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Geothermal Energy Development in the Eastern United States

EVALUATION OF POTENTIAL GEOTHERMAL RESOURCE AREAS

FRANKLIN O. MITCHELL

This work was supported by the Department of Energy under Interagency Agreements EX–76–A–36–1008 and DE–AIo1–79ET27025

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ABSTRACT

A method for the comparative evaluation of geothermal prospects in the eastern United States is proposed and illustrated. Comparisons are based on quantified data from geologic, engineering, and socio-economic sources including temperature gradient, depth to basement, drilling costs, population, and distribution by town size, as well as energy use in residential, commercial, and industrial applications. This revision incorporates new data for Mississippi and Pennsylvania. New data for New York State were reviewed and were found to be consistent with the previous data used in this analysis.

PREFACE

This report is one of a series by The Johns Hopkins University Applied Physics Laboratory in its role of supporting the development of geothermal energy in the eastern United States. Prior reports are listed below.

Planning Scenarios - to assist states and DOE in planning for geothermal development:

"Geothermal Energy and the Eastern U.S., a Scenario for Geothermal Energy Development, the Atlantic Coastal Plain," APL/JHU QM-77-129, Oct 1977.

"Geothermal Energy and the Eastern U.S., a Scenario for Geothermal Energy Development, the Coastal Plain in Southern Arkansas," APL/JHU QM-77-129-1, Oct 1977.

"Geothermal Energy and the Eastern U.S., a Scenario for Geothermal Energy Development, the Madison Limestone Aquifer in Western South Dakota," APL/JHU QM-77-129-2, Nov 1977.

"Geothermal Energy and the Eastern U.S., a Scenario for Geothermal Energy Development, the Eastern Gulf Coastal Plain," APL/JHU QM-77-129-3, Feb 1978.

"Geothermal Energy and the Eastern U.S., a Draft Scenario for Geothermal Energy Development, Hot Dry Rock," APL/JHU QM-77-129-4, Mar 1978.

*"Potential Application of Madison Formation Waters for Community Heating — South Dakota," APL/JHU QM-78-042R, Sep 1978.

"Geothermal Energy Development by Oglala Sioux at Kyle, South Dakota," APL/JHU QM-78-226, Apr 1978.

*"A Review of Recent Energy Price Projections for Traditional Space and Process Heating Fuels in the Post 1985 Period," APL/JHU GEMS-007 (QM-80-070), Apr 1980.

*Available for distribution.

*"Economic Evaluation Model for Direct Use of Moderate Temperature (up to 250°F) Geothermal Resources in the Northern Atlantic Coastal Plain," APL/JHU GEMS-003 (QM-79-124), Jun 1979.

*"Fact Sheets Relating to the Use of Geothermal Energy (Eastern United Sates)," APL/JHU QM-79-037, Jan 1979.

*"A Framework for a Site Prospectus for Geothermal Energy Development — Delmarva Peninsula," APL/JHU QM-79-145, Jun 1979.

*"Geothermal Energy Market Study in the Atlantic Coastal Plain, Definition of Markets for Geothermal Energy in the Northern Atlantic Coastal Plain," APL/JHU GEMS-002 (QM-80-075), May 1980.

The work reported here is sponsored as part of the Program for Development of Geothermal Energy in the Eastern United States by the Department of Energy/Division of Geothermal Energy under the direction of Dr. David Lombard, Program Manager, Resource Applications.

*Available for distribution.

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1. INTRODUCTION AND BACKGROUND

The Applied Physics Laboratory (APL), in its role of supporting the development of geothermal energy in the eastern United States, has developed a method for comparing potential geothermal resource areas in the region. A description of the method and a summary of initial results are presented herein.

The Department of Energy (DOE) maintains an active program to target, confirm, and assess geothermal resources on the Atlantic Coastal Plain. In addition, DOE and selected states are participating in joint programs to define geothermal characteristics within those states. To coordinate the results of this latter work and to give suggestions for future prospecting efforts require a systematic technique for examining the geothermal potential of the areas. Also needed is a quantitative technique for evaluating alternative future federal resource allocation strategies in support of DOE/DGE (Division of Geothermal Energy) and DOE/RA (Resource Applications) programs intended to stimulate the commercialization of low-to-moderate temperature geothermal resources.

This report presents a relatively straightforward method to satisfy both needs. The method combines geologic, engineering, and economic factors at the county level where the data are available. As data become available for a state not previously included, or better data become available for an included area, the entire set of prospects can be reassessed readily.

2. OVERVIEW

Comparative evaluations of geothermal prospects must consider geologic, engineering, and socio-economic information. Because the data are most readily available at the county level, the prospects are evaluated at that level in this report.

The proposed method for comparing prospects is an outgrowth of work during the 1940's arising from the von Neumann-Morgenstern axiomatization of utility (Ref. 1) and is related to the work of Arrow and Goodman at the Cowles Commission in the 1950's. Goodman's review (Ref. 2) of the work is the basic reference for this application. Keeney and Raifa (Ref. 3) present a thorough modern discussion of methods that might be used to extend this procedure.

Consider a matrix in which the prospects are presented as rows and the columns represent the several bases of comparison. An algorithm assigns a score that measures the preference for that prospect to each row of the matrix. Because comparisons must be made relative to some purpose, the method makes a clear distinction between the basis of comparison and the weight that must be associated with it for the stated purpose. (We anticipate that the purpose for which a comparative evaluation is conducted will vary with the point of view and with the echelon of the office needing the evaluation.) The algorithm scores prospects by ranking the columns individually and then takes a weighted average of the rankings in the columns for each prospect.

The bases of comparison fall into three broad categories: characteristics of the prospective resources, cost factors, and market factors.

The first, resource characteristics, is limited by the availability of uniform data to estimate the resource temperature and the extractable heat (in Btu/gal). It is assumed that extractable water exists at some depth in each prospective area. When reliable data on water availability and flow rate are obtainable, they can be taken into consideration.

Cost factors are limited to the cost of drilling and casing wells because of the availability of American Petroleum Institute (API) data. Other engineering costs are too site-specific to be included. Engineering cost studies being pursued in the energy community may well develop useful measures that can be included in the future.

Market factors contain measures that relate to the current use of energy for residential, commercial, and industrial purposes and for space heating demands.

The data we have assembled for deriving the bases of comparisons are considered only as convenient starting points to make comparisons. As field work progresses and as new statistics are evolved from energy programs, comparisons between geothermal prospects can be expected to change, both quantitatively and qualitatively. New data for Mississippi and Pennsylvania have been incorporated in this revised report and have modified the rankings in detail without, however, modifying the overall results. New data on New York State (Ref. 4) have been reviewed and are not significantly different from AAPG data used herein.

3. THE DATA

Data have been gathered for 260 counties in 12 states to illustrate the method for assessing their geothermal potential (Table 1). The first seven columns are taken from published sources; the last eight columns are derived from them. U.S. Department of Commerce maps are included in Appendix A. The counties selected as prospects have been shaded for emphasis.

The purpose of this analysis is to identify areas where geologic conditions favorable to hydrothermal energy development are colocated with concentrations of energy users. The identification and ordering of these resource/market areas provide direction and justification for more definitive work in the future. Areas such as the Atlantic Coastal Plain are excluded since an active resource assessment program is in process (Ref. 5) in that area. This area is marked by line shading in Fig. 1.

DEPTH AND GRADIENT

Comparisons were restricted to sedimentary basins where subsurface temperatures and drilling costs are known from previous explorations for hydrocarbons. Moreover, the potential for locating and extracting water as a heat exchange medium is greater in sedimentary sequences than in crystalline terraces (Ref. 6).

Information on depths to basement and geothermal gradients is published by the U.S. Geological Survey (Refs. 7 and 8). The data for geothermal gradients are incomplete for parts of the eastern United States, notably New England, eastern New York, along the Appalachians, and central Missouri (see Fig. 1). The data from the two reference maps (Refs. 7 and 8) were plotted to a common scale. Counties were selected where the depth to basement was greater than 1000 ft (the assumed minimum value needed for insulation) and the geothermal gradient exceeded 1.6°F/100 ft (illustrated in Fig. A-11). New data have been incorporated in the table for Pennsylvania (Ref. 9) and Mississippi (Ref. 10). The county names where new data appear are preceded by an asterisk in the tables.

Areas where data were incomplete were omitted, but no implication is intended that they might not be valid geothermal prospects according to some other criterion or source of data. Both the gradient and the depth to basement vary over areas as large as a county; columns 1 and 2 of Table 1 give estimates of averages

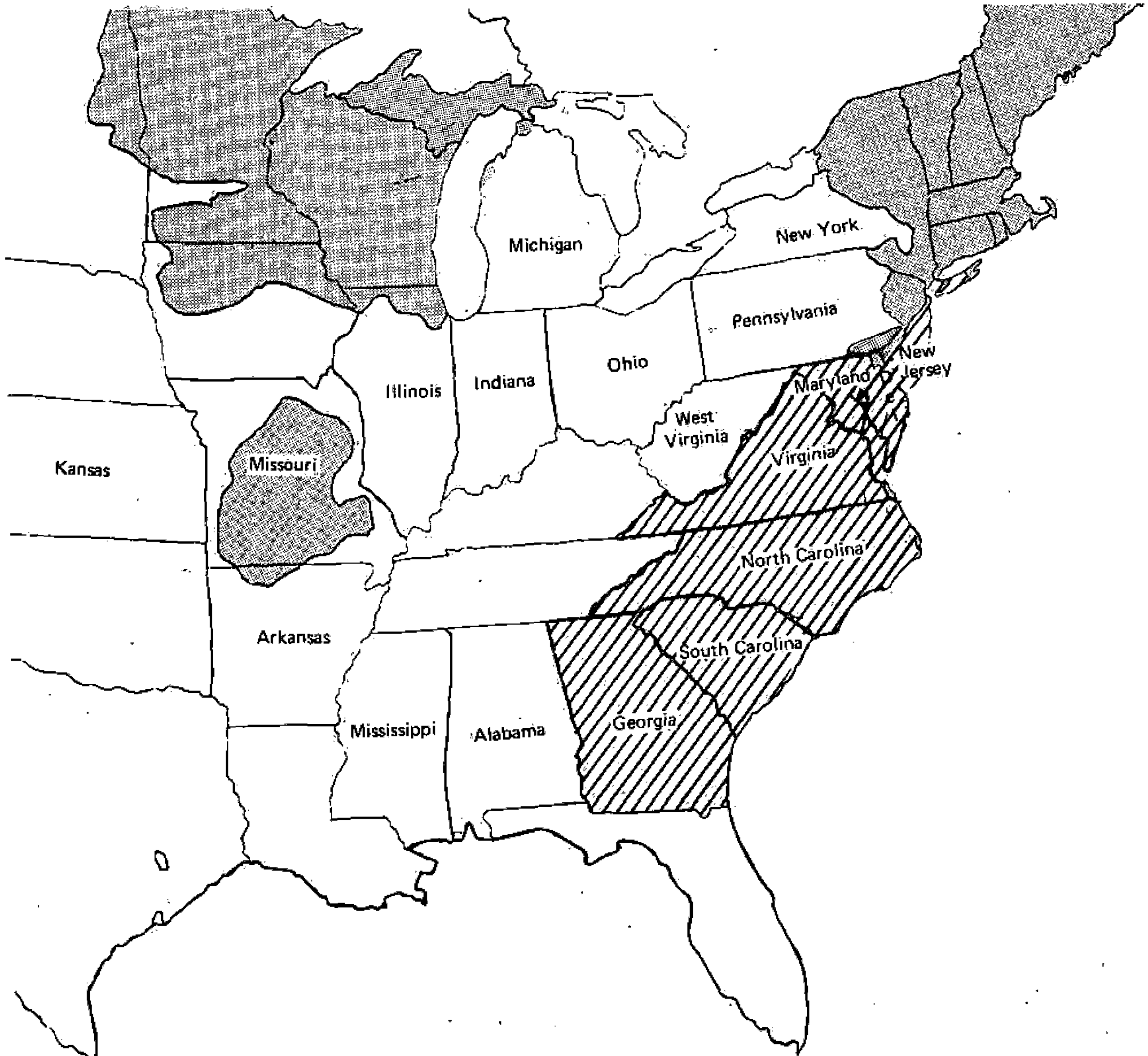

Fig. 1 Geographical areas covered in comparative evaluation. Shaded areas are excluded without prejudice because gradient data are unavailable. For ruled areas see text.

Table 1

Geologic, geothermal, demographic, and industrial data. (States and counties where thermal gradient exceeds 1.6° F/100 ft.)

States/Counties	Depth (thousand ft)	Gradient (°F/100 ft)	Population (thousands)	Towns	Cities	Heating degree days (hundreds)	Value added in manufacture	Well depth (assumed)	Temperature (°F)	Extractable heat (Btu/gal)	Cost ($ per ft)	Residential use (trillion Btu)	Commercial use (trillion Btu)	Industrial use (trillion Btu)
ALABAMA														
BALDWIN	14.0	1.8	70.8	9	0	17	23.30	10.0	190	751	61	1.50	1.27	1.82
BLOUNT	10.0	1.6	32.1	2	0	32	10.50	7.5	175	626	43	.68	.58	.82
CULLMAN	8.0	1.6	58.9	5	0	34	27.00	6.0	151	426	35	1.24	1.06	2.10
LAMAR	8.0	1.6	15.6	3	0	29	7.10	6.0	151	426	35	.33	.28	.55
LAWRENCE	6.0	1.6	28.6	2	0	32	2.90	4.5	127	225	29	.60	.51	.23
LIMESTONE	7.0	1.6	43.5	2	0	32	4.40	5.3	139	325	32	.92	.78	.34
LOWNDES	6.0	1.6	13.3	1	0	21	6.00	4.5	127	225	29	.28	.24	.47
MARENGO	10.0	1.6	23.7	3	0	21	33.70	7.5	175	626	43	.50	.43	2.63
MORGAN	7.5	1.6	83.9	3	1	33	206.00	5.6	145	376	34	1.77	1.51	16.05
PIKE	5.0	1.6	24.3	2	0	26	15.50	3.8	115	125	26	.51	.44	1.21
WALKER	7.0	1.6	64.5	9	0	29	22.80	5.3	139	325	32	1.36	1.16	1.78
WINSTON	8.0	1.6	19.7	3	0	33	18.80	6.0	151	426	35	.42	.35	1.46
ARKANSAS														
CALHOUN	5.0	1.8	5.6	2	0	27	5.00	3.8	123	188	26	.20	.14	.60
CLARK	7.0	1.8	22.2	3	0	29	22.20	5.3	150	413	32	.80	.55	2.67
CLEBURNE	6.0	1.8	14.7	1	0	36	9.00	4.5	136	300	29	.53	.36	1.08
CROSS	8.0	1.9	20.7	3	0	32	12.50	6.0	169	576	35	.75	.51	1.50
DREW	5.0	1.8	16.1	2	0	27	17.20	3.8	123	188	26	.58	.40	2.07
FRANKLIN	10.0	1.8	13.0	2	0	32	3.80	7.5	190	751	43	.47	.32	.46
HOWARD	7.0	1.8	13.3	3	0	30	13.90	5.3	150	413	32	.48	.33	1.67
JACKSON	7.0	1.9	21.2	4	0	32	10.80	5.3	155	457	32	.77	.52	1.30
JEFFERSON	7.0	1.9	84.2	3	1	26	92.40	5.3	155	457	32	3.04	2.08	11.11
LINCOLN	7.0	1.8	13.1	3	0	27	7.49	5.3	150	413	32	.47	.32	.90
LITTLE RIVER	5.0	1.9	11.7	2	0	28	12.20	3.8	126	219	26	.42	.29	1.47
LONOKE	8.0	1.8	26.2	3	0	34	9.10	6.0	163	526	35	.95	.65	1.09
OUCHITA	5.0	1.7	29.4	4	0	27	38.50	3.8	119	156	26	1.06	.73	4.63
PIKE	8.0	1.8	9.4	2	0	33	3.40	6.0	163	526	35	.34	.23	.41
POINSETT	7.0	1.8	27.5	5	0	35	17.10	5.3	150	413	32	.99	.68	2.06
SEVIER	6.0	1.8	12.2	3	0	29	5.90	4.5	136	300	29	.44	.30	.71
VANBUREN	6.0	1.7	10.3	1	0	36	4.82	4.5	131	263	29	.37	.25	.58
ILLINOIS														
BOND	7.0	1.6	14.7	4	0	49	13.20	5.3	139	325	32	.82	.47	.35
CASS	3.5	1.7	14.0	4	0	55	5.50	2.6	100	0	23	.78	.44	.15
CHAMPAIGN	6.0	1.6	164.4	12	3	56	60.60	4.5	127	225	29	9.20	5.21	1.61
CLARK	7.0	1.8	16.2	4	0	53	.00	5.3	150	413	32	.91	.51	.46
CLAY	11.0	1.5	14.9	3	0	48	7.70	8.3	168	563	48	.83	.47	.20
COLES	7.0	2.0	49.9	5	0	53	59.00	5.3	160	501	32	2.79	1.58	1.57
CRAWFORD	9.0	1.9	19.9	4	0	49	48.40	6.8	183	695	39	1.11	.63	1.29
CUMBERLAND	9.0	1.8	10.3	3	0	53	2.50	6.8	177	638	39	.58	.33	.07
DE WITT	6.0	1.7	16.9	5	0	56	18.80	4.5	131	263	29	.95	.54	.50
DOUGLAS	6.0	1.6	19.5	6	0	55	50.60	4.5	127	225	29	1.09	.62	1.35
EDGAR	7.0	1.8	21.6	3	0	53	20.80	5.3	150	413	32	1.21	.68	.55
EDWARDS	13.0	1.8	7.5	3	0	46	.00	9.8	190	751	59	.42	.24	.32
EFFINGHAM	9.0	1.8	28.2	4	0	52	14.70	6.8	177	638	39	1.58	.89	.39
FAYETTE	7.0	1.6	20.8	5	0	51	7.70	5.3	139	325	32	1.16	.66	.20
GREENE	3.5	1.5	16.7	4	0	51	4.40	2.6	94	0	23	.93	.53	.12
LAWRENCE	10.0	1.9	17.5	4	0	47	.00	7.5	197	814	43	.98	.55	.60
LOGAN	5.0	1.8	31.1	4	0	50	65.00	3.8	123	188	26	1.74	.99	1.73
MACOUPIN	4.3	1.8	46.1	11	0	51	8.70	3.2	113	109	24	2.58	1.46	.23
MADISON	4.0	1.8	247.8	20	2	49	645.20	3.0	109	0	24	13.87	7.85	17.17
MASON	4.5	1.8	18.8	3	0	56	4.30	3.4	116	131	25	1.05	.60	.11
MENARD	4.5	2.0	10.9	4	0	56	.00	3.4	123	188	25	.61	.35	.26
MONROE	3.0	1.8	18.9	3	0	44	.90	2.3	96	0	21	1.06	.60	.02
MONTGOMERY	6.0	1.6	30.6	9	0	50	15.00	4.5	127	225	29	1.71	.97	.40

Table 1 (cont'd)

States/Counties	Depth (thousand ft)	Gradient (°F/100 ft)	Population (thousands)	Towns	Cities	Heating degree days (hundreds)	Value added in manufacture	Well depth (assumed)	Temperature (°F)	Extractable heat (Btu/gal)	Cost ($ per ft)	Residential use (trillion Btu)	Commercial use (trillion Btu)	Industrial use (trillion Btu)
MORGAN	3.5	1.7	35.6	7	0	53	55.10	2.6	100	0	23	1.99	1.13	1.47
MOULTRIE	7.0	1.7	13.2	4	0	54	10.10	5.3	144	369	32	.74	.42	.27
PIATT	6.0	1.7	16.0	5	0	55	.00	4.5	131	263	29	.90	.51	.52
RICHLAND	11.0	1.8	17.2	2	0	47	15.20	8.3	190	751	48	.96	.55	.40
SA CLAIR	3.7	1.6	280.7	20	3	46	267.30	2.8	99	0	23	15.71	8.90	7.12
SANGAMON	4.5	1.8	172.9	19	1	56	159.60	3.4	116	131	25	9.68	5.48	4.25
SHELBY	7.0	1.9	23.2	7	0	53	5.90	5.3	155	457	32	1.30	.74	.16
VERMILLION	6.0	1.8	98.7	13	1	55	195.60	4.5	136	300	29	5.53	3.13	5.21
WABASH	13.0	1.9	13.5	1	0	46	18.40	9.8	197	814	59	.76	.43	.49
WAYNE	13.0	1.6	17.3	3	0	46	.00	9.8	175	626	59	.97	.55	.40
WHITE	14.0	1.7	16.8	4	0	44	4.50	10.0	182	688	61	.94	.53	.12
INDIANA														
BOONE	4.0	1.8	32.9	5	0	58	29.50	3.0	109	0	24	1.70	.89	1.22
CARROLL	3.5	1.9	17.8	4	0	56	8.70	2.6	105	0	23	.92	.48	.36
CASS	3.5	1.8	39.6	4	0	59	46.20	2.6	102	0	23	2.05	1.07	1.91
CLAY	7.0	2.0	24.5	5	0	54	6.70	5.3	160	501	32	1.27	.66	.28
CLINTON	3.7	1.8	30.6	5	0	60	30.30	2.8	105	0	23	1.58	.83	1.25
DAVIESS	8.0	1.8	26.0	3	0	46	17.60	6.0	163	526	35	1.35	.70	.73
DELAWARE	2.7	1.7	128.9	5	1	59	263.50	2.0	89	0	21	6.67	3.49	10.87
DUBOIS	8.0	1.7	32.3	4	0	47	57.60	6.0	157	476	35	1.67	.87	2.38
GIBSON	13.5	1.8	31.2	7	0	46	23.40	10.0	190	751	61	1.62	.84	.97
GREENE	7.0	2.0	28.1	5	0	53	10.40	5.3	160	501	32	1.45	.76	.43
HAMILTON	3.0	1.8	70.9	8	0	57	35.90	2.3	96	0	21	3.67	1.92	1.48
HANCOCK	3.0	1.8	41.0	6	0	56	9.70	2.3	96	0	21	2.12	1.11	.40
HENDRICKS	5.0	1.8	62.2	6	0	56	3.50	3.8	123	188	26	3.22	1.68	.14
HENRY	3.0	1.7	53.5	3	1	58	87.80	2.3	93	0	21	2.77	1.45	3.62
HOWARD	3.0	1.8	87.2	2	1	56	313.80	2.3	96	0	21	4.52	2.36	12.95
JOHNSON	5.0	1.8	70.6	7	0	53	41.50	3.8	123	188	26	3.66	1.91	1.71
KNOX	9.0	1.9	40.2	6	0	49	30.10	6.8	183	695	39	2.08	1.09	1.24
MADISON	2.9	1.8	138.4	10	1	56	453.50	2.2	94	0	21	7.17	3.74	18.72
MARION	4.0	1.8	775.8	10	2	56	1679.60	3.0	109	0	24	40.17	20.99	69.32
MARTIN	7.0	1.7	11.0	4	0	48	17.20	5.3	144	369	32	.57	.30	.71
MONROE	7.0	1.8	91.2	1	1	49	197.10	5.3	150	413	32	4.72	2.47	8.13
MONTGOMERY	5.0	1.8	34.1	6	0	58	63.10	3.8	123	188	26	1.77	.92	2.60
MORGAN	6.0	1.8	48.7	5	0	54	10.80	4.5	136	300	29	2.52	1.32	.45
OWEN	6.0	1.8	13.2	2	0	54	2.50	4.5	136	300	29	.68	.36	.10
PARKE	6.0	1.9	15.7	3	0	53	1.30	4.5	140	338	29	.81	.42	.05
PIKE	9.0	1.7	12.2	2	0	46	.30	6.8	170	592	39	.63	.33	.01
POSEY	13.5	1.7	22.8	4	0	40	31.40	10.0	182	688	61	1.18	.62	1.30
PULASKI	3.8	1.8	12.7	3	0	62	8.30	2.8	106	0	23	.66	.34	.34
PUTNAM	6.0	1.9	27.9	4	0	55	29.40	4.5	140	338	29	1.44	.75	1.21
RUSH	3.0	1.6	20.3	2	0	56	12.30	2.3	91	0	21	1.05	.55	.51
SHELBY	4.0	1.6	38.7	2	0	54	45.10	3.0	103	0	24	2.00	1.05	1.86
SULLIVAN	8.0	2.0	19.7	6	0	52	5.50	6.0	175	626	35	1.02	.53	.23
TIPPECANOE	4.5	1.8	114.1	3	2	58	171.60	3.4	116	131	25	5.91	3.09	7.08
TIPTON	3.0	1.8	16.0	7	0	56	11.30	2.3	96	0	21	.83	.43	.47
VANDERBURGH	13.5	1.7	161.6	1	1	46	.00	10.0	182	688	61	8.37	4.37	14.69
VIGO	8.0	2.0	110.6	2	1	54	158.80	6.0	175	626	35	5.73	2.99	6.55
WARRICK	12.0	1.7	34.7	5	0	46	.00	9.0	182	688	53	1.80	.94	1.78
WHITE	4.0	1.9	22.0	6	0	57	.00	3.0	112	100	24	1.14	.60	2.09
KANSAS														
ALLEN	1.0	1.8	15.4	2	0	44	10.30	1.0	69	0	18	4.20	2.38	2.60
ANDERSON	1.5	1.8	8.5	1	0	50	1.20	1.1	75	0	18	2.32	1.31	.30
BOURBON	1.0	2.0	15.7	1	0	42	5.80	1.0	70	0	18	4.28	2.42	1.46
CHEROKEE	1.0	2.0	21.4	4	0	41	29.80	1.0	70	0	18	5.83	3.30	7.52

Table 1 (cont'd)

States/Counties	Depth (thousand ft)	Gradient (°F/100 ft)	Population (thousands)	Towns	Cities	Heating degree days (hundreds)	Value added in manufacture	Well depth (assumed)	Temperature (°F)	Extractable heat (Btu/gal)	Cost ($ per ft)	Residential use (trillion Btu)	Commercial use (trillion Btu)	Industrial use (trillion Btu)
CRAWFORD	1.0	2.0	36.8	6	0	41	24.40	1.0	70	0	18	10.03	5.68	6.15
DOUGLAS	2.0	1.6	64.4	1	1	47	46.10	1.5	79	0	19	17.55	9.94	11.63
FRANKLIN	1.5	1.8	20.2	3	0	47	7.20	1.1	75	0	18	5.50	3.12	1.82
JEFFERSON	2.0	1.6	13.4	5	0	51	.60	1.5	79	0	19	3.65	2.07	.15
LABETTE	1.0	1.8	24.8	4	0	40	11.90	1.0	69	0	18	6.76	3.83	3.00
LEAVENWORTH	2.0	1.6	56.7	3	1	50	10.30	1.5	79	0	19	15.45	8.75	2.60
LINN	1.0	1.9	8.3	3	0	47	.80	1.0	69	0	18	2.26	1.28	.20
MIAMI	1.5	1.7	20.9	3	0	50	8.00	1.1	74	0	18	5.70	3.22	2.02
NEOSHO	1.0	1.8	18.5	3	0	46	13.10	1.0	69	0	18	5.04	2.85	3.30
MICHIGAN														
ALCOMA	7.5	1.6	8.9	1	0	81	1.50	5.6	145	376	34	.46	.26	.04
BAY	12.0	1.6	119.6	2	0	68	189.70	9.0	175	626	53	6.23	3.50	5.35
CLARE	18.0	1.6	22.3	3	0	76	11.20	10.0	175	626	61	1.16	.65	.32
IOSCO	8.0	1.6	28.9	3	0	75	6.70	6.0	151	426	35	1.50	.85	.19
MISSAUKEE	10.0	1.6	9.1	2	0	81	.50	7.5	175	626	43	.47	.27	.01
NEWAYGO	8.0	1.6	31.7	4	0	75	35.10	6.0	151	426	35	1.65	.93	.99
OGEMAW	11.0	1.6	15.1	2	0	81	7.10	8.3	175	626	48	.79	.44	.20
OSCEOLA	10.0	1.6	17.8	3	0	76	19.40	7.5	175	626	43	.93	.52	.55
ROSCOMMON	12.0	1.8	15.2	1	0	81	1.40	9.0	190	751	53	.79	.45	.04
TUSCOLA	8.0	1.7	54.1	9	0	70	31.40	6.0	157	476	35	2.82	1.59	.88
WEXFORD	1.6	1.6	22.1	2	1	84	24.70	1.2	74	0	19	1.15	.65	.70
MISSISSIPPI														
*ADAMS	5.2	.0	37.3	0	1	19	57.20	3.9	158	860	27	.90	.68	5.24
*AMITE	5.4	.0	13.7	2	0	19	5.50	4.0	158	860	27	.33	.25	.50
*CLAIBORNE	5.2	.0	10.1	1	0	24	4.10	3.9	158	860	27	.24	.18	.38
*CLARKE	6.4	.0	15.0	4	0	23	9.30	4.8	158	860	30	.36	.27	.85
*COPIAH	5.2	.0	24.7	3	0	20	17.30	3.9	158	860	27	.60	.45	1.58
*COVINGTON	6.0	.0	14.0	2	0	19	4.30	4.5	158	860	29	.34	.26	.39
*FORREST	5.2	.0	57.8	1	1	19	41.70	3.9	158	860	27	1.40	1.05	3.82
*FRANKLIN	5.2	.0	8.0	3	0	20	1.40	3.9	158	860	27	.19	.15	.13
*GEORGE	5.2	.0	12.5	1	0	17	2.40	3.9	158	860	27	.30	.23	.22
*GREENE	5.6	.0	8.5	2	0	19	.00	4.2	158	860	28	.21	.15	1.14
GRENADA	11.5	1.9	20.0	1	0	26	31.70	8.6	197	814	50	.48	.36	2.90
*HANCOCK	5.2	.0	17.4	2	0	16	.00	3.9	158	860	27	.42	.32	.81
*HARRISON	5.2	.0	134.6	2	2	16	42.70	3.9	158	860	27	3.26	2.45	3.91
*HINDS	4.8	.0	215.0	6	1	22	154.80	3.6	158	860	26	5.21	3.92	14.18
HOLMES	10.5	1.8	22.6	4	0	26	5.40	7.9	190	751	46	.55	.41	.49
*HUMPHREYS	4.8	.0	14.6	2	0	26	4.00	3.6	158	860	26	.35	.27	.37
*ISSAQUENA	4.9	.0	2.7	0	0	23	.00	3.7	158	860	26	.07	.05	.00
*JACKSON	5.0	.0	88.0	1	2	16	169.90	3.8	158	860	26	2.13	1.60	15.56
*JASPER	6.0	.0	16.0	2	0	23	6.00	4.5	158	860	29	.39	.29	.55
*JEFFERSON	5.2	.0	9.3	1	0	21	1.10	3.9	158	860	27	.23	.17	.10
*JEFFERSON DAVIS	5.4	.0	12.9	1	0	20	2.10	4.0	158	860	27	.31	.24	.19
*JONES	6.0	.0	56.4	2	1	21	41.80	4.5	158	860	29	1.37	1.03	3.83
LAFAYETTE	9.5	1.9	24.0	1	0	31	3.60	7.1	190	754	41	.58	.44	.33
*LAMAR	5.6	.0	15.2	3	0	19	12.60	4.2	158	860	28	.37	.28	1.15
*LAWRENCE	6.0	.0	11.1	2	0	20	.00	4.5	158	860	29	.27	.20	.81
*LINCOLN	5.6	.0	26.2	1	0	20	16.90	4.2	158	860	28	.63	.48	1.55
*MADISON	4.5	.0	29.7	4	0	24	22.70	3.4	158	860	25	.72	.54	2.08
*MARION	5.4	.0	22.9	1	0	18	11.10	4.0	158	860	27	.55	.42	1.02
MONROE	8.0	1.8	13.2	2	0	26	9.00	6.0	163	526	35	.32	.24	.82
MONTGOMERY	11.5	1.9	34.5	4	0	27	52.30	8.6	197	814	50	.84	.63	4.73
NOXUBEE	12.0	2.0	14.3	2	0	26	4.60	9.0	205	876	53	.35	.26	.42
*PEARL RIVER	4.8	.0	27.8	2	0	16	7.10	3.6	158	860	26	.67	.51	.65
*PERRY	5.2	.0	9.1	3	0	19	2.60	3.9	158	860	27	.22	.17	.24

Table 1 (cont'd)

States/Counties	Depth (thousand ft)	Gradient (°F/100 ft)	Population (thousands)	Towns	Cities	Heating degree days (hundreds)	Value added in manufacture	Well depth (assumed)	Temperature (°F)	Extractable heat (Btu/gal)	Cost ($ per ft)	Residential use (trillion Btu)	Commercial use (trillion Btu)	Industrial use (trillion Btu)
*PIKE	5.2	.0	31.8	4	0	19	22.10	3.9	158	860	27	.77	.58	2.02
PONTOTOC	9.5	1.9	17.4	1	0	29	6.30	7.1	190	754	41	.42	.32	.58
*SCOTT	5.2	.0	21.4	2	0	25	30.50	3.9	158	860	27	.52	.39	2.79
*SHARKEY	5.0	.0	8.9	2	0	24	.00	3.8	158	860	26	.22	.16	.33
*SMITH	6.0	.0	13.6	2	0	23	3.70	4.5	158	860	29	.33	.25	.34
*STONE	5.2	.0	8.1	1	0	17	4.20	3.9	158	860	27	.20	.15	.38
*WALTHALL	5.6	.0	12.5	1	0	19	2.30	4.2	158	860	28	.30	.23	.21
*WARREN	4.8	.0	45.0	0	1	21	53.00	3.6	158	860	26	1.09	.82	4.86
*WASHINGTON	4.7	.0	70.6	4	1	26	48.40	3.5	158	860	25	1.71	1.29	4.43
*WAYNE	6.0	.0	16.7	1	0	21	5.80	4.5	158	860	29	.40	.30	.53
*WILKINSON	5.4	.0	11.1	2	0	19	2.90	4.0	158	860	27	.27	.20	.27
*YAZOO	5.1	.0	27.3	2	0	24	65.20	3.8	158	860	26	.66	.50	5.97
MISSOURI														
BARTON	1.0	1.9	10.9	2	0	48	3.30	1.0	69	0	18	.13	.10	.08
BATES	1.0	1.6	16.2	3	0	46	1.30	1.0	67	0	18	.19	.15	.03
BOLLINGER	2.0	1.8	10.0	2	0	44	2.90	1.5	82	0	19	.12	.09	.07
CAPE GIRARDE	3.0	1.7	52.6	1	1	42	35.70	2.3	93	0	21	.63	.47	.91
DUNKLIN	4.8	1.6	36.3	8	0	36	16.00	3.6	113	105	26	.43	.33	.41
JASPER	1.0	1.9	82.6	8	1	41	121.90	1.0	69	0	18	.99	.74	3.10
JEFFERSON	1.0	1.7	124.6	7	1	47	66.40	1.0	68	0	18	1.49	1.12	1.69
MCDONALD	1.0	1.7	15.2	3	0	44	6.20	1.0	68	0	18	.18	.14	.16
MADISON	2.0	1.8	9.4	1	0	45	4.50	1.5	82	0	19	.11	.08	.11
NEW MADRID	4.5	1.6	24.1	7	0	41	3.30	3.4	109	0	25	.29	.22	.08
NEWTON	1.0	1.7	36.4	5	0	40	22.80	1.0	68	0	18	.44	.33	.58
PEMISCOT	4.8	1.6	24.7	4	0	36	9.40	3.6	113	105	26	.30	.22	.24
PERRY	2.0	1.8	15.5	1	0	46	7.70	1.5	82	0	19	.19	.14	.20
ST FRANCOIS	2.0	1.8	39.5	8	0	46	10.80	1.5	82	0	19	.47	.36	.27
STE GENEVIEVE	2.0	1.8	14.2	2	0	46	21.50	1.5	82	0	19	.17	.13	.55
STODDARD	3.0	1.7	28.2	5	0	41	12.20	2.3	93	0	21	.34	.25	.31
VERNON	1.0	1.9	20.0	1	0	43	3.10	1.0	69	0	18	.24	.18	.08
NEW YORK														
ALLEGANY	7.5	1.6	50.9	10	0	74	43.00	5.6	145	376	34	2.33	1.46	.44
CATTARAUGUS	7.5	1.6	85.7	13	0	74	130.70	5.6	145	376	34	3.92	2.45	1.32
CAYUGA	5.0	2.0	77.6	7	1	69	79.00	3.8	130	250	26	3.55	2.22	.80
CHEMUNG	11.0	1.8	99.8	3	1	66	226.00	8.3	106	720	48	4.56	2.85	2.29
ERIE	3.0	2.0	1089.4	16	3	71	1896.50	2.3	100	0	21	49.79	31.15	19.21
NIAGRA	3.0	2.0	238.6	2	11	67	756.90	2.3	100	0	21	10.90	6.82	7.67
ONONDAGA	4.0	1.8	475.2	14	1	67	792.80	3.0	109	0	24	21.72	13.59	8.03
SCHUYLER	8.0	1.7	17.7	3	0	68	17.40	6.0	157	476	35	.81	.51	.18
SENECA	6.0	1.8	34.0	4	0	68	66.10	4.5	136	300	29	1.55	.97	.67
STEUBEN	10.0	1.7	101.2	15	0	67	181.70	7.5	182	688	43	4.63	2.89	1.84
TIOGA	11.0	1.7	49.1	6	0	73	45.20	8.3	182	688	48	2.24	1.40	.46
WYOMING	5.0	1.8	38.6	7	0	68	41.80	3.8	123	188	26	1.76	1.10	.42
YATES	6.0	1.7	20.7	2	0	64	8.50	4.5	131	263	29	.95	.59	.09
OHIO														
BELMONT	12.0	1.7	82.2	11	0	54	46.20	9.0	182	688	53	4.16	1.82	1.53
CARROLL	10.0	1.6	26.0	3	0	63	12.70	7.5	175	626	43	1.32	.58	.42
CHAMPAIGN	2.2	1.6	31.7	5	0	60	50.60	1.6	81	0	20	1.61	.70	1.68
DARKE	2.5	1.8	53.6	7	0	61	34.10	1.9	89	0	20	2.71	1.19	1.13
DEFIANCE	3.0	1.6	37.2	3	0	61	107.20	2.3	91	0	21	1.88	.82	3.56
ERIE	3.0	1.6	77.4	6	1	59	160.70	2.3	91	0	21	3.92	1.71	5.33
FULTON	3.0	1.6	35.6	7	0	65	55.60	2.3	91	0	21	1.80	.79	1.84
HARDIN	2.0	1.7	31.7	7	0	60	58.80	1.5	80	0	19	1.61	.70	1.95
HARRISON	11.0	1.8	17.9	4	0	57	6.10	8.3	190	751	48	.91	.40	.20
HENRY	3.0	1.6	27.8	6	0	60	83.70	2.3	91	0	21	1.41	.62	2.78

Table 1 (cont'd)

States/Counties	Depth (thousand ft)	Gradient (°F/100 ft)	Population (thousands)	Towns	Cities	Heating degree days (hundreds)	Value added in manufacture	Well depth (assumed)	Temperature (°F)	Extractable heat (Btu/gal)	Cost ($ per ft)	Residential use (trillion Btu)	Commercial use (trillion Btu)	Industrial use (trillion Btu)
LOGAN	2.3	1.7	37.3	9	0	59	34.80	1.7	84	0	20	1.89	.83	1.15
MIAMI	2.5	1.9	87.3	6	1	56	177.90	1.9	90	0	20	4.42	1.93	5.90
MONTOE	12.0	1.7	15.6	1	0	56	29.14	9.0	182	688	53	.79	.35	.97
SHELBY	2.4	1.8	40.1	5	0	60	90.10	1.8	87	0	20	2.03	.89	2.99
WOOD	2.5	1.8	101.3	18	1	59	137.80	1.9	89	0	20	5.13	2.24	4.57
PENNSYLVANIA														
BEDFORD	20.0	1.6	42.4	4	0	58	19.50	10.0	175	626	61	1.66	.94	.59
BLAIR	17.0	1.6	133.8	7	1	59	173.50	10.0	175	626	61	5.24	2.98	5.23
*BRADFORD	14.0	1.6	60.6	8	0	64	87.00	10.0	175	626	61	2.38	1.35	2.62
*BUTLER	11.0	1.8	138.8	12	1	60	203.30	8.2	190	751	48	5.44	3.09	6.13
CAMBRIA	17.0	1.6	188.4	26	1	57	239.00	10.0	175	626	61	7.38	4.20	7.21
CAMERON	12.0	1.6	6.8	1	0	66	.00	9.0	175	626	53	.27	.15	.00
*CARBON	27.0	2.1	52.2	12	0	64	54.70	10.0	213	939	61	2.05	1.16	1.65
CENTRE	17.0	1.6	108.3	8	1	61	75.10	10.0	175	626	61	4.24	2.41	2.26
CLEARFIELD	13.0	1.6	78.5	8	0	66	60.90	9.8	175	626	59	3.08	1.75	1.84
*COLUMBIA	17.0	1.8	59.5	7	0	60	105.90	10.0	190	751	61	2.33	1.33	3.19
CRAWFORD	13.0	1.8	85.5	10	0	68	132.30	9.8	186	720	59	3.35	1.91	3.99
ELK	12.0	1.6	37.1	3	0	71	48.60	9.0	175	626	53	1.45	.83	1.47
FOREST	10.0	1.6	5.2	1	0	71	6.20	7.5	175	626	43	.20	.12	.19
GREENE	14.0	1.6	38.3	2	0	57	4.40	10.0	175	626	61	1.50	.85	.13
HUNTINGDON	22.0	1.6	39.8	4	0	59	34.70	10.0	175	626	61	1.56	.89	1.05
INDIANA	14.0	1.6	85.5	5	0	60	61.00	10.0	175	626	61	3.35	1.91	1.84
JEFFERSON	12.0	1.7	46.0	8	0	65	40.20	9.0	182	688	53	1.80	1.03	1.21
*LACKAWANA	17.0	1.9	234.0	18	1	61	293.60	10.0	197	814	61	9.17	5.21	8.85
LAWRENCE	11.0	1.6	105.2	8	0	58	156.30	8.3	175	626	48	4.12	2.34	4.71
*LUZERNE	20.0	1.8	342.2	33	2	64	462.70	10.0	190	751	61	13.41	7.63	13.95
LYCOMING	15.0	1.6	115.1	8	1	60	244.00	10.0	175	626	61	4.51	2.56	7.36
MCKEAN	11.0	1.7	51.5	7	0	74	121.80	8.3	182	688	48	2.02	1.15	3.67
MIFFLIN	20.0	1.6	44.2	3	0	57	85.50	10.0	175	626	61	1.73	.98	2.58
*MONROE	25.0	2.2	55.7	4	0	62	55.40	10.0	220	1001	61	2.18	1.24	1.67
*MONTOUR	18.0	1.9	17.1	1	0	60	52.10	10.0	197	814	61	.67	.38	1.57
*NORTHAMPTON	18.0	2.2	224.8	19	2	58	513.90	10.0	220	1001	61	8.81	5.01	15.49
*NORTHUMBERLAND	21.0	1.9	100.2	11	0	60	171.30	10.0	197	814	61	3.93	2.23	5.16
*PIKE	17.0	2.2	14.5	2	0	67	.00	10.0	220	1001	61	.57	.32	2.36
POTTER	12.0	1.6	16.9	5	0	71	5.60	9.0	179	657	53	.66	.38	.17
*SCHUYKILL	30.0	1.8	158.7	26	1	63	177.80	10.0	190	751	61	6.22	3.54	5.36
SNYDER	20.0	1.6	31.3	6	0	60	19.00	10.0	175	626	61	1.23	.70	.57
SOMERSET	17.0	1.6	78.8	13	0	57	27.10	10.0	175	626	61	3.09	1.76	.82
UNION	17.0	1.6	31.3	3	0	60	22.10	10.0	175	626	61	1.23	.70	.67
WARREN	8.0	1.6	47.2	5	0	65	82.70	6.0	151	426	35	1.85	1.05	2.49
WASHINGTON	13.0	1.8	213.5	26	0	59	205.20	9.8	190	751	59	8.37	4.76	8.90
*WAYNE	15.0	1.8	34.3	3	0	73	25.60	10.0	190	751	61	1.34	.76	.77
WESTMORELAND	15.0	1.6	380.9	36	0	57	566.60	10.0	175	626	61	14.93	8.49	17.08
WEST VIRGINIA														
BARBOUR	19.0	1.8	16.1	3	0	53	1.80	10.0	190	751	61	.55	.28	.15
BRAXTON	17.0	1.6	13.1	3	0	49	1.70	10.0	175	626	61	.45	.23	.14
MARSHALL	12.0	1.6	39.4	5	0	56	86.00	9.0	175	626	53	1.35	.68	7.10
NICHOLAS	25.0	1.6	25.7	2	0	51	3.80	10.0	175	626	61	.88	.44	.31
PRESTON	18.0	1.6	27.6	4	0	59	7.60	10.0	175	626	61	.94	.47	.63
RANDOLPH	25.0	1.7	26.4	3	0	60	10.80	10.0	182	688	61	.90	.45	.89
TAYLOR	17.0	1.6	15.5	1	0	53	4.30	10.0	175	626	61	.53	.27	.35
UPSHUR	18.0	1.6	21.7	1	0	53	11.40	10.0	175	626	61	.74	.37	.94

of the depths and gradients of the whole county using the cited references. Maps giving greater detail are available for site selection within the county.

POPULATION AND DISTRIBUTION OF TOWNS BY SIZE

Estimates of the population of the states, counties, and towns for 1976, published by the Bureau of the Census (Ref. 11), are reproduced in column 3 of Table 1. The distribution of towns by size was determined by classifying the town populations as follows:

0 - 250
251 - 500
501 - 1000
1001 - 2500
2501 - 5000
5001 - 10,000
10,001 - 20,000
over 20,000.

Column 4 gives the total count of incorporated places with populations between 500 and 20,000; column 5 gives the number of incorporated places with populations greater than 20,000.

HEATING DEGREE DAYS

The normal annual numbers of heating degree days are published by the National Climatic Center (Ref. 12) for the several National Weather Service offices and principal climatological stations within each state. The normals vary considerably from station to station. The normals for the counties (column 6) have been obtained by using the value for a station within the county or the average of the values if there is more than one station. When no station is listed within a county, the value has been determined by interpolation from nearby stations, using two or three pairs of stations where possible. All tabulated values have been rounded to the nearest hundred degree days. From a study of the data, this precision seems to be adequate for this report.

VALUE ADDED

Data on value added in manufacturing (1967), published by the Bureau of the Census (Ref. 13) for the states and counties, are reproduced as column 7 of Table 1. Value added in manufacture is the difference between the total cost of materials and energy and the value of shipments of the finished product adjusted for the change in inventories at the beginning and end of the year.

4. DERIVED ELEMENTS OF THE BASES OF COMPARISON

TEMPERATURE AND EXTRACTABLE HEAT

The temperature of the resource is estimated arbitrarily at 75% of the depth to basement (not to exceed 10,000 ft), assuming 55°F as the normal ground temperature. Extractable heat (in Btu/gal) is calculated using a spent-water temperature of 100°F. This quantity is not now used in the bases of comparison since it is a linear function of estimated temperature; however, it is retained in Table 1 for use when flow rates are available.

The following equations are used in the calculation:

$$T = 55 + G \times (0.75 \times D),$$

$$Q = 8.34 \times (T - S),$$

where

T is temperature of the resource,

G is gradient,

D is depth,

Q is extractable heat, and

S is spent-water temperature.

In Table 1, the depth used for calculation is listed in column 8 in thousands of feet. Temperature and extractable heat, rounded to the nearest unit, are listed in columns 9 and 10. This latter precision is unwarranted by the data but is required in order to retain a consistent correlation between the two columns. Counties that do not have sufficient extractable heat to warrant further consideration as geothermal prospects are indicated by a zero in column 10.

An arbitrary limit of extractable heat has been assumed at 100 Btu/gal. This assumption implies a minimum resource temperature of 112°F since normal ground temperature has been assumed at 55°F and spent-water is rejected at 100°F. This lower limit causes certain prospects to be eliminated from consideration by the ranking scheme and accounts for some changes in the ordering.

In addition the calculation of resource temperature and extractable heat has been limited to maximum depths of 10,000 ft. The actual depths used in the calculation are given in column 8 of Table 1. This refinement in calculation also accounts for some few changes in the order of ranks. Most changes in the rankings are caused by the introduction of the new prospects.

WELL COST

The cost of drilling and casing an 8 in. well is discussed by Milora and Tester (Ref. 14). The cost curves can be fitted by the following equation:

$$\log C_w = 6K + D/17{,}140 ,$$

where

C_w is well cost per foot (in 1976 dollars),

D is depth in feet, and

K is 1.6 in hard rock or

1.2 in soft rock.

These costs have been compared with those published by API (Refs. 15 and 16). The very high costs that occasionally are published seem to result from off-shore drilling and drilling to very great depths rather than from inflation. The estimates derived using the above equation seem to be adequate for wells in the locations of interest in this report and for depths less than 10,000 ft.

ENERGY USE

Information on energy use in residential, commercial, and industrial sectors — according to type of fuel — was collected and published in the Geothermal Fact Sheets (Ref. 17). For this report, the energy use in each sector was determined by summing the use of each fuel type except "electricity purchased," under the assumption that electrical energy usually would not be replaced by geothermal energy in the regions under consideration. The residential and commercial use of energy for each state was then apportioned to the counties on the basis of population.

The industrial use of energy in the state was apportioned to the counties on the basis of value added in manufacturing. If value added is not disclosed in Ref. 13, industrial energy is apportioned to the counties on the basis of the number of manufacturing establishments.

5. THE METHOD

The method discussed below is based on the definite opinion that there will never be adequate data or a clear policy that will determine, once and for all, the strategy to be followed in the commercialization of geothermal energy. From this point of view, it is clear that the available data must be assessed according to criteria and policies that are given as much visibility as possible so that new data or a change in the purpose for which the evaluation of a strategy is undertaken can be accommodated.

This method evaluates alternative strategies by ranking the geothermal prospects. The ranking is carried out by amalgamating the assessments of the prospects according to several bases of comparison. The process of amalgamation requires that the different bases of comparison be assigned weights to indicate the importance of each basis to the overall purpose of the evaluation.

To state the problem more formally, consider a matrix in which the prospects to be ranked are presented as rows and the columns represent the bases of comparison. The problem is to devise rules for selecting the "best" row. If the elements of the matrix can be interpreted as "utilities" in the von Neumann-Morgenstern sense, there are a number of methods of amalgamation that might be considered (Refs. 1 and 2). However, the natural bases of comparison for ranking geothermal prospects are as disparate as temperature and population.

To improve the comparability, each basis can be scaled to the unit interval, or ranks can be assigned to each basis separately. Where a natural scaling exists (e.g., the boiling point of water), the scaling method has some advantages, but for the present problem natural scalings are not immediately apparent. The method of ranking each basis separately has therefore been adopted, with 1 the highest rank, 2 the next highest, and so on. Tied ranks are replaced with their averages. Observe that, in a given column, functions of the data that preserve order (in particular, linear functions) do not change the assigned ranks.

The bases of comparison are selected from the available data in order to satisfy in part the purpose of the evaluation. Another way to reflect the policy or purpose is to recognize that the elements of the bases do not enter equally into consideration. Each column must be weighted in accordance with its importance.

$$S = C \cdot W,$$

where

S is the weighted score for each row,

C is the matrix of ranks of the bases of comparison, and

W is a column matrix of the weights to be assigned each element of the basis (each column).

The operation in this formula is ordinary matrix multiplication. The scores obtained represent a weighted average of the ranks assigned to each prospect; the row with the lowest score is the "best" prospect. The scores themselves are ranked in the tables accompanying the example for easier reading.

The proposed ranking scheme can be carried out by hand or on a pocket calculator for small data bases. As the data bases become larger, the work becomes tedious, and a small set of computer routines has been coded to handle them.

6. EXAMPLES AND RESULTS

The examples given below may make the proposed method seem less abstract and may provide insight into the way ranks change under different criteria. It should be understood that what is proposed is a method of ranking a given set of prospects; it is not a selection of prospects. The particular set of counties used in the example was chosen because the data were readily available. Other prospects might be selected as being especially pertinent for exploration, for example, or other data may be used as the bases of comparison. In either case, the additional prospects or the different criteria can be accommodated easily.

Examples of ranking are given for four categories of development. The first overall ranking gives equal weight to temperature, cost, energy use in the three categories, the number of towns and cities, the number of heating degree days, and value added in manufacturing. The second ranking emphasizes residential use and selects as the bases of comparison temperature, well cost, current residential use of energy, the number of towns and cities, and the number of heating degree days. The third emphasizes commercial applications and uses the same bases of comparison as the second except that the current commercial use of energy is substituted for residential use. The fourth emphasizes industrial development and selects temperature, well cost, current industrial use, the number of towns and cities, and value added in manufacturing.

In these examples, the weightings are always taken as equal although it is obvious that a particular criterion (e.g., the number of towns and cities) should have a greater importance under the residential criterion than under the industrial one. Appendix B gives the ranks for all the prospects. Table 2 lists 39 counties in 7 states that rank among the first 25 under at least one criterion.

Table 2
Select prospects under different criteria.

States/Counties	Overall	Residential	Commercial	Industrial
ALABAMA				
ARKANSAS				
ILLINOIS				
CHAMPAIGN	19	27	27	44
SANGAMON	9	13	13	11
VERMILLION	13	30	29	21
INDIANA				
KNOX	38	34	36	25
TIPPECANOE	28	25	26	23
KANSAS				
MICHIGAN				
TUSCOLA	31	22	24	70
MISSISSIPPI				
*HARRISON	60	77	74	20
*HINDS	18	36	32	1
*JACKSON	79	95	88	16
*MADISON	84	89	80	15
MONTGOMERY	72	94	82	17
*WASHINGTON	42	45	44	6
MISSOURI				
NEW YORK				
ALLEGANY	36	26	25	97
CATTARAUGUS	20	17	16	59
CAYUGA	26	10	9	52
CHEMUNG	30	15	15	33
STEUBEN	7	1	1	10
TIOGA	33	12	11	64
WYOMING	43	24	22	84
OHIO				
BELMONT	23	19	21	26
PENNSYLVANIA				
BLAIR	21	32	33	34
*BUTLER	5	2	2	2
CAMBRIA	12	23	23	19
*CARBON	17	14	14	22
CENTRE	22	29	30	45
CLEARFIELD	24	21	20	39
*COLUMBIA	25	28	28	24
CRAWFORD	10	8	8	12
JEFFERSON	29	16	17	35
*LACKAWANA	2	4	4	5
LAWRENCE	14	20	19	18
*LUZERNE	1	3	3	7
LYCOMING	15	31	31	27
MCKEAN	16	9	10	14
*NORTHAMPTON	4	6	6	3
*NORTHUMBERLAND	11	11	12	9
*SCHUYKILL	6	7	7	8
WASHINGTON	3	5	5	4
WESTMORELAND	8	18	18	13
WEST VIRGINIA				

7. REVIEW

The proposed method presents a practical scheme for evaluating geothermal prospects by amalgamating evaluations arising from separate considerations of many criteria. The examples point up the fact that rankings vary according to one's point of view and to the purpose for which they are constructed.

Certain aspects of the method are being refined. The data on industrial energy uses are being reconsidered. The present data may place too great an emphasis on high-temperature uses, especially in Alabama and Pennsylvania. Sorting data by standard industry code and by county would give better estimates of the use of energy for process heat. Data are also available on the distribution of the use of process heat according to temperature and should permit a better match between the resource and its possible market.

Further consideration is being given to changing data categories to improve comparability. The transformation to ranks de-emphasizes the nonlinearity of a category such as well cost. Transformation to a quantile function (Ref. 18) may provide a more faithful representation.

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APPENDIX A

Maps of States Showing the Counties Selected as Geothermal Prospects (modified from Ref. 13)

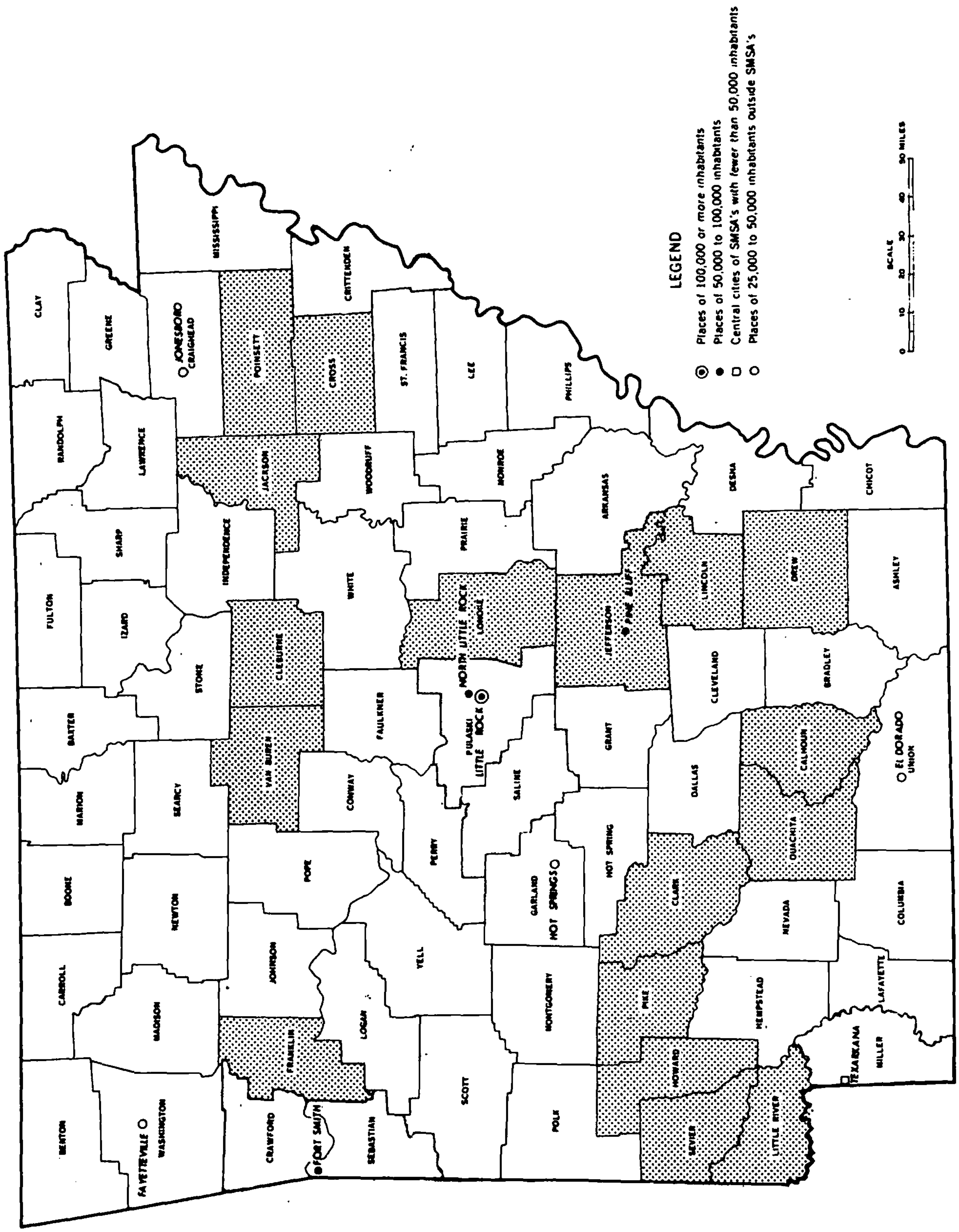

Fig. A-2 Arkansas.

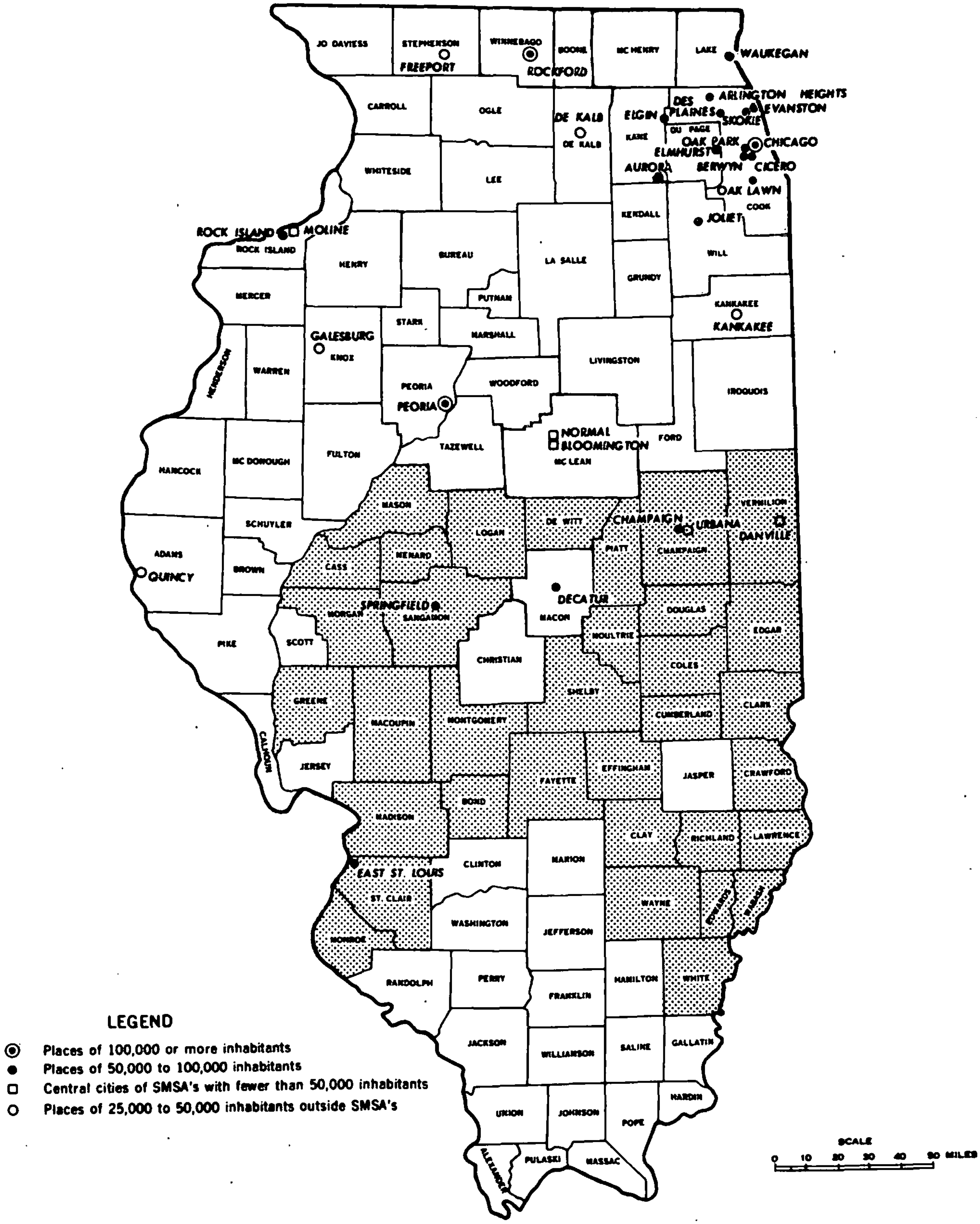

Fig. A-3 Illinois.

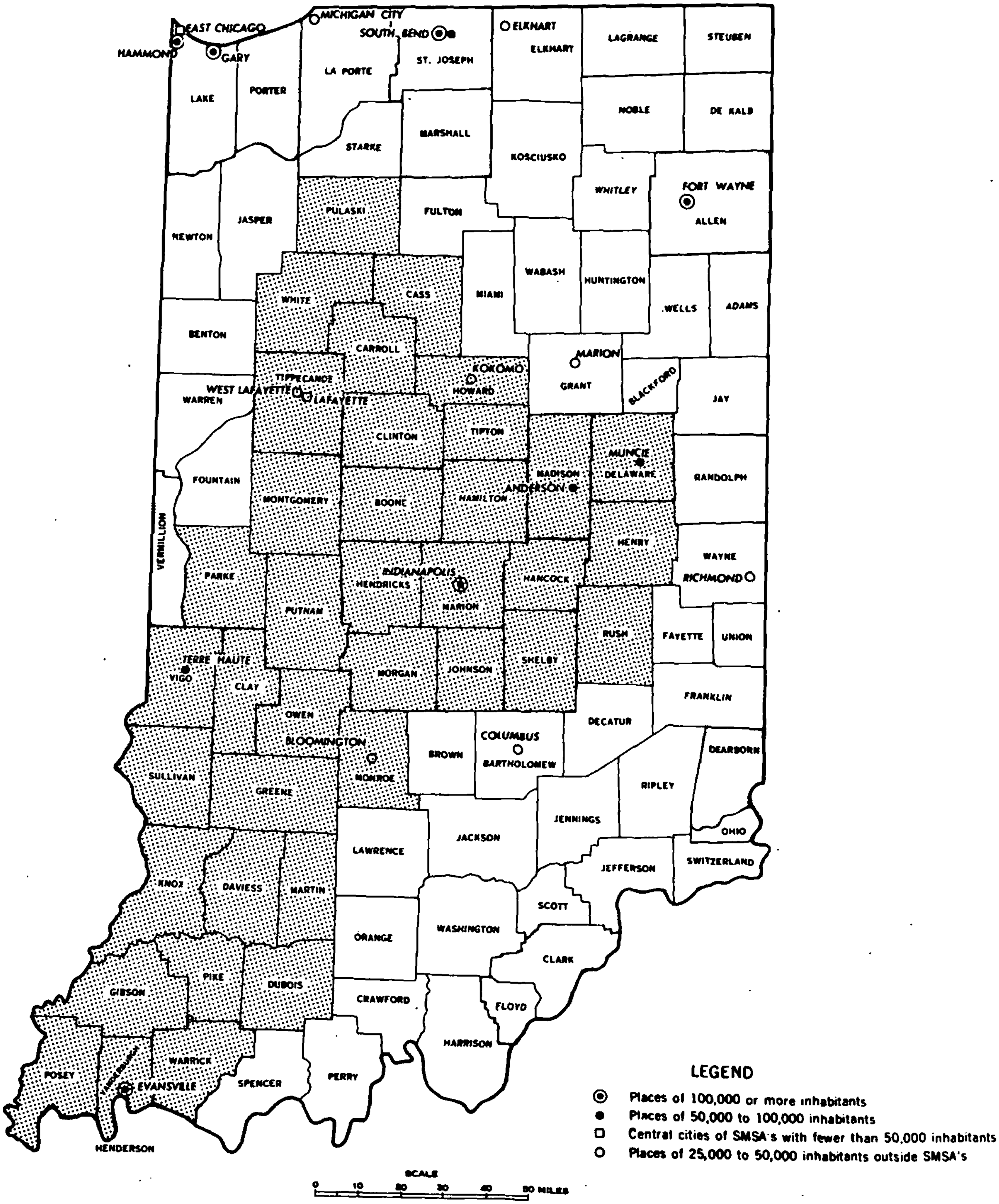

Fig. A-4 Indiana.

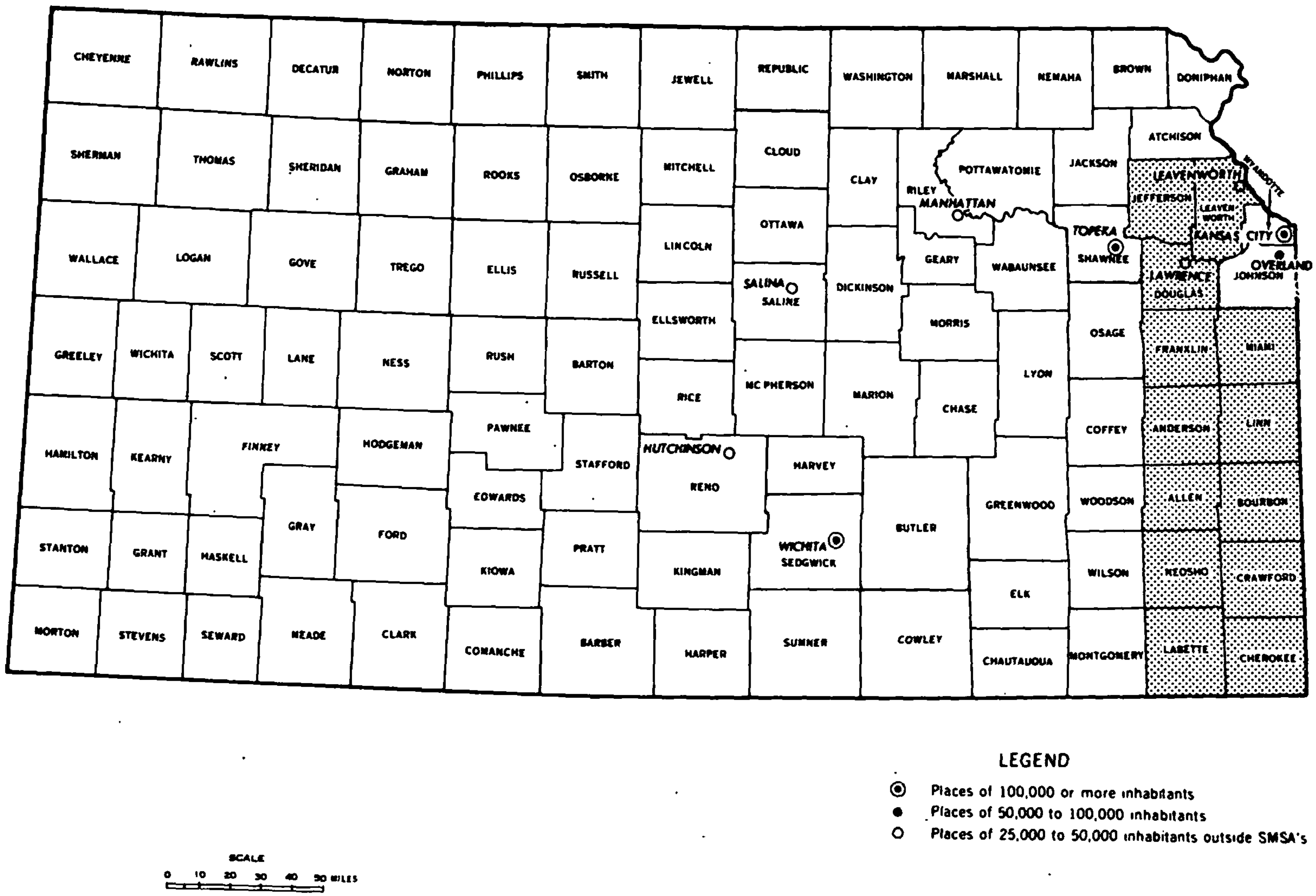

Fig. A-5 Kansas.

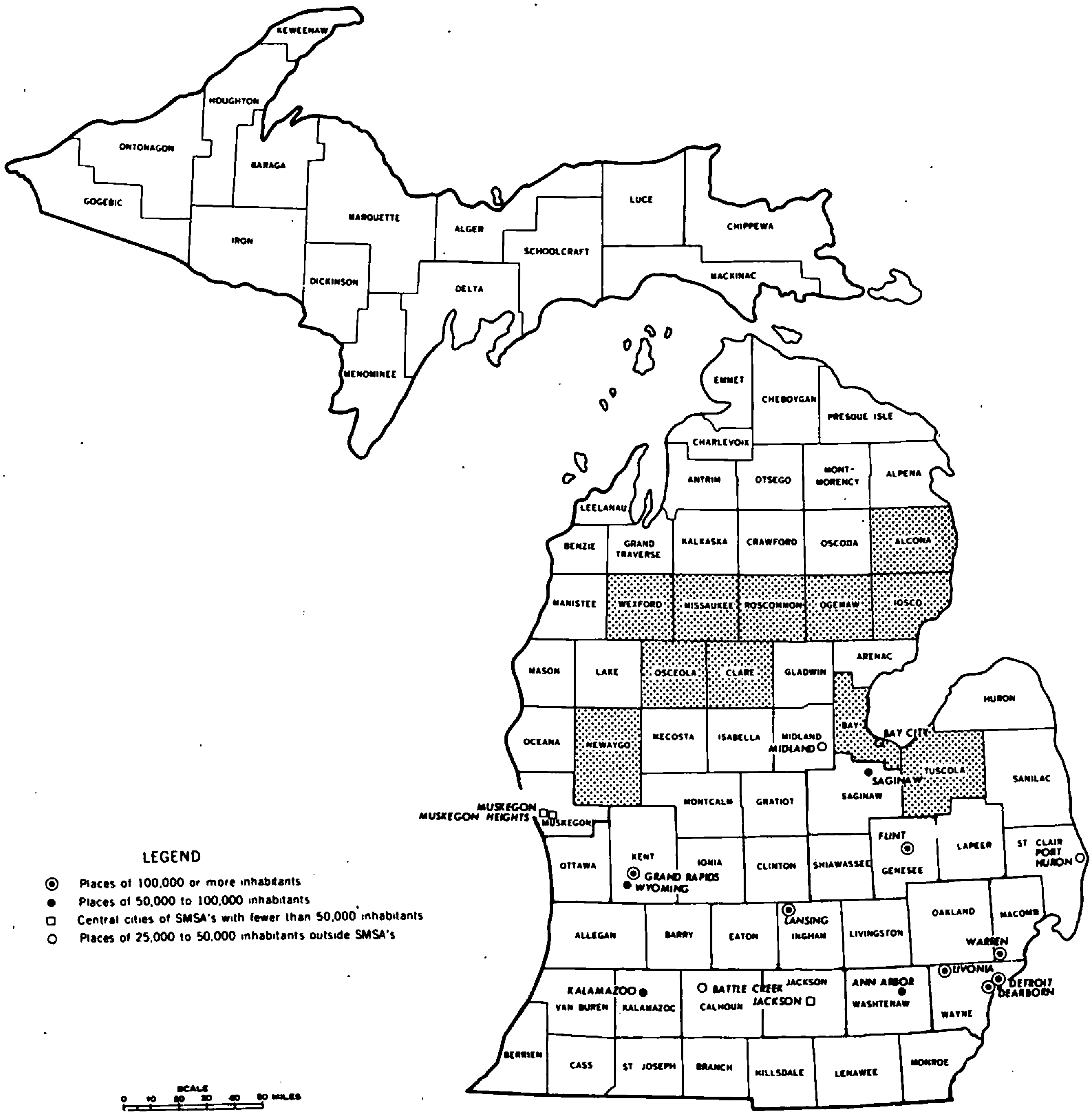

Fig. A-6 Michigan.

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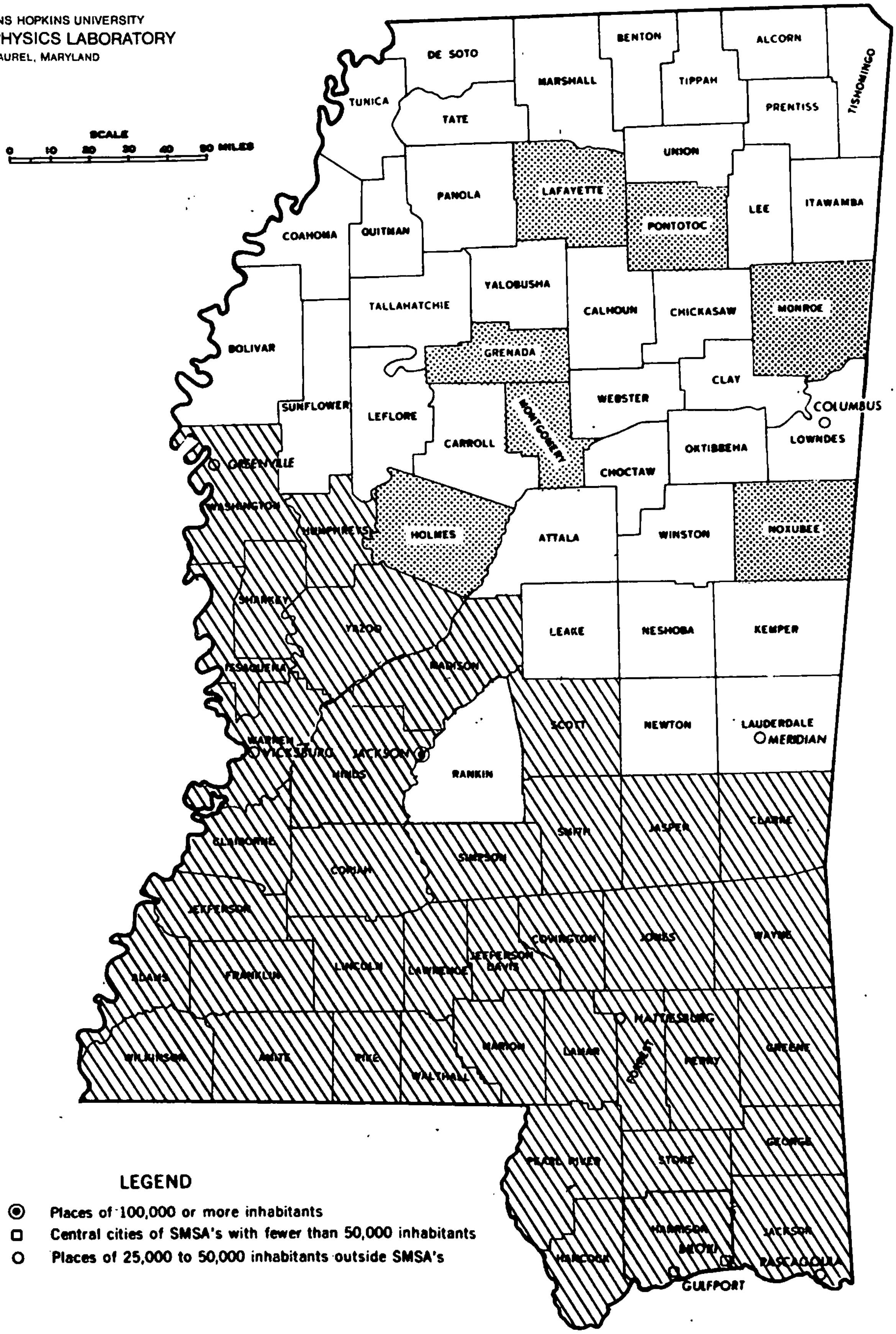

Fig. A-7 Mississippi.

LEGEND

- ◎ Places of 100,000 or more inhabitants
- ● Places of 50,000 to 100,000 inhabitants
- ○ Places of 25,000 to 50,000 inhabitants outside SMSA's

Fig. A-8 Missouri.

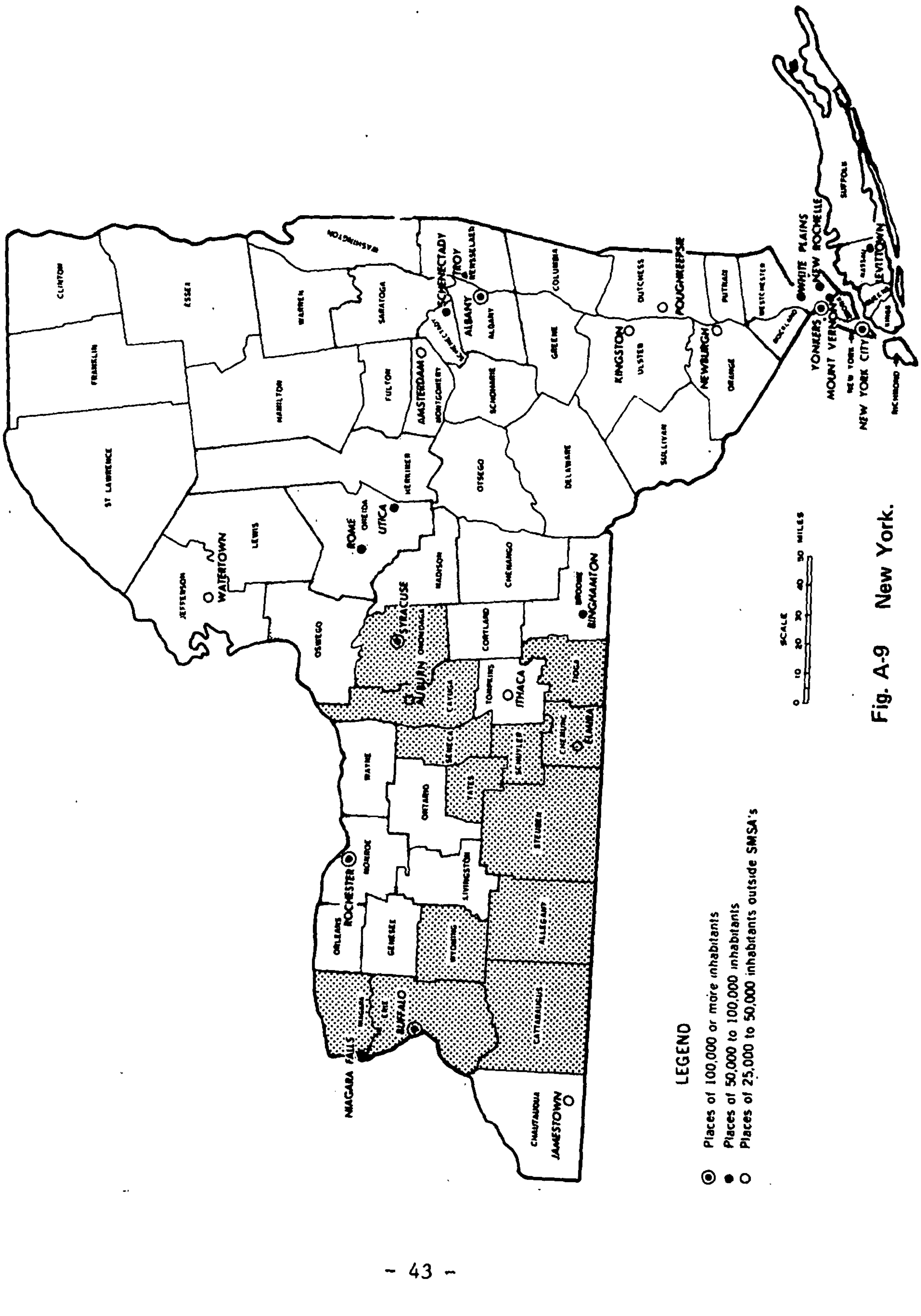

Fig. A-9 New York.

LEGEND

- ◉ Places of 100,000 or more inhabitants
- ● Places of 50,000 to 100,000 inhabitants
- ◻ Central cities of SMSA's with fewer than 50,000 inhabitants
- ○ Places of 25,000 to 50,000 inhabitants outside SMSA's

Fig. A-10 Ohio.

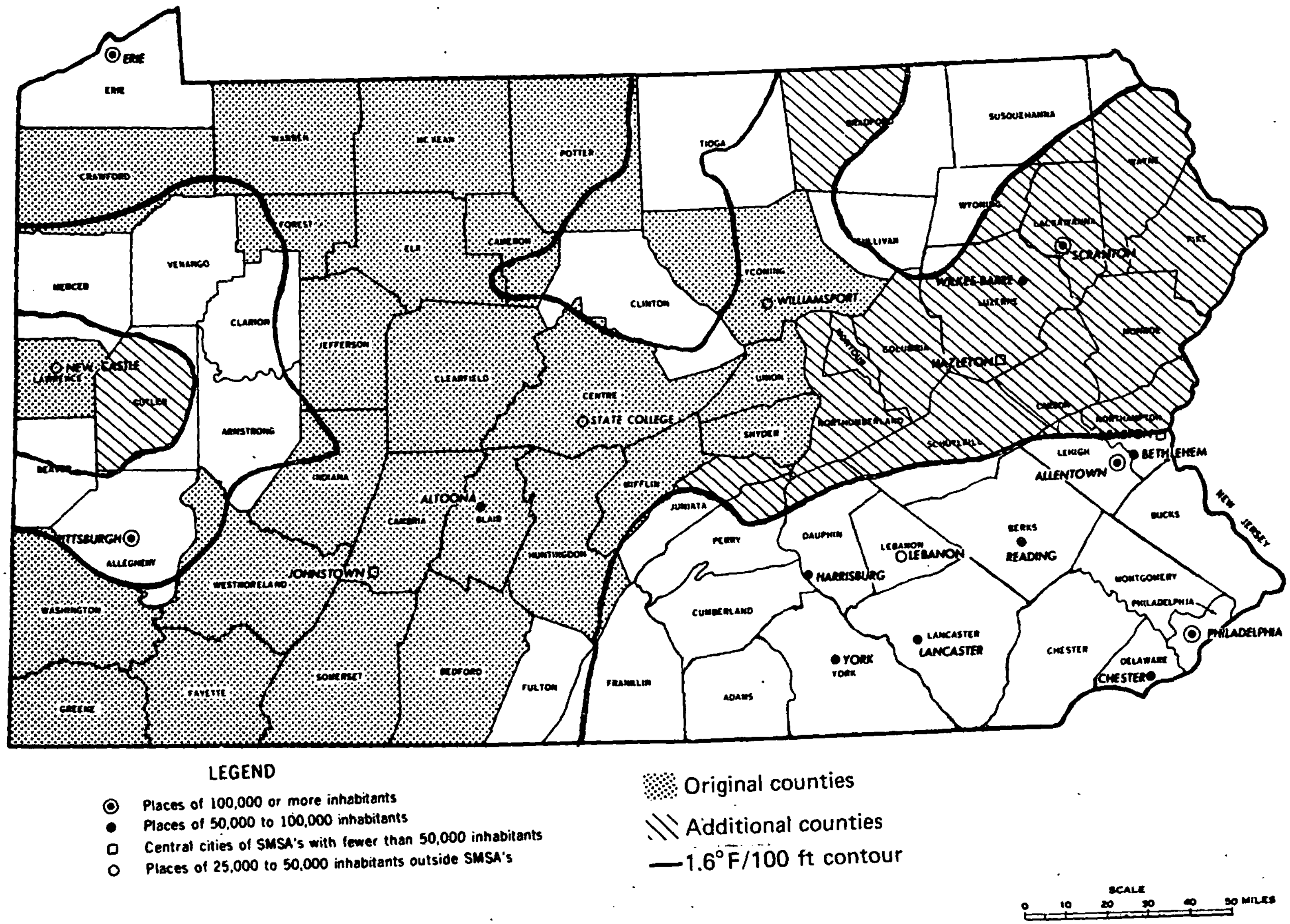

Fig. A-11 Pennsylvania.

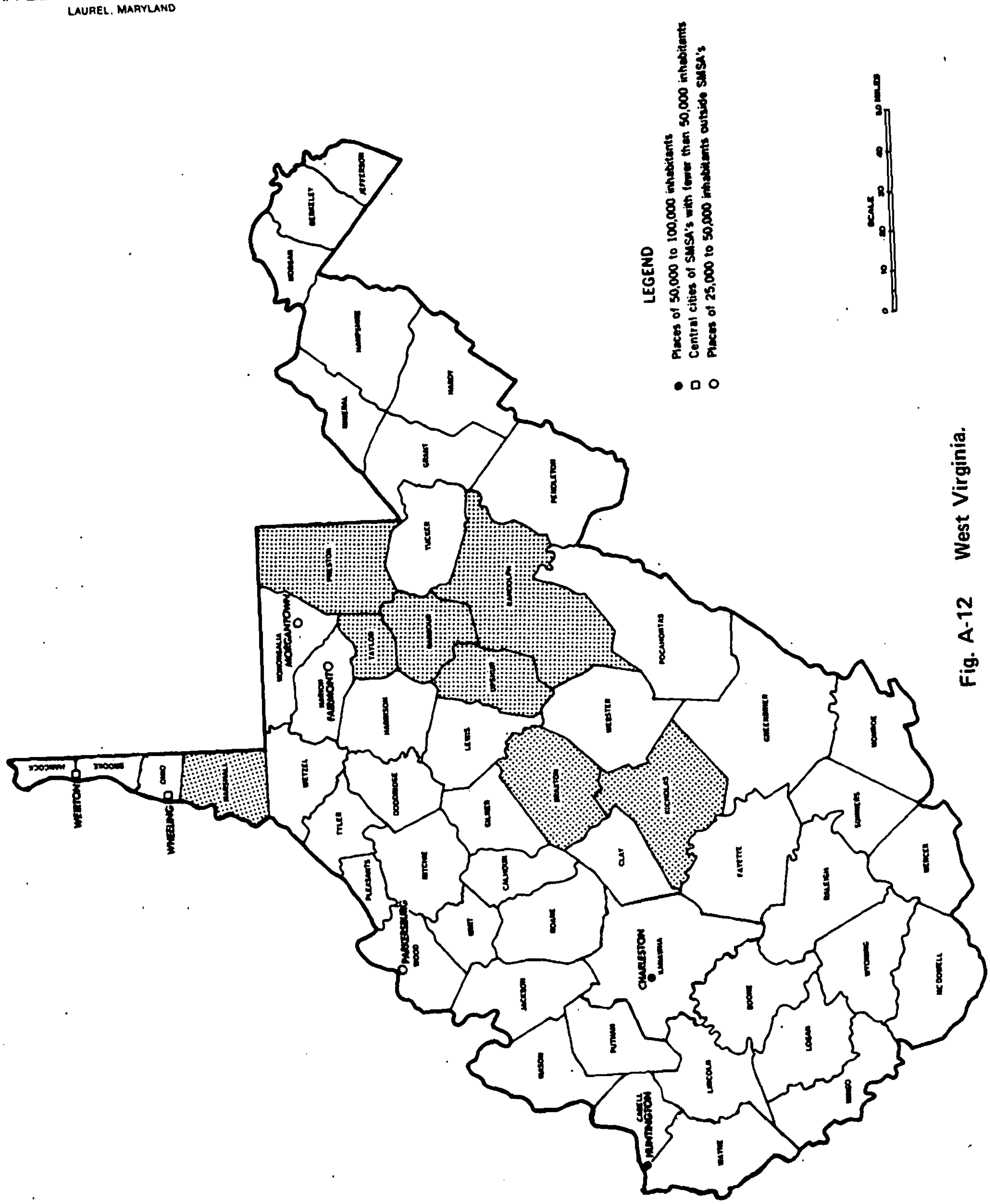

Fig. A-12 West Virginia.

APPENDIX B

Ranked Prospects under Different Criteria

States/Counties	Overall	Residential	Commercial	Industrial
ALABAMA				
BALDWIN	51	86	79	28
BLOUNT	132	146	132	134
CULLMAN	66	107	90	65
LAMAR	162	180	177	163
LAWRENCE	166	173	162	190
LIMESTONE	147	157	149	186
LOWNDES	195	196	196	188
MARENGO	122	155	150	61
MORGAN	63	106	97	55
PIKE	154	176	169	143
WALKER	54	88	78	51
WINSTON	141	169	161	129
ARKANSAS				
CALHOUN	183	191	191	153
CLARK	109	148	140	87
CLEBURNE	168	183	180	168
CROSS	110	129	125	82
DREW	140	165	165	101
FRANKLIN	151	138	139	122
HOWARD	135	160	158	102
JACKSON	102	127	121	83
JEFFERSON	56	93	89	40
LINCOLN	146	167	168	135
LITTLE RIVER	156	171	174	114
LONOKE	103	118	118	92
OUCHITA	81	115	112	46
PIKE	174	166	172	165
POINSETT	78	105	99	60
SEVIER	150	164	166	145
VANBUREN	188	193	194	180
ILLINOIS				
BOND	118	121	123	155
CHAMPAIGN	19	27	27	44
CLARK	105	103	107	136
CLAY	133	126	129	170
COLES	39	41	40	36
CRAWFORD	67	68	64	41
CUMBERLAND	134	104	111	148
DE WITT	86	78	81	108
DOUGLAS	64	75	76	69
EDGAR	106	111	113	147
EDWARDS	148	132	136	141
EFFINGHAM	74	54	55	89
FAYETTE	99	91	93	154
LAWRENCE	80	67	67	50
LOGAN	50	59	58	63
MACOUPIN	45	37	38	78
MASON	113	79	83	167
MENARD	111	83	92	123
MONTGOMERY	59	66	63	99
MOULTRIE	120	114	119	161
PIATT	92	84	87	105
RICHLAND	123	108	115	144
SANGAMON	9	13	13	11
SHELBY	83	70	66	128
VERMILLION	13	30	29	21
WABASH	153	135	141	156
WAYNE	121	123	126	157
WHITE	117	112	117	164
INDIANA				
CLAY	76	48	52	90
DAVIESS	98	101	101	107
DUBOIS	69	92	98	73
GIBSON	53	63	62	53
GREENE	62	46	48	75
HENDRICKS	52	39	39	124
JOHNSON	32	42	41	38
KNOX	38	34	36	25
MARTIN	124	131	138	118
MONROE	82	102	102	91
MONTGOMERY	35	40	42	32
MORGAN	57	55	56	109
OWEN	160	137	148	191
PARKE	137	120	127	178
PIKE	169	143	153	185
POSEY	87	98	103	79
PUTNAM	71	74	77	85
SULLIVAN	85	69	69	93
TIPPECANOE	28	25	26	23
VANDERBURGH	70	97	94	77
VIGO	47	53	50	47
WARRICK	49	58	61	37
WHITE	48	47	51	31
KANSAS				
MICHIGAN				
ALCOMA	180	139	147	196
BAY	46	49	47	86
CLARE	100	76	75	172
IOSCO	96	71	70	182
MISSAUKEE	145	99	106	181
NEWAYGO	55	51	49	111
OGEMAW	125	81	86	177
OSCEOLA	88	64	60	116
ROSCOMMON	136	80	85	184
TUSCOLA	31	22	24	70
MISSISSIPPI				
*ADAMS	127	152	145	66
*AMITE	175	177	178	126
*CLAIBORNE	189	182	182	160
*CLARKE	130	144	144	74
*COPIAH	116	133	128	54
*COVINGTON	182	181	181	152
*FORREST	104	125	120	57
*FRANKLIN	177	159	160	139
*GEORGE	191	192	192	169
*GREENE	173	185	186	94
GRENADA	143	161	157	76
*HANCOCK	159	170	170	98
*HARRISON	60	77	74	20

States/Counties	Overall	Residential	Commercial	Industrial
*HINDS	18	36	32	1
HOLMES	115	116	114	71
*HUMPHREYS	161	147	146	113
*ISSAQUENA	196	186	187	176
*JACKSON	79	95	88	16
*JASPER	167	172	171	140
*JEFFERSON	194	188	189	174
*JEFFERSON DAVIS	190	190	190	173
*JONES	93	117	110	48
LAFAYETTE	157	141	133	151
*LAMAR	142	154	155	72
*LAWRENCE	176	187	188	120
*LINCOLN	152	168	164	106
*MADISON	84	89	80	15
*MARION	164	178	175	121
MONROE	172	179	179	138
MONTGOMERY	72	94	82	17
NOXUBEE	165	156	156	133
*PEARL RIVER	138	142	137	88
*PERRY	171	158	159	117
*PIKE	89	119	109	30
PONTOTOC	163	153	151	125
*SCOTT	128	149	143	58
*SHARKEY	178	162	163	132
*SMITH	181	175	176	159
*STONE	192	195	195	158
*WALTHALL	193	194	193	171
*WARREN	112	130	122	56
*WASHINGTON	42	45	44	6
*WAYNE	184	189	185	162
*WILKINSON	186	184	184	150
*YAZOO	114	136	131	42
MISSOURI				
DUNKLIN	107	110	105	80
PEMISCOT	149	140	142	142
NEW YORK				
ALLEGANY	36	26	25	97
CATTARAUGUS	20	17	16	59
CAYUGA	26	10	9	52
CHEMUNG	30	15	15	33
SCHUYLER	119	96	95	179
SENECA	58	50	46	110
STEUBEN	7	1	1	10
TIOGA	33	12	11	64
WYOMING	43	24	22	84
YATES	131	109	108	192
OHIO				
BELMONT	23	19	21	26
CARROLL	90	65	72	137

States/Counties	Overall	Residential	Commercial	Industrial
HARRISON	97	57	68	103
MONTOE	139	128	135	146
PENNSYLVANIA				
BEDFORD	75	73	71	131
BLAIR	21	32	33	34
*BRADFORD	27	35	35	43
*BUTLER	5	2	2	2
CAMBRIA	12	23	23	19
CAMERON	187	150	152	195
*CARBON	17	14	14	22
CENTRE	22	29	30	45
CLEARFIELD	24	21	20	39
*COLUMBIA	25	28	28	24
CRAWFORD	10	8	8	12
ELK	65	60	59	96
FOREST	179	134	134	187
GREENE	126	113	116	194
HUNTINGDON	68	72	73	104
INDIANA	37	43	43	67
JEFFERSON	29	16	17	35
*LACKAWANA	2	4	4	5
LAWRENCE	14	20	19	18
*LUZERNE	1	3	3	7
LYCOMING	15	31	31	27
MCKEAN	16	9	10	14
MIFFLIN	73	82	84	95
*MONROE	40	33	34	49
*MONTOUR	129	122	124	130
*NORTHAMPTON	4	6	6	3
*NORTHUMBERLAND	11	11	12	9
*PIKE	108	100	104	81
POTTER	91	52	54	115
*SCHUYKILL	6	7	7	8
SNYDER	61	62	57	100
SOMERSET	34	38	37	68
UNION	95	87	91	149
WARREN	41	44	45	62
WASHINGTON	3	5	5	4
*WAYNE	77	56	53	112
WESTMORELAND	8	18	18	13
WEST VIRGINIA				
BARBOUR	144	124	130	166
BRAXTON	170	151	167	183
MARSHALL	44	61	65	29
NICHOLAS	155	145	154	189
PRESTON	94	85	96	127
RANDOLPH	101	90	100	119
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