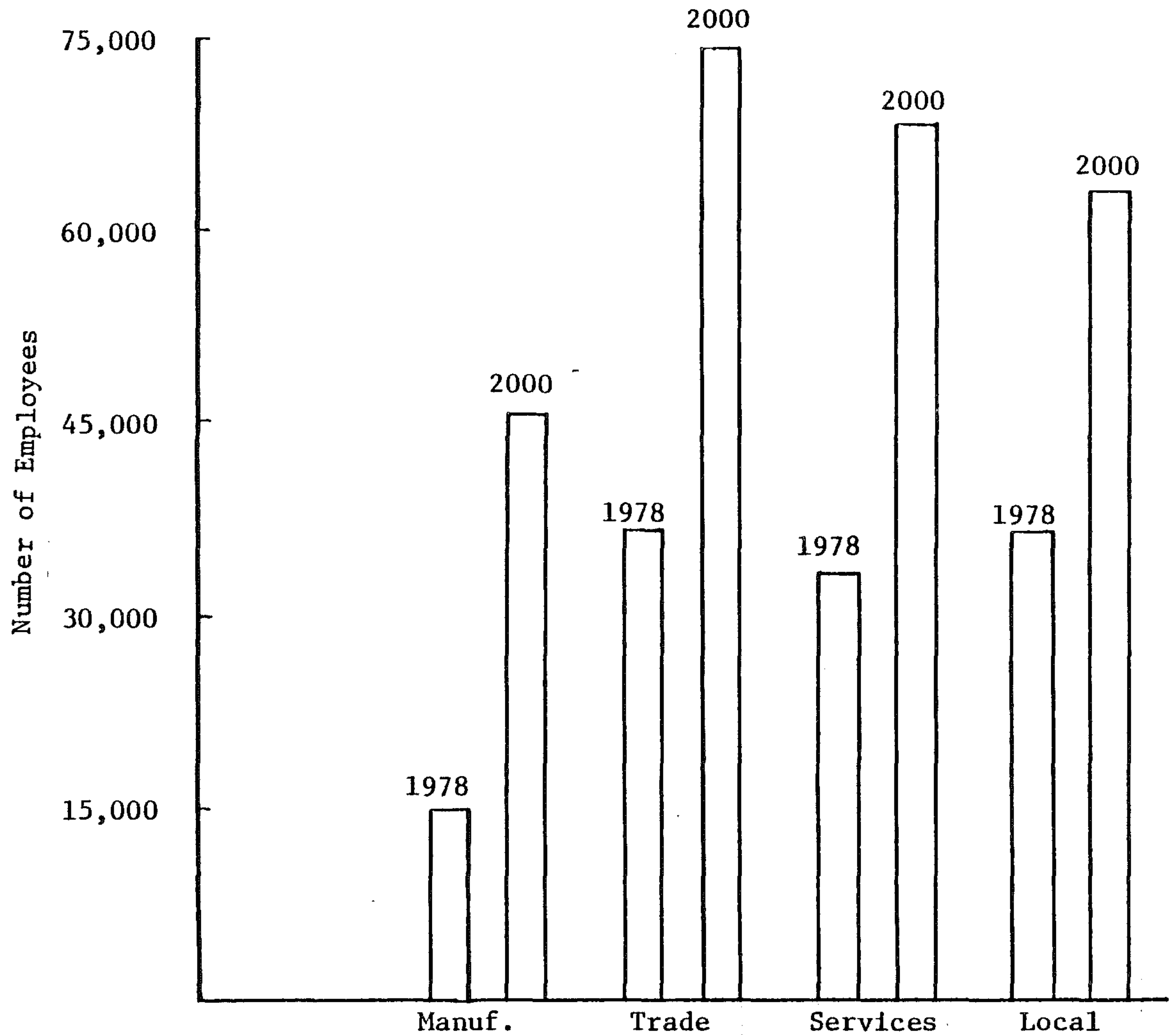


Figure 5: Major Employment Sector Projections for Pima County.
Source: Department of Economic Security

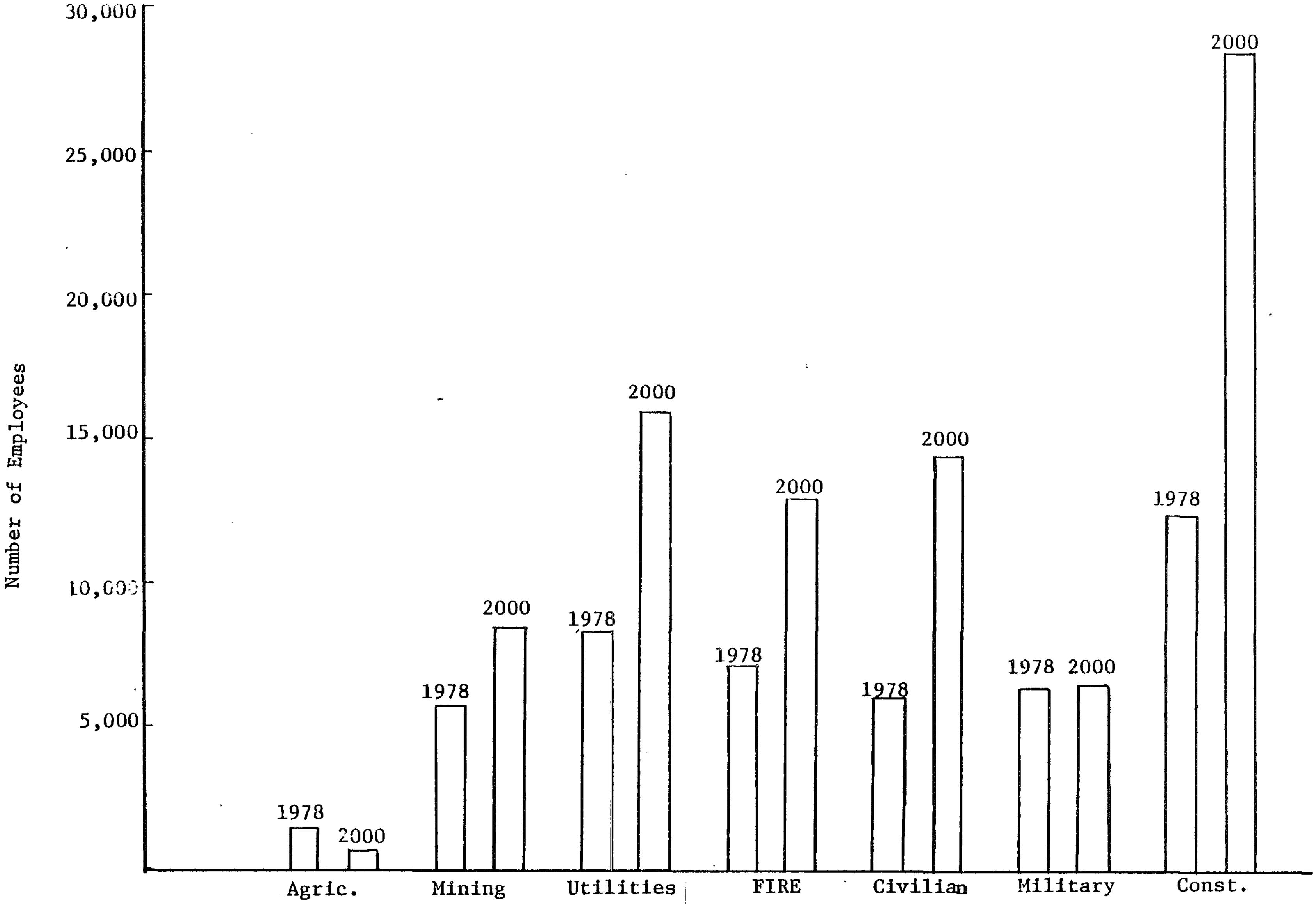


Figure 6: Other Employment Sector Projections for Pima County.
Source: Department of Economic Security

county is expected to grow at a 3.2 percent annual rate to 2000. Most rapid growth is expected in the manufacturing sector followed by the civilian government labor force and the construction industry.

Income

Personal income and per capita income are considered strong indicators of the economic health of a region. Since there is a direct relationship between income and energy consumption, changes in personal income and per capita income are a reflection of both economic growth and energy consumption. During the period 1970-1977, aggregate personal income in Pima County grew by 12.5 percent per year. Figures 7 and 8 show projected growth of personal income and per capita income to the year 2000 as projected by the Department of Economic Security. This growth in income can be attributed to the predominance of high-wage industries such as manufacturing, construction and government.

Other Economic Indicators

The general welfare of the economy is indicated not only by such factors as population, employment and income but also by total retail sales and bank deposits. During the period 1968-1978, retail sales in Pima County grew by 215 percent; bank deposits increased by 180 percent over the same period. These figures further illustrate the continuing, rapid economic growth of Pima County.

In summary, the economic indicators investigated all point to continued economic growth within Pima County. In fact, the Chase Econometric Association found that Tucson is the fastest growing city in the United States. In order to support this growth, large amounts of energy will be required for both the expansion of residential housing and the growth of industry and trade centers. It is believed that geothermal energy could provide some of the energy needed in the future.

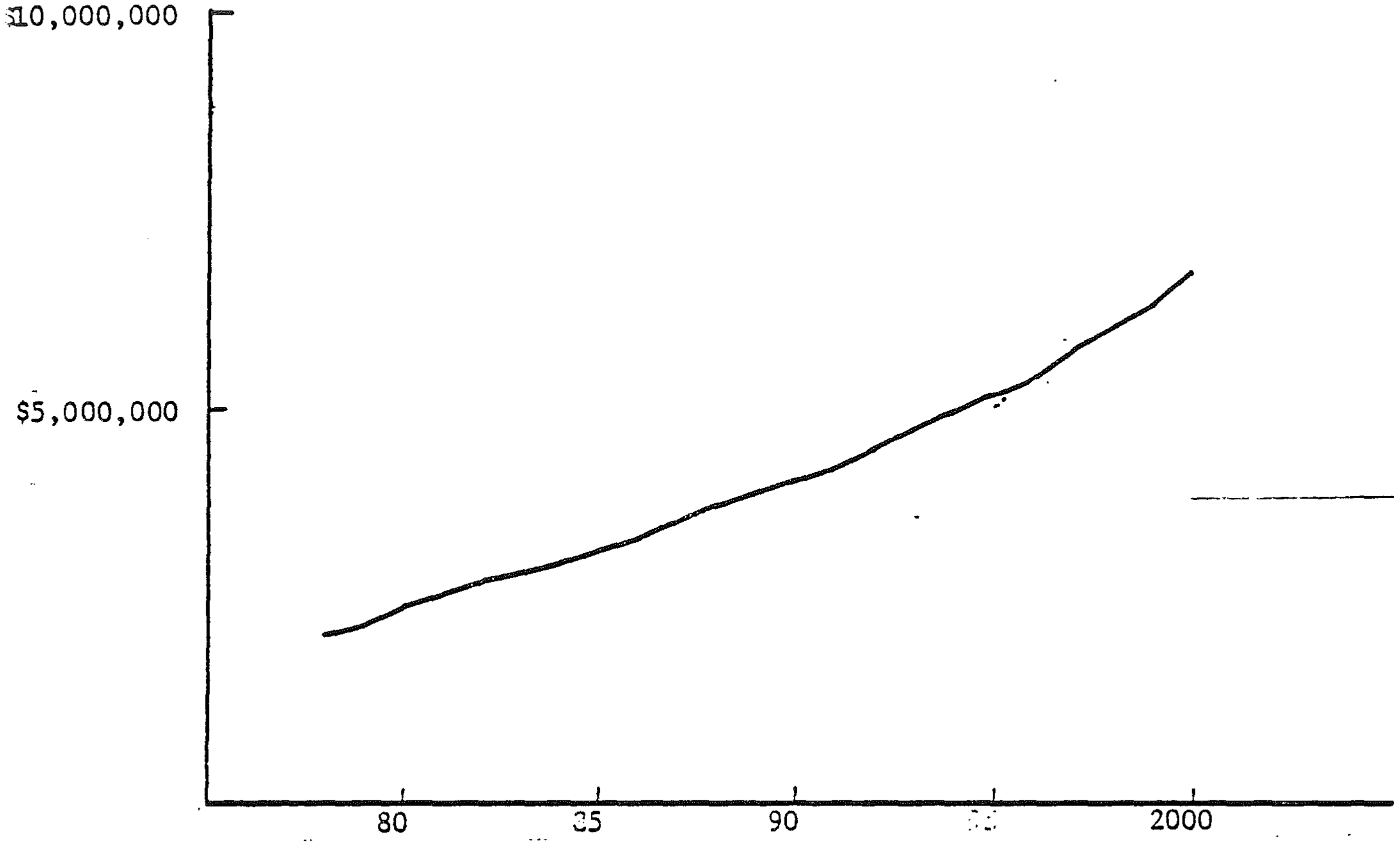


Figure 7: Projections of Personal Income (1972 Dollars) for Pima County.
Source: Department of Economic Security

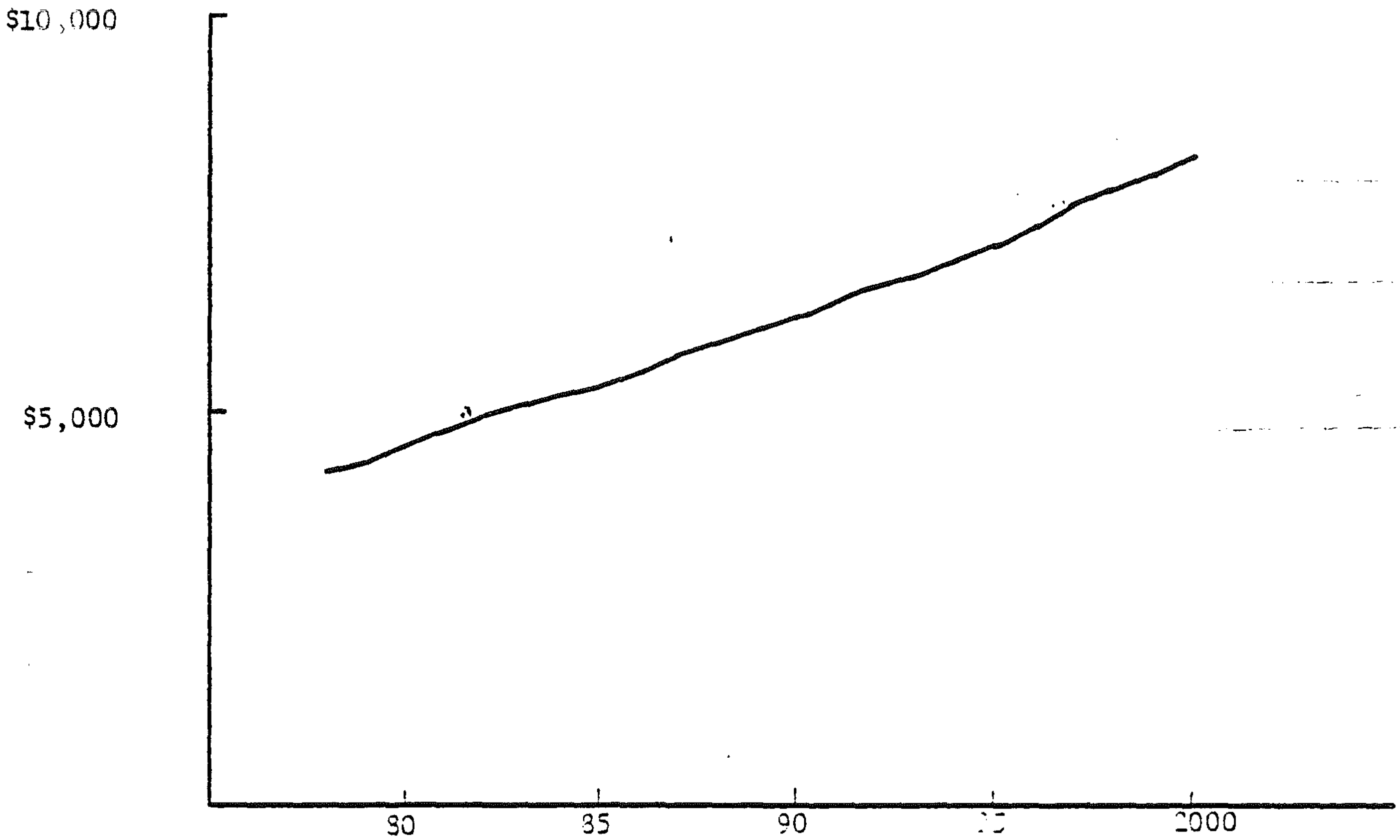


Figure 8: Projections of Personal Per Capita Income (1972 Dollars) for Pima County.
Source: Department of Economic Security

LAND OWNERSHIP

Figure 9 presents a general land ownership map for Pima County. The majority of the land is owned by the Indians. Table 5 presents acres owned by various sectors. Procedures for acquiring surface and mineral rights depend upon which sector owns the land.

TABLE 5: LAND OWNERSHIP BY ACRES

Sector	Percentage	Acres
Indian	42	2,483,880
Federal	28	1,655,920
State	16	946,240
Private	14	827,960
Total	100	5,914,000

ENERGY USE

Table 6 presents energy use during 1978 for the various users within Pima County. Projections are also provided to illustrate expected trends in energy use. Estimated 1978 average prices for the energy types are presented by user class in Table 7.

With the exception of electricity the energy price increases shown in Table 8 were based on Energy Information Administration projections to the year 2020. These price increases reflect regional trends not state trends. Western Regional price increases for fuel sources will probably reflect trends in Arizona. However, due to the current and projected excess electrical generating capacity for Pima County, price increases for electricity will be minimal through 2020 since rising fuel and labor costs are relatively insignificant when compared to the cost of new power plants. Thus,

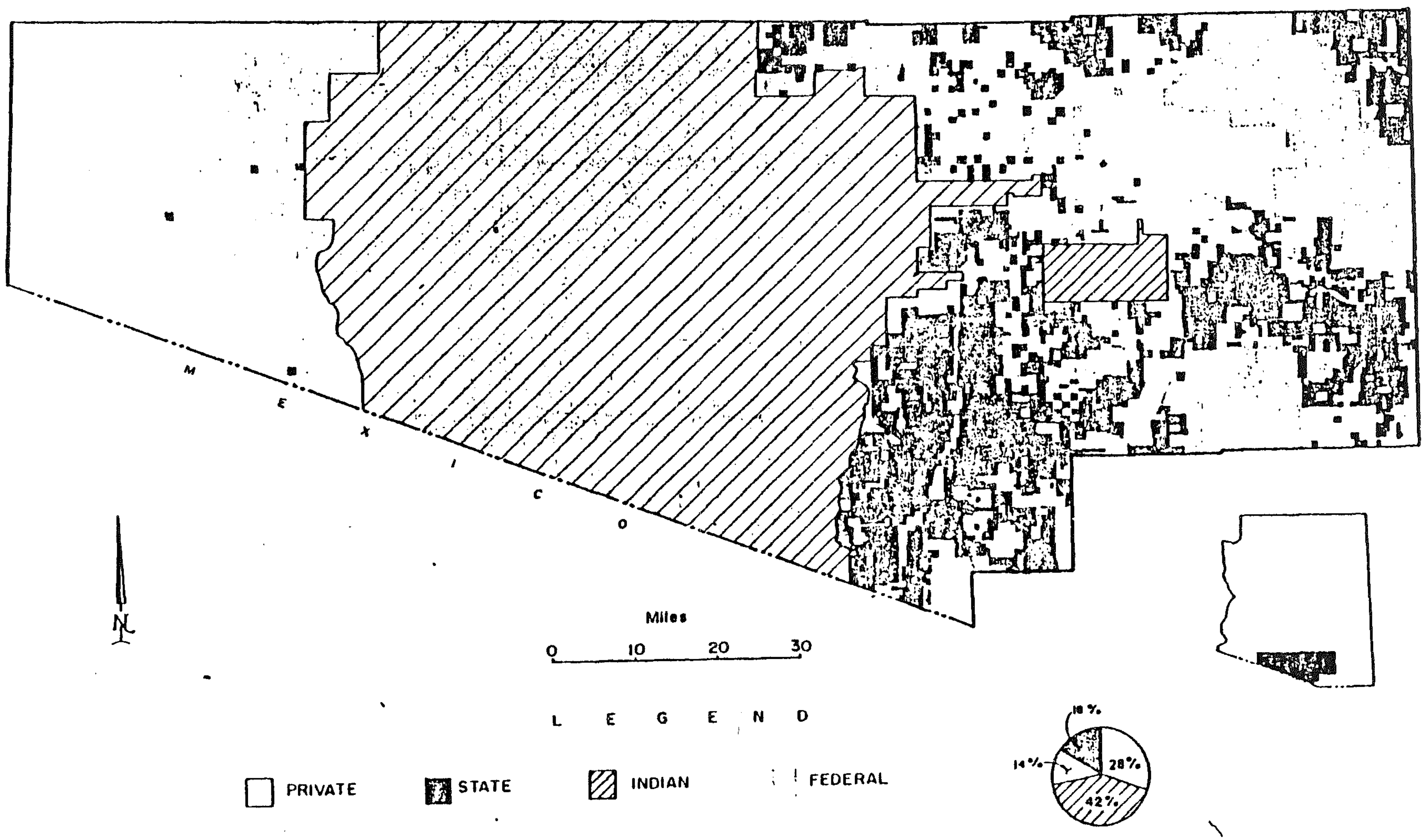


Figure 9: General Land Ownership Map for Pima County.

TABLE 6: PIMA COUNTY ENERGY-USE PROJECTIONS[1] (Trillion Btu)

User Class	1978[2]	1985[3]	2000	2020
Residential	12.54	11.44	10.04	10.98
Commercial	14.72	16.24	22.40	45.28
Industrial	7.55	8.00	10.00	15.17
Total	34.81	35.68	42.44	71.43

(1) Excludes transportation, conversion and line losses.

(2) Developed from Arizona Energy Use 1978, by the Division of Economic and Business Research, University of Arizona.

(3) Projections derived from growth rates from state projections performed by New Mexico Energy Institute.

TABLE 7: ESTIMATED AVERAGE ENERGY PRICES BY USER CLASS, 1978 (Per Million Btu)

	Residential	Commercial	Industrial
Electricity	$16.20	$16.50	$12.86
Natural Gas	$ 2.69	$ 2.10	$ 1.90
Liquid Petroleum Gas	$ 6.25	same	same
Distillates	$ 5.44	same	same

TABLE 8: REAL PRICE GROWTH RATES (By Fuel Type and Consuming Sector)

TIME FRAME	Electricity	Distillates	Liquid Petroleum Gas	Natural Gas
		RESIDENTIAL		
1980 - 1990	0.05	.04	.044	.066
1990 - 2020	0	.03	.035	.05
		COMMERCIAL		
1980 - 1990	0.05	.042	.052	.066
1990 - 2020	0	.032	.045	.05
		INDUSTRIAL		
1980 - 1990	0.05	.035	-	.085
1990 - 2020	0	.03	-	.06

Source: Energy Information Administration (1979)

electricity price increases will experience less increase relative to increases in other fuel prices over the next forty years.

Excluding gasoline for transportation, electricity and natural gas are the two major types of energy consumed in Pima County. Table 9 lists 1978 levels of sales for electricity and natural gas.

TABLE 9: ENERGY USE BY USER CLASS, 1978

	Electric[1] (MWh)	Natural Gas[2] (MMCF)
Residential	1,117,795	7,866,457
Commercial	1,170,393	5,079,622
Large Users[3]	1,883,692	3,776,957
Irrigation	22,468	655,204
Total	4,194,348	17,378,240

1) Source is Tucson Electric Power & Trico Electric

2) Source is Tucson Gas & Electric & Ajo Improvement Co.

3) Includes Large Commercial Users

	Btu Equivalents (Trillion Btu's)		
	Electric	Natural Gas	Total
Residential	3.815	7.866	11.681
Commercial	3.995	5.079	9.079
Large Users[1]	6.429	3.777	10.206
Irrigation	.0767	.655	.7317
Total	14.3157	17.377	31.6977

1) Includes large commercial users.

Tucson Electric Power Company provides electricity to 90 percent of the customers in Pima County. Current and projected breakdowns of energy sales are presented in Table 10. As indicated in the table, the industrial and large-user sector currently accounts for 50 percent of Tucson Electric Power Company's total electric energy sales; in 1995, this figure is expected to decrease to 39 percent of the total sales.

TABLE 10: PROJECTED DISTRIBUTION OF ELECTRICITY SALES IN PIMA COUNTY

	Percent of Sales			
Customer Class	1980	1985	1990	1995
Residential	26	30	33	35
Commercial	19	20	20	22
Industrial & Large Users	50	46	42	39
Others	5	4	5	4

Source: Tucson Electric Power

The residential sector, however, is expected to account for a larger percentage of total electric energy sales in 1995 (35 percent) than it currently does (26 percent). This increase is largely due to the expected population growth and increased demand for electric heating. The industrial sector has more flexibility than the residential sector and can modify its energy needs more easily. Thus, the industrial sector will not have to rely as heavily upon electric power in the future as it does now, and percent of total electric energy consumed by the industrial sector can be expected to decrease.

During 1979, data were collected for monthly electricity sales by user class. Figure 10 shows that the peak demand for electricity in the summer months substantially tapered off in the winter months due to a decline in usage of electricity for space cooling. This pattern is also followed by the commercial and industrial sectors. Mining, however, shows a steady increase in demand throughout the year.

Associated with monthly electric sales is a daily load curve. Figure 11 illustrates the capacity necessary to meet the daily peak in Pima County. On July 19, 1978 the annual peak of 833 MW was reached. It is this peak which defines the capacity in use and the capacity for which local utility companies must design their total systems.

Figure 12 presents growth in the peak as experienced by Tucson Electric Power Company between 1973 and 1979. The peak summer load has grown an average of three percent per year since 1973. However, no change in the peak was experienced in 1974, 1975 or 1976, a reflection of a recession in Pima County and doubled electric rates. Tucson Electric Power Company is required to maintain an additional margin of capacity above the annual peak. Over the period indicated, this margin has ranged from 24 percent to 69 percent of capacity, excluding sales for resale.

In some areas, different rates are charged for electric power based on the time of day the electricity is used. Higher rates are charged for electricity used during the day when the power company is operating on more expensive fuel types. This time-of-day pricing is currently in the experimental stage.

Southwest Gas Corporation provides natural gas to Pima County. Revenue provides the closest estimate of its natural gas sales since Southwest Gas

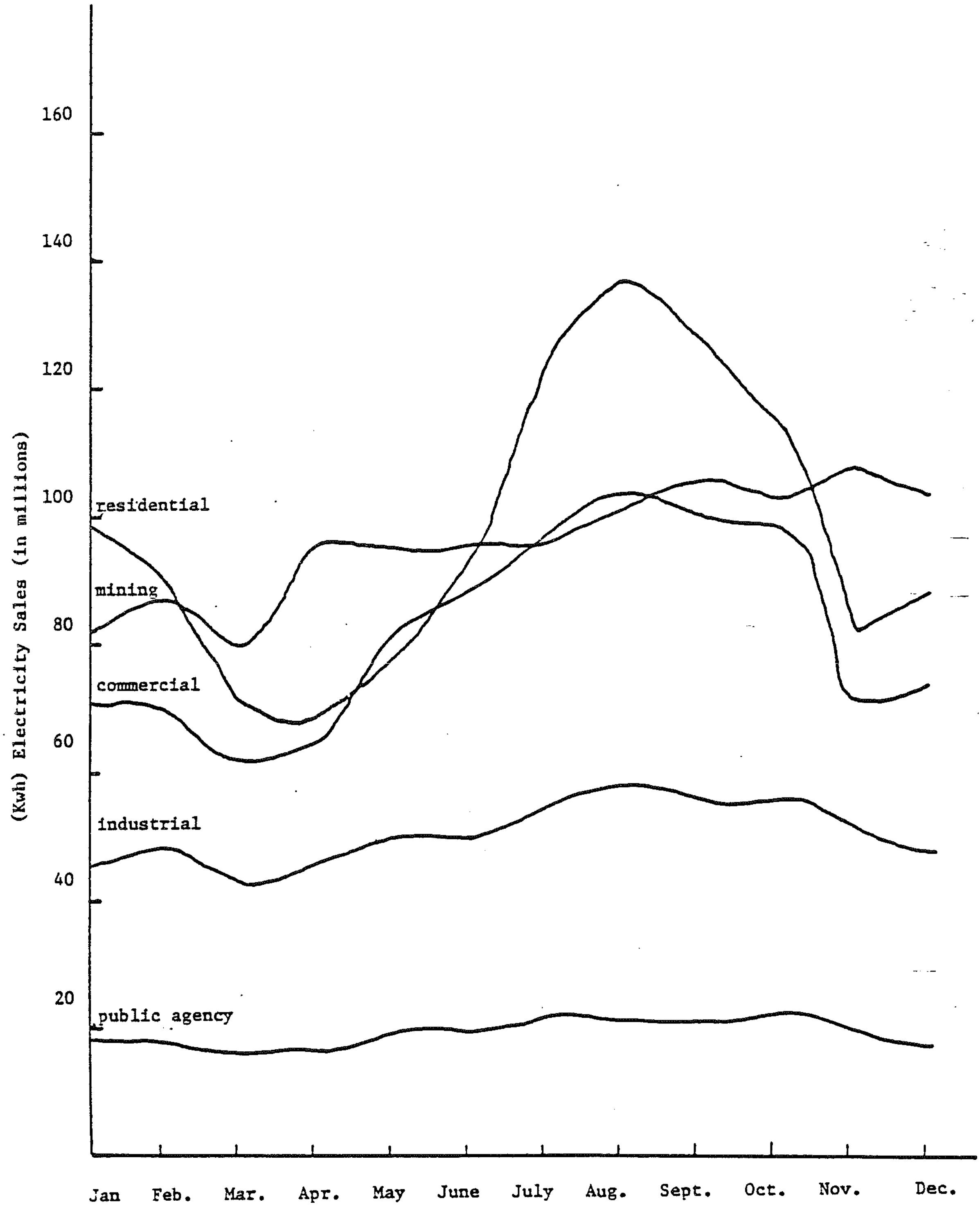


Figure 10: Estimated Electric Power Sales by Month for 1979.

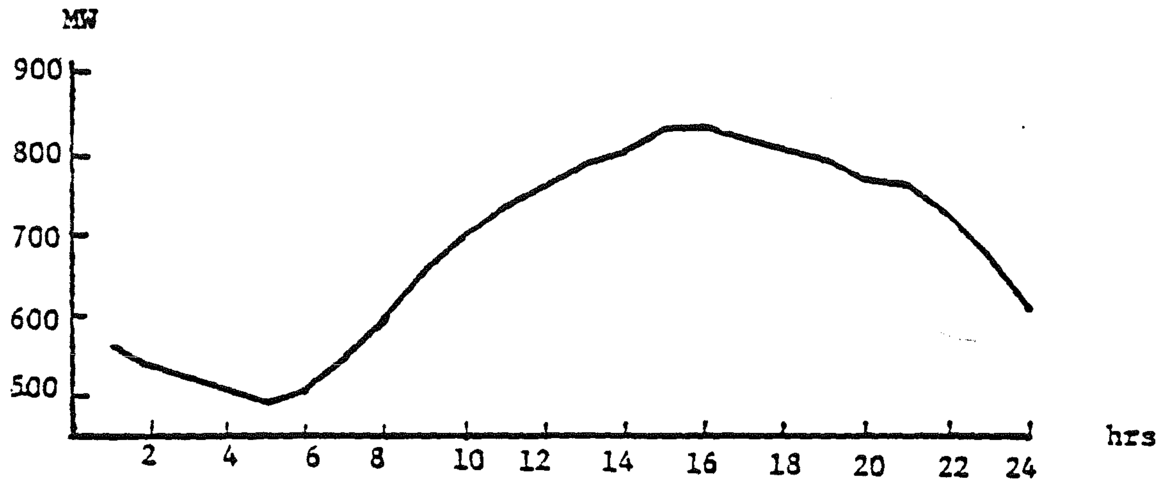


Figure 11: Daily Load Curve for Tucson Electric Power Co., July 19, 1978.
Peak Load - 833 MW

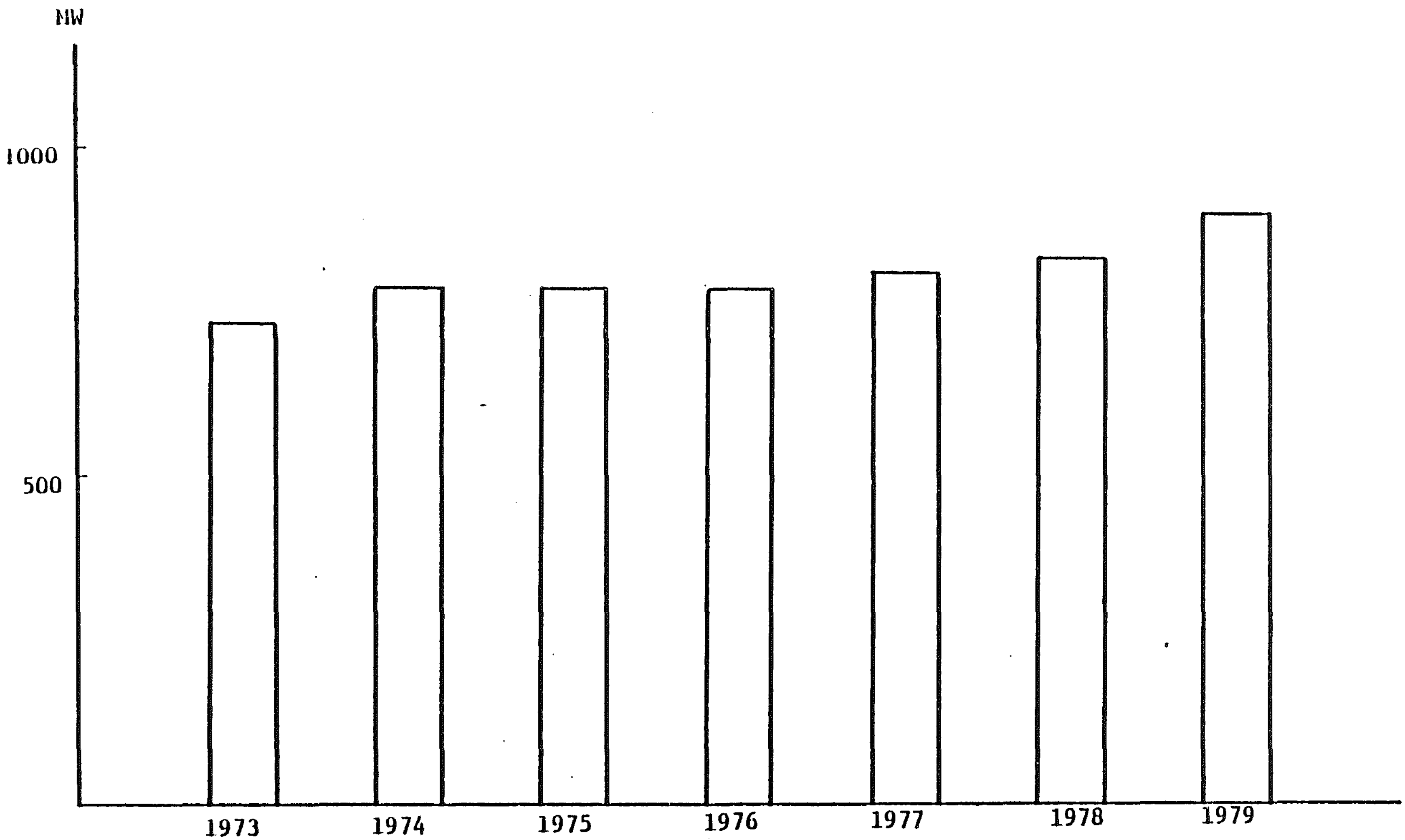


Figure 12: Peak Electric Load, 1973 - 1979.
Source: Tucson Electric Power Co.

Corporation does not collect monthly sales data. Booked volume sales, revenues received during the month for previous sales, for 1979 are presented in Figure 13. As anticipated, natural gas sales show peak demand for residential and commercial consumption for space heating in the winter months. The majority of residential dwellings in Tucson and the surrounding area use natural gas heating.

WATER

Water is rapidly becoming the major constraint to growth in Pima County. In Figure 14, the three alternative futures for water availability and use indicate that water demand currently exceeds and will continue to exceed dependable supplies. Demand for water will increase with the projected increases in population and mining activity. The Alternative Futures Summary shows that under each alternative, urban depletions in 2020 will exceed current urban depletions by at least 24 acre-feet. Also, the alternatives indicate that water use for mining will increase nearly 100 percent by 1990 and 350-500 percent by 2020.

Currently, Pima County's water supply comes entirely from underground sources which are rapidly being depleted. Central Arizona Project deliveries to Pima County will more than double the county's current dependable supply. Even the increased supplies, however, will not be enough to meet the increased demand. Only under Alternative III is water supply even approximately equal to water demand. Under this alternative, water for harvested acres and agricultural use has been greatly reduced or eliminated. Thus, in order to have enough water for urban growth and mining, agriculture will have to be drastically reduced over the next 40 years.

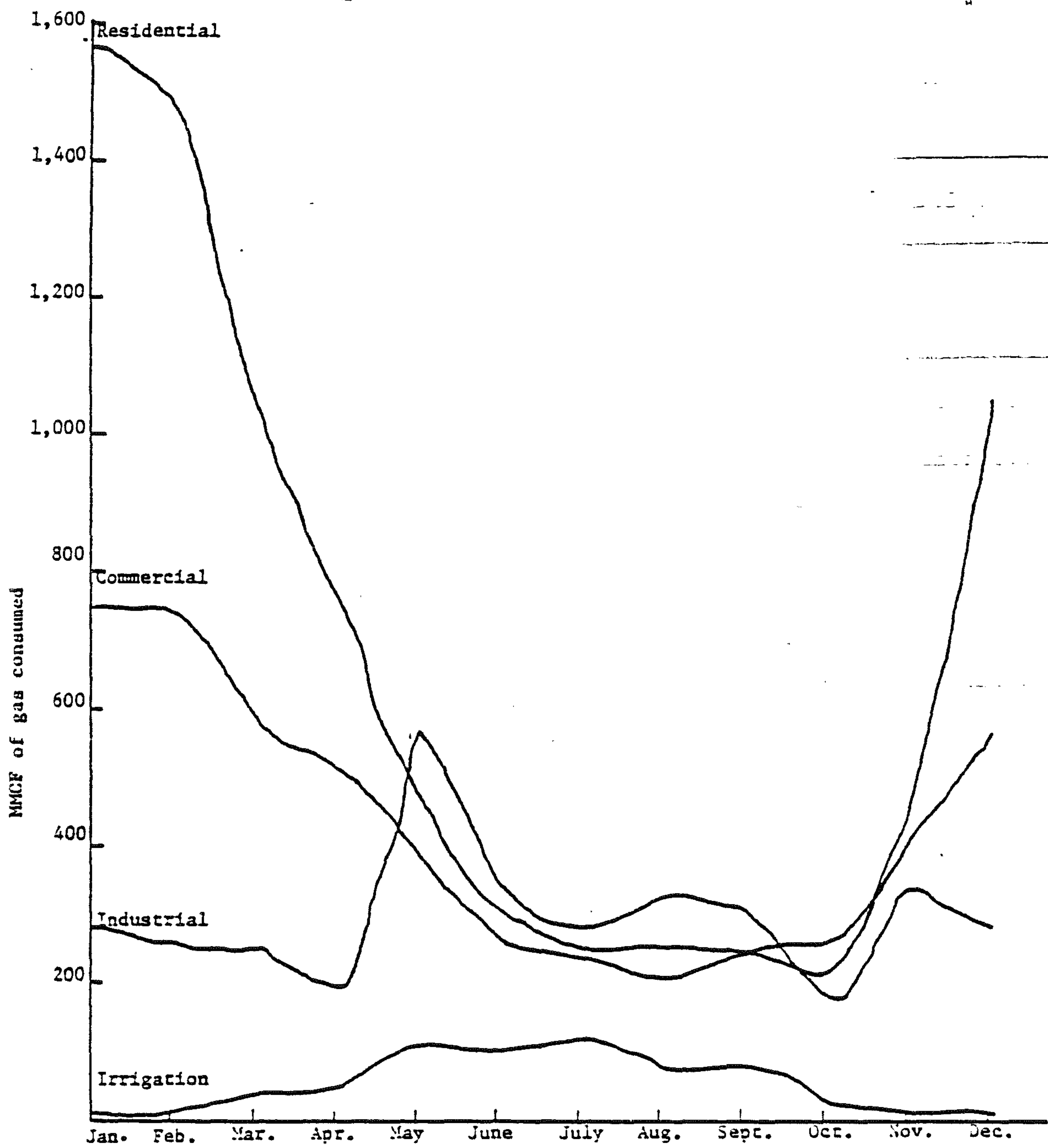
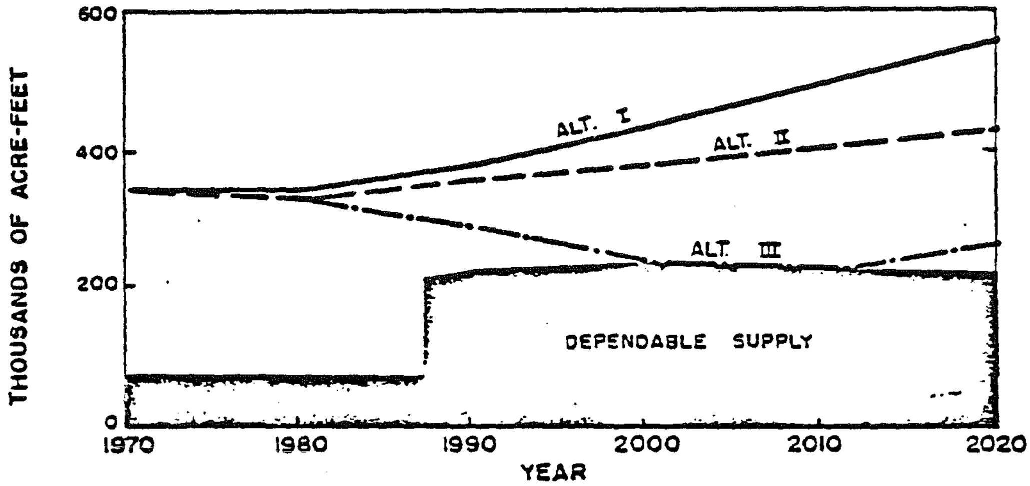


Figure 13: Estimated Natural Gas Sales by Month, 1979.

PIMA COUNTY
ALTERNATIVE FUTURES

PROJECTED ALTERNATIVE WATER DEPLETIONS AND DEPENDABLE SUPPLY



ALTERNATIVE FUTURES SUMMARY

ITEM (Quantities in Thousands)		ALTERNATIVE				FUTURES	
		I		II		III	
	1970	1990	2020	1990	2020	1990	2020
POPULATION	352.0	790.0	1490.0	645.0	960.0	645.0	960.0
HARVESTED ACRES	54.0	53.9	54.0	53.4	52.6	34.0	0
URBAN DEPLETIONS AF/YR	69.1	79.0	144.0	64.7	93.1	64.7	93.1
STEAM ELECTRIC DEPLETIONS AF/YR	6.1	4.4	7.8	3.4	5.8	3.4	5.8
MINERAL DEPLETIONS AF/YR	53.0	101.0	240.0	100.0	170.0	100.0	170.0
AGRICULTURAL DEPL. AF/YR	211.0	196.0	172.0	194.0	168.0	123.0	0
TOTAL WATER DEPL. AF/YR	339	380	564	362	437	291	269
DEPENDABLE WATER AF/YR	72	228	225	228	225	228	225
SURPLUS SUPPLY (Def.)	(267)	(152)	(339)	(134)	(212)	(63)	(44)

Figure 14: Projected Alternatives for Water Use in Pima County.
Source: Arizona Water Commission (1977)

MATCHING GEOTHERMAL RESOURCES TO POTENTIAL USERS

The final aim of the ADP is to match potential users of geothermal energy to potential resources. An attempt is also made to define a time frame in which geothermal resources will realize commercial use.

Several approaches were taken to match potential users to geothermal resources. One approach concentrated on the industrial sector within Pima County. Only those industries whose process heat requirements are less than the assumed reservoir temperature of 100°C (212°F) were considered potential users of geothermal energy. Table 11 presents an estimate of process heat requirements for such industries within the county. It should be noted that industrial process heat requirements do not include energy consumed for space heating and cooling.

Estimated annual energy consumption was then used to model the introduction of geothermal energy into the process heat market. Projections of the amount of geothermal heat on line as a function of time over the next forty years resulted from work performed in conjunction with the New Mexico Energy Institute (NMEI). Figures 15 and 16 illustrate time line results for private development and city development, respectively, with differences between the two types of development primarily arising due to differing capital costs. The results indicate that under city utility development, geothermal energy could be cost competitive by 1983 whereas under private development geothermal energy would come on line by 1988. In essence, city utility development would result in faster development of geothermal energy.

TABLE 11: ESTIMATED PROCESS HEAT ENERGY REQUIREMENTS FOR SELECTED INDUSTRIES IN PIMA COUNTY
Assumed Reservoir Temperature: 100°C (212°F)

SIC Code	Number of Firms	Description	Energy Use Btu/yr x 10^{9}
2026	2	Fluid Mild	12.27
2086	11	Soft Drinks	147.8
2097	6	Ice	6.76
2431	7	Millwork	18.9
2499	3	Misc. Wood Products	147.9
2511	9	Wood Furniture	17.62
2515	2	Mattresses	2.1
2519	3	Misc. Furniture	1.1
2522	1	Metal Office Furniture	49.1
2591	3	Drapery Hardware	3.5
3161	1	Luggage	5.1
3171	1	Handbags	1.0
3273	5	Ready-Mixed Concrete	55.62
3281	12	Cut Stone Products	3.04
3441	6	Structural Metal	42.4
3442	5	Metal Doors	17.9
3443	2	Boiler Shops	3.7
3444	9	Sheet Metal Work	145.9
3449	2	Misc. Metal Work	39.43
3452	1	Nuts/Bolts/Screws	5.0
3471	1	Metal Plating	7.7
3496	1	Wire Products	0.09
3499	6	Misc. Metal Products	11.2
3519	1	Internal Combustion Engines	8.391
3811	3	Engineering Instruments	3.9
3841	1	Medical Instruments	16.8
3843	1	Dental Equipment	0.4
3911	1	Jewelry	0.5
3914	1	Silverware	10.8
3949	3	Sporting Goods	6.291
3953	2	Marking Devices	1.1
3999	3	Misc. Manufactured Products	166.3

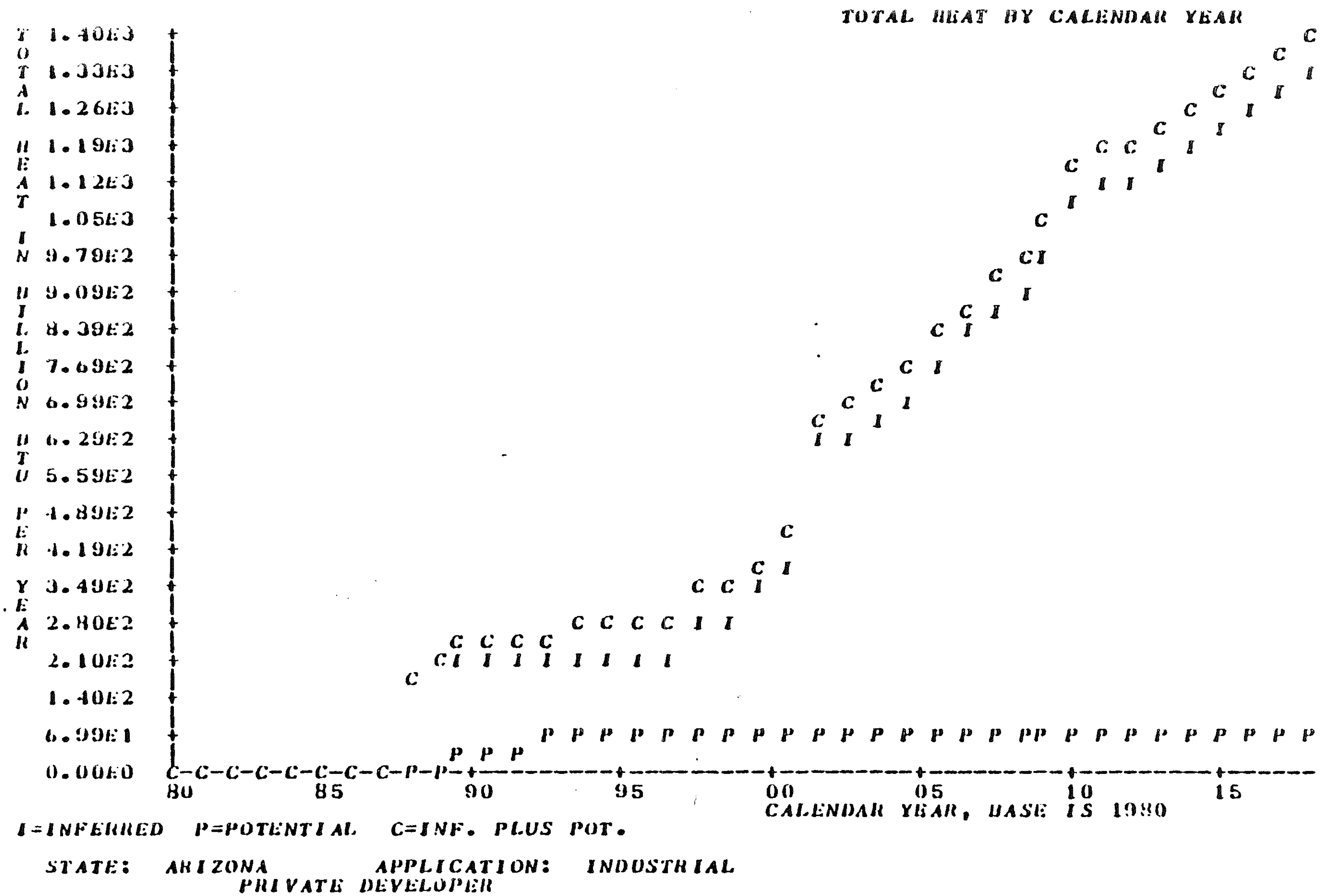


Figure 15: Projected Geothermal Heat on Line Under Private Development.
Source: New Mexico Energy Institute

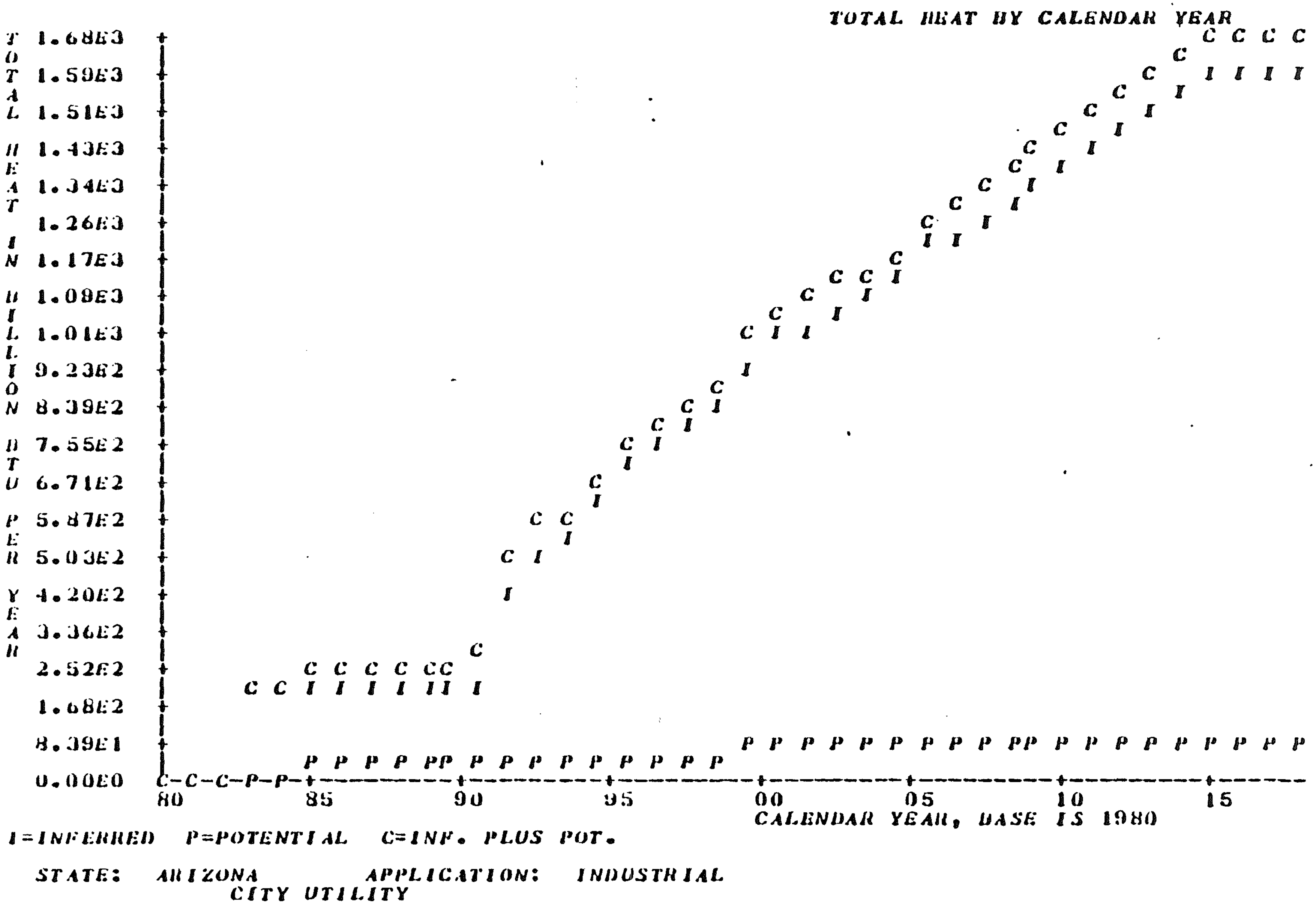


Figure 16: Projected Geothermal Heat On Line Under City Development.
Source: New Mexico Energy Institute

For comparison, the results of the modeling are presented in Table 12 in terms of barrels of oil replaced by geothermal energy. Clearly, geothermal energy's contribution to the process heat market could save a significant number of barrels of oil before 1990 and would be expected to contribute even more energy past 1990.

The NMEI model is discussed more fully in Appendix A.

TABLE 12: BARRELS OF OIL REPLACED BY GEOTHERMAL ENERGY PER YEAR
Process Heat Market

	1985	1990	2000	2020
Private Developer	0	44,643	87,320	250,000
City Utility	45,000	58,930	180,357	300,000

Modeling was also performed for the residential and commercial sectors. However, the scope of work was confined to space heating energy requirements. It is believed that the space heating market in Pima County is limited to a few winter months and as such would not justify the establishment of district heating systems. Therefore, results from the residential and commercial sectors have been omitted until a system including space heating and space cooling can be modeled.

In a second approach to identify potential users of geothermal energy, industrial parks, industries, shopping centers, schools and hospitals located in southern Tucson were identified. These facilities may consume enough energy each year to warrant conversion to geothermal energy for space heating and cooling. The names of these facilities and their addresses are listed in Appendix B.

Agribusiness and agriculturally related industries in Tucson are also identified. Tucson has five agricultural chemical operations, three cattle raising operations, one large dairy, nine meat packing plants and eight poultry farms. Any of these operations may be able to use geothermal energy in their operations in place of conventional energy sources.

Geothermal energy may also have process heat applications in the primary copper, soft drink and ready-mix concrete industries. The 1980 Directory of Arizona Manufacturers identifies industries by a four-digit SIC code and estimates of annual energy consumption as well as the process temperatures required by these industries were provided by the Solar Energy Research Institute. Information on the specific heat temperatures needed in each of the operations within these industries was gathered from three principal sources: the Noyes Data Corporation publication entitled "Energy-Saving Techniques for the Food Industry;" Drexel University's Energy Analysis of 108 Industrial Processes, Phase I of an Industrial Applications Study, 1979; and a Survey and Analysis of Solar Process Heating Opportunities in Arizona prepared by the University of Arizona.

Primary Copper (SIC 3331)

Pima County, the largest copper producer in Arizona, provides 40 percent of the copper produced in the state. There are about 2,200 million tons of proven copper ore in the state.

The typical process heat requirements for copper smelting and refining are summarized in Table 13. Process heat requirements exceed 1090°C (2000°F) for all processes except solution heating.

TABLE 13: TYPICAL PROCESS HEAT CONSUMPTION IN THE COPPER INDUSTRY

Process	Temperature (°F) & (°C)		MBtu per ton
Smelting			
Drying Concentrate	--	--	1.40
Reverberatory Furnace	2200	1204	14.67
Converter	2200	1204	0.89
Anode Furnace	2050	1121	3.49
Acid Plant	--	--	0
Electrolytic Refining			
Heating Solution	140	60	4.34
Melting Cathode	2050	1121	1.87
Total			26.66

Source: Battelle Labs, Final Report on Survey of the Applications of Solar Thermal Energy Systems to Industrial Process Heat, Vol. 2, Industrial Process Heat Survey, January 1977.

Drying the copper concentrate requires the same total amount of energy whether the concentrate is dried prior to or during the smelting process. In Arizona, no direct drying process is involved since the smelters use a wet charge of copper concentrate. Electricity is used during the smelting process, but if geothermal energy was used to pre-dry the concentrate about 1.4×10^{12} Btu's of conventional fuel could be displaced annually. This represents about four percent of the total thermal energy used by this industry.

The electrolytic refining process uses process heat in the range of $60^{\circ}C$ ($140^{\circ}F$) to $77^{\circ}C$ ($170^{\circ}F$) to heat electrolytic solutions. Heating the solutions requires 4.34 MBtu per ton of refined copper; the total energy required annually for this process is about 1.2×10^{12} Btu. Presently, most of the heat is supplied by natural gas and fuel oil. However, low temperature geothermal energy could be applied to this process.

Table 14 indicates the use of process heat for the individual processes within the primary and secondary copper industry.

TABLE 14: AGGREGATE PROCESS HEAT REQUIREMENTS FOR PRIMARY AND SECONDARY COPPER

Trillion Btu's/year, 1973

Process	Hot Water under 100°C	Steam 100-177°C	Steam Over 177°C
Copper (primary & secondary)			
Drying	0	0	0
Reverberatory Furnace	0	0	0
Converting	0	0	0
Anode Refining	0	0	0
Electrolytic Refining	4.6	0	0

Process	Direct Heat/Hot Air under 100°C	Direct Heat/Hot Air 100-177°C	Direct Heat/Hot Air Over 177°C
Copper (primary & secondary)			
Drying	0	0	0
Reverberatory Furnace	0	0	21.4
Converting	0	0	0.8
Anode Refining	0	0	3.0
Electrolytic Refining	0	0	0

Source: See Table 13 for Source

A new copper refining process has recently been developed which offers possibilities for geothermal applications. The new process is a hydrometallurgical extraction of copper. This process is a low energy-consuming process with an assessed total energy requirement of 32MBtu/ton. The process energy required for solution heating is normally provided by 30-psi steam at a temperature of approximately 121°C (250°F). The solution temperatures required for this process are about 37°C (100°F) to 107°C (225°F). Since the assessed geothermal reservoir temperature for Pima County is 100°C (212°F), the required solution temperatures are suitable to geothermal application.

In addition, it is important to note that copper dump leaching is practiced in some form in all of the mines in Pima County. Increased temperatures of the leaching fluid are known to enhance the rate of copper extraction. Low-temperature geothermal energy could be used in place of fossil fuels to heat the leaching fluid. Two reports being prepared by the Commercialization Team will discuss the leaching process for copper recovery. These reports, entitled "Geothermal Energy for Copper Dump Leaching" and "Geothermal Energy for the Extraction of Copper by Flotation", should be available by late 1981.

Soft Drink Industry (SIC 2086)

The 1980 Arizona Directory of Manufacturers lists three soft drink industries within Pima County. Each is primarily engaged in manufacturing soft drinks and carbonated waters. The significant operations with potential geothermal energy use are fructose storage, returnable bottle washing, can washing and cleanup.

Presently, natural gas is used for all of these operations with hot water as the medium. Fructose storage requires a process heat temperature of 32°C (90°F); bottle washing, 77°C - 88°C (170°F - 190°F); can washing, 54°C - 60°C (130°F - 140°F); and the clean-up operation, 60°C - 77°C (140°F - 170°F). It is estimated that the bottle- and can-washing processes alone consume about 0.19×10^{12} Btu's/yr. Thus given the average assessed geothermal temperature in Pima County of 100°C (212°F), the above processes appear to be suitable for geothermal process heat applications.

Ready-Mix Concrete Industry (SIC 3273)

There are three large firms within this industry in Pima County. Since the concrete is poured wet and is allowed to set at ambient temperature at the job site, energy consumption is for fuel for transportation rather than for process heat. Electricity is the prevailing energy source used in the crushing and mixing process so the low- to moderate-temperature geothermal resources of Pima County are not suitable for these applications. However, the ready-mix concrete industry does require large quantities of hot water for cleaning, mixing and storing. Geothermal energy potentially could be used to heat the water for these applications.

SUMMARY

Work to date has concentrated on simple identification of potential users of geothermal energy. Specification of annual heating and cooling demands as well as further details on various industrial and agricultural heat requirements remains to be done. Such detail will better define the role which geothermal energy may play in future years.

Appendix A

The New Mexico Energy Institute at New Mexico State University has developed a computer simulation model, BTHERM, to assess the economic feasibility of residential and commercial district space heating, hot water heating and industrial process heating using low temperature geothermal energy. Another model, CASH, was developed to depict the growth of geothermal energy on line over the next 40 years as a function of price of competing energy sources. A major assumption of these models is that geothermal energy must be price-competitive with the lowest-cost conventional energy source in order to assure market capture.

Development of a geothermal resource is characterized by large capital outlays, but a long-term geothermal investment has the potential to provide relatively inexpensive energy at a stable price. Unlike natural gas and electricity, however, geothermal energy is an unknown energy involving certain risks such as price and reservoir life and the need for back-up systems. An analysis of the costs and economic competitiveness of geothermal energy must take these uncertainties into account. Thus, costs may be overestimated so that the benefits will not be overstated.

The BTHERM computer simulation model models the residential, commercial and industrial sectors of a typical city, each sector having unique energy costs and energy system physical parameters as well as different growth rates. The model possesses the ability to model each sector individually and can analyze the application of geothermal energy to new growth only, to conversion of existing structures or to a combination of both. The model also has the capability to model both private and city-owned utility development of the geothermal resource.

Output of the model includes the levelized price per million Btu of delivered energy, the discounted present value of investment necessary and the undiscounted values of investments for policy studies. Also, from input of the price and price growth rate of conventional energy, the model determines the discounted or undiscounted values for federal and state taxes, tax credits, royalty rates, property taxes and consumer savings due to conversion from conventional energy to geothermal.

Certain limitations of the model have already been suggested. Costs, for example, may be overestimated due to safeguards built into the model to take into account the risks associated with geothermal energy. This overestimation of costs might result in the exclusion of a potential use of geothermal energy. Another limitation is that the price of natural gas is taken as the price of competitive (conventional) energy, but not all users have access to natural gas.

The output of the model is not a substitute for detailed engineering design studies but it is useful for determining order-of-magnitude costs and potential benefits of geothermal energy development.

Appendix B

POTENTIAL USERS OF GEOTHERMAL ENERGY IN TUCSON

Type of Development

Hospitals

Air Force Base Hospital
Building 400
Davis Monthan AFB

Kino Community Hospital
2800 E. Ajo Road

Veterans Hospital
3601 S. 6th Avenue

High Schools

Santa Rita High School
3951 S. Pantano Raod

Pueblo High School
3500 S. 12th Avenue

Sunnyside High School
1725 E. Bilby Road

Shopping Centers

Ajo Way & S. 12th Avenue
W. Ajo Way & S. 12th Avenue

Grant Plaza South
S. Nogales Hwy. & E. Drexel Road

Southgate
Interstate 10 & S. 6th Avenue

Irvington Plaza
E. Irvington Road & S. Campbell Avenue

K-Mart on Valencia
Interstate 19 & W. Valencia Road

Potential Users of Geothermal Energy in Tucson

Type of Development

Shopping Centers (continued)

Mission Manor
W. Valencia Road & S. 12th Avenue

San Xavier Plaza
W. Ajo Way & S. Mission Road

Major Industrial Parks

Broadbent Business Center
S. Palo Verde & Veterans

Caylor Business & Industrial Center
44th Street & Dodge Blvd.

Edelbrock Industrial Park
S. Park Avenue & Evans Blvd.

Park Avenue Industrial Center
4690 S. Park Avenue

Tucson Business Park
Park Avenue & Ajo Way

Tucson Industrial Center
Irvington Road & S. 3rd Avenue

Papago-Tucson Foreign Trade Zone No. 48
Los Reales Road & Old Nogales Hwy.

San Xavier Industrial Park
Los Reales Road & Old Nogales Hwy.

Santa Cruz
West of Interstate 19 between
Irvington & Valencia Roads

Tucson Aviation Center
7000 S. Nogales Hwy.

Tucson International Airport Industrial Park
7777 S. Nogales Hwy.

Valley Industrial Park No. 1
Country Club Road & Valencia Road

Appendix B (continued)

Potential Users of Geothermal Energy in Tucson

Type of Development

Air Force Bases

Davis Monthan Air Force Base

Industry

IBM
Interstate 10 & Rita Road

Hughes Aircraft
Nogales Hwy.

Newspapers

Arizona Daily Star/Tucson Citizen
4850 S. Park

Airports

Tucson International Airport
Valencia Road

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