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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-A101-79ET27025

THE JOHNS HOPKINS UNIVERSITY ■ APPLIED PHYSICS LABORATORY

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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.

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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 Heating Fuel 1985-2000," APL/JHU GEMS-005 (QM-79-016), Mar 1979.

*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 States)," 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.

The work reported here was initiated under the direction of Mr. Robert Oliver in the Planning Office of the Division of Geothermal Energy. It was completed under the direction of Mr. W. L. R. Rice, Office of the Resource Manager for Geothermal Energy Resource Applications.

*Available for distribution.

CONTENTS

List of Illustrations	9
List of Tables	9
1. Introduction and Background	11
2. Overview	12
3. The Data	14
Depth and Gradient	14
Population and Distribution of Towns by Size	14
Heating Degree Days	21
Value Added	21
4. Derived Elements of the Bases of Comparison	22
Temperature and Extractable Heat	22
Well Cost	22
Energy Use	23
5. The Method	24
6. Examples and Results	26
7. Review	28
8. Future Work	29
References	31
Appendix A: Maps of States Showing the Countries Selected as Geothermal Prospects	33
Appendix B: Ranked Prospects under Different Criteria	51

ILLUSTRATIONS

1	Geographical areas covered in comparative evaluation	.	15
A-1	Alabama		35
A-2	Arkansas		36
A-3	Georgia		37
A-4	Illinois		38
A-5	Indiana		39
A-6	Kansas		40
A-7	Michigan		41
A-8	Mississippi		42
A-9	Missouri		43
A-10	New Jersey		44
A-11	New York		45
A-12	North Carolina		46
A-13	Ohio		47
A-14	Pennsylvania		48
A-15	South Carolina		49

Tables

1	Geologic, geothermal, demographic, and industrial data		16
2	Select prospects under different criteria		27

[The text in this section is extremely faint and illegible. It appears to be a series of paragraphs or a list of items.]

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 the work and to give direction to future efforts require a systematic and synoptic technique for examining the geothermal potential of the area. 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 Application) 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.

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.

3. THE DATA

Data have been gathered for 226 counties in 16 states to illustrate the method for assessing geothermal potential (Table 1). The first seven columns are taken from published sources; the last six 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.

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. 3).

Information on depths to basement and geothermal gradients is published by the U.S. Geological Survey (Refs. 4 and 5). 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. 4 and 5) 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 $1.6^{\circ}\text{F}/100\text{ ft}$.

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 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. 6), are reproduced in column 3 of Table 1. The distribution of towns by size was determined by classifying the town populations as follows:

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

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	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	244	1202	61	1.50	1.27	1.82
BLOUNT	10.0	1.6	32.1	2	0	32	10.50	175	628	43	.68	.58	.82
CULLMAN	8.0	1.6	58.9	5	0	34	27.00	151	426	35	1.24	1.06	2.10
LAMAR	8.0	1.6	15.6	3	0	29	7.10	151	426	35	.33	.28	.55
LAWRENCE	6.0	1.6	28.6	2	0	32	2.90	127	225	29	.60	.51	.23
LIMESTONE	7.0	1.6	43.5	2	0	32	4.40	139	325	32	.92	.78	.34
LOWNDES	6.0	1.6	13.3	1	0	21	6.00	127	225	29	.28	.24	.47
MARENGO	10.0	1.6	23.7	3	0	21	33.70	175	626	43	.50	.43	2.63
MORGAN	7.5	1.6	83.9	3	1	33	206.00	145	376	34	1.77	1.51	16.05
PIKE	5.0	1.6	24.3	2	0	26	15.50	115	125	26	.51	.44	1.21
WALKER	7.0	1.6	64.5	9	0	29	22.80	189	325	32	1.36	1.16	1.78
WINSTON	8.0	1.6	19.7	3	0	33	18.80	151	426	35	.42	.35	1.46
ARKANSAS													
CALHOUN	5.0	1.8	5.6	2	0	27	5.00	123	188	26	.20	.14	.60
CLARK	7.0	1.8	22.2	3	0	29	22.20	150	413	32	.80	.55	2.67
CLEBURNE	6.0	1.8	14.7	1	0	36	9.00	136	300	29	.53	.36	1.08
CROSS	8.0	1.9	20.7	3	0	32	12.50	169	576	35	.75	.51	1.50
DREW	5.0	1.8	16.1	2	0	27	17.20	123	188	26	.58	.40	2.07
FRANKLIN	10.0	1.8	13.0	2	0	32	3.80	190	751	43	.47	.32	.46
HOWARD	7.0	1.8	13.3	3	0	30	13.90	150	413	32	.48	.33	1.67
JACKSON	7.0	1.9	21.2	4	0	32	10.80	155	457	32	.77	.52	1.30
JEFFERSON	7.0	1.9	84.2	3	1	26	92.40	156	457	32	3.04	2.08	11.11
LINCOLN	7.0	1.8	13.1	3	0	27	7.49	150	413	32	.47	.32	.90
LITTLE RIVER	5.0	1.9	11.7	2	0	28	12.20	126	219	26	.42	.29	1.47
LONG	8.0	1.8	26.2	3	0	34	9.10	163	526	35	.95	.65	1.09
OUCHITA	5.0	1.7	29.4	4	0	27	38.50	119	156	26	1.06	.73	4.63
PIKE	8.0	1.8	9.4	2	0	33	3.40	163	526	35	.34	.23	.41
POINSETT	7.0	1.8	27.5	5	0	35	17.10	150	413	32	.99	.68	2.06
SEVIER	6.0	1.8	12.2	3	0	29	5.90	136	300	29	.44	.30	.71
VANBUREN	6.0	1.7	10.3	1	0	36	4.82	131	263	29	.37	.25	.58
GEORGIA													
EVANS	3.5	1.8	8.3	2	0	18	4.90	102	18	23	.19	.12	.22
LONG	3.5	1.8	3.5	1	0	17	.40	102	18	23	.08	.05	.02
MONTGOMERY	3.5	1.8	6.3	3	0	19	1.70	102	19	23	.14	.09	.08
TATTHALL	3.5	1.8	17.1	3	0	18	3.80	102	18	23	.39	.25	.17
TOOMBS	3.5	2.0	21.5	2	0	19	12.50	108	63	23	.49	.32	.56
WAYNE	3.5	1.8	19.1	2	0	17	23.40	102	19	23	.44	.28	1.05
ILLINOIS													
BOND	7.0	1.6	14.7	4	0	49	13.20	139	325	32	.82	.47	.35
CASS	3.5	1.7	14.0	4	0	55	5.50	100	*	23	.78	.44	.15
CHAMPAIGN	6.0	1.6	164.4	12	3	56	60.60	127	225	29	9.20	5.21	1.61
CLARK	7.0	1.8	16.2	4	0	53	.00	150	413	32	.91	.51	.46
CLAY	11.0	1.5	14.9	3	0	48	7.70	179	657	48	.83	.47	.20
COLES	7.0	2.0	49.9	5	0	53	59.00	160	501	32	2.79	1.58	1.57
CRAWFORD	9.0	1.9	19.9	4	0	49	48.40	183	695	39	1.11	.63	1.29
CUMBERLAND	9.0	1.8	10.3	3	0	53	2.50	177	698	39	.58	.33	.07
DE WITT	6.0	1.7	16.9	5	0	56	18.80	131	283	29	.95	.54	.50
DOUGLAS	6.0	1.6	19.5	6	0	55	50.60	127	225	29	1.09	.62	1.35
EDGAR	7.0	1.8	21.6	3	0	53	20.80	150	413	32	1.21	.68	.55
EDWARDS	13.0	1.8	7.5	3	0	46	.00	231	1089	59	.42	.24	.32
EFFINGHAM	9.0	1.8	28.2	4	0	52	14.70	177	698	39	1.58	.89	.39
FAYETTE	7.0	1.6	20.8	5	0	51	7.70	139	325	32	1.16	.66	.20
GREENE	3.5	1.5	16.7	4	0	51	4.40	94	*	23	.93	.53	.12
LAWRENCE	10.0	1.9	17.5	4	0	47	.00	197	814	43	.98	.55	.60

Table 1 (cont'd)

States/Countries	Depth (thousand ft)	Gradient (° F/100 ft)	Population (thousands)	Towns	Cities	Heating degree days (hundreds)	Value added in manufacture	Temperature (° F)	Extractable heat (Btu/gal)	Cost (\$ per ft)	Residential use (trillion Btu)	Commercial use (trillion Btu)	Industrial use (trillion Btu)
LOGAN	5.0	1.8	31.1	4	0	56	65.00	123	188	26	1.74	.99	1.73
MACOUPIN	4.3	1.8	46.1	11	0	51	8.70	119	109	24	2.58	1.46	.23
MADISON	4.0	1.8	247.8	20	2	49	645.20	109	75	24	13.87	7.85	17.17
MASON	4.5	1.8	18.8	3	0	56	4.30	116	131	25	1.05	.60	.11
MENARD	4.5	2.0	10.9	4	0	56	.00	123	188	28	.61	.35	.26
MONROE	3.0	1.8	18.9	3	0	44	.90	96	*	21	1.06	.60	.02
MONTGOMERY	6.0	1.6	30.6	9	0	50	15.00	127	225	29	1.71	.97	.40
MORGAN	3.5	1.7	35.6	7	0	53	55.10	100	*	23	1.99	1.13	1.47
MOULTRIE	7.0	1.7	13.2	4	0	54	10.10	144	369	32	.74	.42	.27
PIATT	6.0	1.7	16.0	5	0	55	.00	131	263	29	.90	.51	.52
RICHLAND	11.0	1.8	17.2	2	0	47	15.20	204	864	48	.96	.55	.40
SA CLAIR	3.7	1.6	280.7	20	3	46	267.30	99	*	23	15.71	8.90	7.12
SANGAMON	4.5	1.8	172.9	19	1	56	159.60	116	131	25	9.68	5.48	4.25
SHELBY	7.0	1.9	23.2	7	0	53	5.90	153	457	32	1.30	.74	.16
VERMILLION	6.0	1.8	98.7	13	1	55	195.60	136	300	29	5.53	3.13	5.21
WABASH	13.0	1.9	13.5	1	0	46	18.40	240	1170	59	.76	.43	.49
WAYNE	13.0	1.6	17.3	3	0	46	.00	211	926	69	.97	.55	.40
WHITE	14.0	1.7	16.8	4	0	44	4.50	238	1114	61	.94	.53	.12
INDIANA													
BOONE	4.0	1.8	32.9	5	0	58	29.50	109	75	24	1.70	.89	1.22
CARROLL	3.5	1.9	17.8	4	0	56	8.70	105	41	23	.92	.46	.36
CASS	3.5	1.8	39.6	4	0	59	46.20	102	19	23	2.05	1.07	1.91
CLAY	7.0	2.0	24.5	5	0	54	6.70	160	501	32	1.27	.66	.28
CLINTON	3.7	1.8	30.6	5	0	60	30.30	105	41	23	1.58	.83	1.25
DAVISS	8.0	1.8	26.0	3	0	46	17.60	162	526	35	1.35	.70	.73
DELAWARE	2.7	1.7	128.9	5	1	59	263.50	89	*	21	6.67	3.49	10.87
DUBOIS	8.0	1.7	32.3	4	0	47	57.60	157	476	35	1.67	.87	2.38
GIBSON	13.5	1.8	31.2	7	0	46	23.40	287	1145	61	1.62	.84	.97
GREENE	7.0	2.0	28.1	5	0	53	10.40	160	501	32	1.45	.76	.43
HAMILTON	3.0	1.8	70.9	8	0	57	35.90	96	*	21	3.67	1.92	1.48
HANCOCK	3.0	1.8	41.0	6	0	56	9.70	98	*	21	2.12	1.11	.40
HENDRICKS	5.0	1.8	62.2	6	0	56	3.50	123	188	26	3.22	1.68	.14
HENRY	3.0	1.7	53.5	3	1	58	87.80	93	*	21	2.77	1.45	3.62
HOWARD	3.0	1.8	87.2	2	1	56	313.80	96	*	21	4.52	2.36	12.95
JOHNSON	5.0	1.8	70.6	7	0	53	41.50	123	188	26	3.66	1.91	1.71
KNOX	9.0	1.9	40.2	6	0	49	30.10	183	695	39	2.08	1.09	1.24
MADISON	2.9	1.8	138.4	10	1	56	453.50	94	*	21	7.17	3.74	18.72
MARION	4.0	1.8	775.8	10	2	56	1679.60	109	75	24	40.17	20.99	69.32
MARTIN	7.0	1.7	11.0	4	0	48	17.20	144	369	32	.57	.30	.71
MONROE	7.0	1.8	91.2	1	1	49	197.10	150	413	32	4.72	2.47	8.13
MONTGOMERY	5.0	1.8	34.1	6	0	58	63.10	123	188	26	1.77	.92	2.60
MORGAN	6.0	1.8	48.7	5	0	54	10.80	136	300	29	2.52	1.32	.45
OWEN	6.0	1.8	13.2	2	0	54	2.50	136	300	29	.68	.36	.10
PARKE	6.0	1.9	15.7	3	0	53	1.30	140	338	29	.81	.42	.05
PIKE	9.0	1.7	12.2	2	0	46	.30	170	582	39	.63	.33	.01
POSEY	13.5	1.7	22.8	4	0	46	31.40	227	1061	81	1.18	.62	1.30
PULASKI	3.8	1.8	12.7	3	0	62	8.30	106	53	23	.66	.34	.34
PUTHAN	6.0	1.9	27.9	4	0	55	29.40	140	338	29	1.44	.75	1.21
RUSH	3.0	1.6	20.3	2	0	56	12.30	91	*	21	1.05	.55	.51
SHELBY	4.0	1.6	38.7	2	0	54	45.10	103	25	24	2.00	1.05	1.86
SULLIVAN	8.0	2.0	19.7	6	0	52	5.50	175	626	35	1.02	.53	.23
TIPPECANOE	4.5	1.8	114.1	3	2	58	171.60	116	131	25	5.91	3.09	7.08
TIPTON	3.0	1.8	16.0	7	0	56	11.30	96	*	21	.83	.43	.47
VANDERBURGH	13.5	1.7	161.6	1	1	46	.00	227	1061	61	8.37	4.37	14.69
VIGO	8.0	2.0	110.6	2	1	54	158.80	175	626	35	5.73	2.99	6.55

Table 1 (cont'd)

States/Countries	Depth (thousand ft)	Gradient (°F/100 ft)	Population (thousands)	Towns	Cities	Heating degree days (hundreds)	Value added in manufacture	Temperature (°F)	Extractable heat (Btu/gal)	Cost (\$ per ft)	Residential use (trillion Btu)	Commercial use (trillion Btu)	Industrial use (trillion Btu)
WARRICK	12.0	1.7	34.7	5	0	46	.00	208	901	53	1.80	.94	1.78
WHITE	4.0	1.9	22.0	6	0	57	.00	112	100	24	1.14	.60	2.09
KANSAS													
ALLEN	1.0	1.8	15.4	2	0	44	10.30	69	*	18	4.20	2.38	2.60
ANDERSON	1.5	1.8	8.5	1	0	50	1.20	75	*	18	2.32	1.31	.30
BOURBON	1.0	2.0	15.7	1	0	42	5.80	70	*	18	4.28	2.42	1.46
CHEROKEE	1.0	2.0	21.4	4	0	41	29.80	70	*	18	5.83	3.30	7.52
CRAWFORD	1.0	2.0	36.8	6	0	41	24.40	70	*	18	10.03	5.68	6.15
DOUGLAS	2.0	1.6	64.4	1	1	47	46.10	79	*	19	17.55	9.94	11.63
FRANKLIN	1.5	1.8	20.2	3	0	47	7.20	75	*	18	5.50	3.12	1.82
JEFFERSON	2.0	1.6	13.4	5	0	51	.60	79	*	19	3.65	2.07	.15
LABETTE	1.0	1.8	24.8	4	0	40	11.90	69	*	18	6.76	3.83	3.00
LEAVENWORTH	2.0	1.6	56.7	3	1	50	10.30	79	*	19	15.45	8.75	2.60
LINN	1.0	1.9	8.3	3	0	47	.80	69	*	18	2.26	1.28	.20
MIAMI	1.5	1.7	20.9	3	0	50	8.00	74	*	18	5.70	3.22	2.02
NEOSHO	1.0	1.8	18.5	3	0	46	13.10	69	*	18	5.04	2.85	3.30
MICHIGAN													
ALCONA	7.5	1.6	8.9	1	0	81	1.50	145	376	34	.46	.26	.04
BAY	12.0	1.6	119.6	2	0	68	189.70	199	826	53	6.23	3.50	5.35
CLARE	18.0	1.6	22.3	3	0	76	11.20	271	1427	61	1.16	.65	.32
IOSCO	8.0	1.6	28.9	3	0	75	6.70	151	426	35	1.50	.85	.19
MISSAUKEE	10.0	1.6	9.1	2	0	81	.50	175	626	43	.47	.27	.01
NEWAYGO	8.0	1.6	31.7	4	0	75	35.10	181	426	35	1.65	.93	.99
OGEMAN	11.0	1.6	15.1	2	0	81	7.10	187	726	48	.79	.44	.20
OSCEOLA	10.0	1.6	17.8	3	0	76	19.40	175	626	43	.93	.52	.55
ROSCOMMON	12.0	1.8	15.2	1	0	81	1.40	217	976	53	.79	.45	.04
TUSCOLA	8.0	1.7	54.1	9	0	70	31.40	157	476	35	2.82	1.59	.88
WEXFORD	1.6	1.6	22.1	2	1	84	24.70	74	*	19	1.15	.65	.70
MISSISSIPPI													
GRENADA	11.5	1.9	20.0	1	0	26	31.70	219	992	50	1.89	1.03	3.47
HOLMES	10.5	1.8	22.6	4	0	26	5.40	197	807	46	2.14	1.17	.59
LAFAYETTE	9.5	1.9	24.0	1	0	31	3.60	190	754	41	2.27	1.24	.39
MADISON	10.5	1.8	29.7	4	0	24	22.70	197	807	46	2.81	1.53	2.48
MONTGOMERY	11.5	1.9	34.5	4	0	27	52.30	219	992	50	3.26	1.78	5.72
MONROE	8.0	1.8	13.2	2	0	26	9.00	163	526	35	1.25	.68	.98
NOXUBEE	12.0	2.0	14.3	2	0	26	4.60	235	1127	53	1.35	.74	.50
PONTOTOC	9.5	1.9	17.4	1	0	29	6.30	190	754	41	1.65	.90	.69
MISSOURI													
BARTON	1.0	1.9	10.9	2	0	48	3.30	69	*	18	.13	.10	.08
BATES	1.0	1.6	16.2	3	0	46	1.30	67	*	18	.19	.15	.03
BOLLINGER	2.0	1.8	10.0	2	0	44	2.90	82	*	19	.12	.09	.07
CAPE GIRARDE	3.0	1.7	52.6	1	1	42	35.70	98	*	21	.63	.47	.91
DUNKLIN	4.8	1.6	36.3	8	0	36	16.00	113	105	26	.43	.33	.41
JASPER	1.0	1.9	82.6	8	1	41	121.90	69	*	18	.99	.74	3.10
JEFFERSON	1.0	1.7	124.6	7	1	47	66.40	68	*	18	1.49	1.12	1.69
MCDONALD	1.0	1.7	15.2	3	0	44	6.20	68	*	18	.18	.14	.16
MADISON	2.0	1.8	9.4	1	0	45	4.50	82	*	19	.11	.08	.11
NEW MADRID	4.5	1.6	24.1	7	0	41	3.30	109	75	25	.29	.22	.08
NEWTON	1.0	1.7	36.4	5	0	40	22.80	68	*	18	.44	.33	.58
PEMISCOT	4.8	1.6	24.7	4	0	36	9.40	113	105	26	.30	.22	.24
PERRY	2.0	1.8	15.5	1	0	46	7.70	82	*	19	.19	.14	.20
ST FRANCOIS	2.0	1.8	39.5	8	0	46	10.80	82	*	19	.47	.36	.27
STE GENEVIEVE	2.0	1.8	14.2	2	0	46	21.50	82	*	19	.17	.13	.55
STODDARD	3.0	1.7	28.2	5	0	41	12.20	93	*	21	.34	.25	.31
VERNON	1.0	1.9	20.0	1	0	43	3.10	69	*	18	.24	.18	.08

Table 1 (cont'd)

States/Countries	Depth (thousand ft)	Gradient (° F/100 ft)	Population (thousands)	Towns	Cities	Heating degree days (hundreds)	Value added in manufacture	Temperature (° F)	Extractable heat (Btu/gal)	Cost (\$ per ft)	Residential use (trillion Btu)	Commercial use (trillion Btu)	Industrial use (trillion Btu)
NEW JERSEY													
MONMOUTH	2.0	1.7	494.3	36	2	52	259.50	80	*	19	19.08	15.55	3.23
OCEAN	3.5	1.8	314.3	17	0	54	49.20	102	19	23	12.13	9.89	.61
NEW YORK													
ALLEGANY	7.5	1.6	50.9	10	0	74	43.00	145	376	34	2.33	1.46	.44
CATTARAUGUS	7.5	1.6	85.7	13	0	74	130.70	145	376	34	3.92	2.45	1.32
CAYUGA	5.0	2.0	77.6	7	1	69	79.00	130	250	26	3.55	2.22	.80
CHEMUNG	11.0	1.8	99.8	3	1	66	226.00	199	829	48	4.56	2.85	2.29
ERIE	3.0	2.0	1089.4	16	3	71	1896.50	100	*	21	49.79	31.15	19.21
NIAGRA	3.0	2.0	238.6	2	11	67	756.90	100	*	21	10.90	6.82	7.67
ONONDAGA	4.0	1.8	475.2	14	1	67	792.80	109	75	24	21.72	13.59	8.03
SCHUYLER	8.0	1.7	17.7	3	0	68	17.40	157	476	35	.81	.51	.18
SENECA	6.0	1.8	34.0	4	0	68	66.10	136	300	29	1.55	.97	.67
STEBEN	10.0	1.7	101.2	15	0	67	181.70	182	688	43	4.63	2.89	1.84
TIOGA	11.0	1.7	49.1	6	0	73	45.20	195	795	48	2.24	1.40	.46
WYOMING	5.0	1.8	38.6	7	0	68	41.80	123	188	26	1.76	1.10	.42
YATES	6.0	1.7	20.7	2	0	64	8.50	131	263	29	.95	.59	.09
NORTH CAROLINA													
JONES	1.5	1.8	9.6	1	0	27	1.00	75	*	18	.19	.09	.03
ONSLOW	1.5	1.8	107.0	3	0	29	3.30	75	*	18	2.09	1.01	.09
OHIO													
BELMONT	12.0	1.7	82.2	11	0	54	46.20	208	901	53	4.16	1.82	1.53
CARROLL	10.0	1.6	26.0	3	0	63	12.70	175	626	43	1.32	.58	.42
CHAMPAIGN	2.2	1.6	31.7	5	0	60	50.60	81	*	20	1.61	.70	1.68
DARKE	2.5	1.8	53.6	7	0	61	34.10	89	*	20	2.71	1.19	1.13
DEFIANCE	3.0	1.6	37.2	3	0	61	107.20	91	*	21	1.88	.82	3.56
ERIE	3.0	1.6	77.4	6	1	59	160.70	91	*	21	3.92	1.71	5.33
FULTON	3.0	1.6	35.6	7	0	65	55.60	91	*	21	1.80	.79	1.84
HARDIN	2.0	1.7	31.7	7	0	60	58.80	80	*	19	1.61	.70	1.95
HARRISON	11.0	1.8	17.9	4	0	57	6.10	204	864	48	.91	.40	.20
HENRY	3.0	1.6	27.8	6	0	60	83.70	91	*	21	1.41	.62	2.78
LOGAN	2.3	1.7	37.3	9	0	59	34.80	84	*	20	1.89	.83	1.15
MIAMI	2.5	1.9	87.3	6	1	56	177.90	90	*	20	4.42	1.93	5.90
MONTOE	12.0	1.7	15.6	1	0	56	29.14	208	901	53	.79	.35	.97
SHELBY	2.4	1.8	40.1	5	0	60	90.10	87	*	20	2.03	.89	2.99
WOOD	2.5	1.8	101.3	18	1	59	137.80	89	*	20	5.13	2.24	4.57
PENNSYLVANIA													
REDFORD	20.0	1.6	42.4	4	0	58	19.50	295	1627	61	1.66	.94	.59
BLAIR	17.0	1.6	133.8	7	1	59	173.50	259	1327	61	5.24	2.98	5.23
CAMBRIA	17.0	1.6	188.4	26	1	57	239.00	259	1327	61	7.38	4.20	7.21
CAMERON	12.0	1.6	6.8	1	0	66	.00	199	826	53	.27	.15	.00
CENTRE	17.0	1.6	108.3	8	1	61	75.10	259	1327	61	4.24	2.41	2.26
CLEARFIELD	13.0	1.6	78.5	8	0	66	60.90	211	926	59	3.08	1.75	1.84
CRAWFORD	13.0	1.8	85.5	10	0	68	132.30	226	1048	59	3.35	1.91	3.99
ELK	12.0	1.6	37.1	3	0	71	48.60	199	826	53	1.45	.83	1.47
FOREST	10.0	1.6	5.2	1	0	71	6.20	175	626	43	.20	.12	.19
GREENE	14.0	1.6	38.3	2	0	57	4.40	223	1026	61	1.50	.85	.13
HUNTINGDON	22.0	1.6	39.8	4	0	59	34.70	319	1828	61	1.56	.89	1.05
INDIANA	14.0	1.6	85.5	5	0	60	61.00	223	1026	61	3.35	1.91	1.84
JEFFERSON	12.0	1.7	46.0	8	0	65	40.20	208	901	53	1.80	1.03	1.21
LAWRENCE	11.0	1.6	105.2	8	0	58	156.30	187	725	48	4.12	2.34	4.71
LYCOMING	15.0	1.6	115.1	8	1	60	244.00	235	1127	61	4.51	2.56	7.36
MCKEAN	11.0	1.7	51.5	7	0	74	121.80	195	795	48	2.02	1.15	3.67
NIFFLIN	20.0	1.6	44.2	3	0	57	85.50	295	1627	61	1.73	.98	2.58
POTTER	12.0	1.6	16.9	5	0	71	5.60	203	864	53	.66	.38	.17

Table 1 (cont'd)

States/Countries	Depth (thousand ft)	Gradient (°F/100 ft)	Population (thousands)	Towns	Cities	Heating degree days (hundreds)	Value added in manufacture	Temperature (°F)	Extractable heat (Btu/gal)	Cost (\$ per ft)	Residential use (trillion Btu)	Commercial use (trillion Btu)	Industrial use (trillion Btu)
SNYDER	20.0	1.6	31.3	6	0	60	19.00	295	1627	61	1.23	.70	.57
SOMERSET	17.0	1.6	78.8	13	0	57	27.10	259	1327	61	3.09	1.76	.82
UNION	17.0	1.6	31.3	3	0	60	22.10	259	1327	61	1.23	.70	.67
WARREN	8.0	1.6	47.2	5	0	65	82.70	151	426	85	1.85	1.05	2.49
WASHINGTON	13.0	1.8	213.5	26	0	59	295.20	231	1089	58	8.37	4.76	8.90
WESTMORELAND	15.0	1.6	380.9	36	0	57	566.60	235	1127	61	14.93	8.49	17.08
SOUTH CAROLINA													
ALLENDALE	1.8	1.6	10.1	2	0	20	3.60	77	*	18	.16	.08	.16
BERKELY	2.0	1.6	69.3	4	0	21	8.30	79	*	19	1.12	.58	.37
CLARENDON	2.0	1.6	27.1	2	0	21	8.90	55	*	18	.44	.23	.40
DORCHESTER	2.0	1.6	47.4	2	0	21	13.30	79	*	19	.76	.39	.59
GEORGETOWN	1.7	1.6	38.1	2	0	22	53.90	75	*	19	.61	.32	2.40
HORRY	1.5	1.6	86.7	6	0	21	13.60	73	*	18	1.40	.72	.61
WEST VIRGINIA													
BARBOUR	19.0	1.8	16.1	3	0	53	1.80	312	1765	61	.55	.28	.15
BRAXTON	17.0	1.6	13.1	3	0	49	1.70	259	1327	61	.45	.23	.14
MARSHALL	12.0	1.6	39.4	5	0	56	86.00	199	826	58	1.35	.68	7.10
NICHOLAS	25.0	1.6	25.7	2	0	51	3.80	355	2128	61	.88	.44	.31
PRESTON	18.0	1.6	27.6	4	0	59	7.60	271	1427	61	.84	.47	.63
RANDOLPH	25.0	1.7	26.4	3	0	60	10.80	374	2284	61	.90	.45	.89
TAYLOR	17.0	1.6	15.5	1	0	53	4.30	259	1327	61	.53	.27	.35
UPSHUR	18.0	1.6	21.7	1	0	53	11.40	271	1427	61	.74	.37	.94

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. 7) 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. 8) 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, 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, temperature and extractable heat, rounded to the nearest unit, are listed in columns 8 and 9. This precision is unwarranted by the data but is required in order to retain a consistent correlation between the two columns. Counties marked with an asterisk do not have sufficient extractable heat to warrant further consideration as geothermal prospects.

WELL COST

The cost of drilling and casing an 8 in. well was discussed by Milora and Tester (Ref. 9). The cost curves can be fitted by the following equation:

$$C_w = 10^K + D/17\ 140,$$

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. 10 and 11). 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. 12). 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. 8, 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 functions of the data in a column 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 34 counties in 10 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				
BALDWIN	48	84	72	21
WALKER	44	78	63	25
ARKANSAS				
JEFFERSON	55	81	74	19
GEORGIA				
ILLINOIS				
CHAMPAIGN	14	16	16	17
MADISON	8	26	25	1
SANGAMON	6	9	9	7
VERMILLION	10	20	18	8
INDIANA				
MARION	5	12	12	4
MONTGOMERY	29	32	36	20
TIPPECANOE	24	27	27	16
WHITE	41	48	50	22
KANSAS				
MICHIGAN				
TUSCOLA	21	10	10	42
MISSISSIPPI				
MISSOURI				
NEW JERSEY				
OCEAN	17	17	17	36
NEW YORK				
ALLEGANY	25	13	13	60
CATTARAUGUS	12	4	4	29
CAYUGA	20	5	5	39
ONONDAGA	1	1	1	6
STEBEN	7	3	2	12
TIOGA	32	21	21	69
WYOMING	34	25	23	65
NORTH CAROLINA				
OHIO				
BELMONT	22	28	29	18
PENNSYLVANIA				
BLAIR	13	14	15	11
CAMBRIA	4	8	7	5
CENTRE	15	11	11	14
CLEARFIELD	18	19	19	24
CRAWFORD	9	6	6	9
JEFFERSON	27	24	26	32
LAWRENCE	16	23	24	13
LYCOMING	11	15	14	10
MCKEAN	19	18	20	15
SOMERSET	23	22	22	33
WASHINGTON	2	2	3	2
WESTMORELAND	3	7	8	3
SOUTH CAROLINA				
WEST VIRGINIA				
MARSHALL	42	58	60	23

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. 13) may provide a more faithful representation.

8. FUTURE WORK

The initial analysis did not include Texas, Louisiana, and parts of the Atlantic Coastal Plain states. Data on these areas will be added in a supplemental report. The evaluation resulting from this method is proposed as one of the bases for the eastern portion of the hydrothermal resource confirmation plan being developed by DOE.

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APPENDIX A

Maps of States Showing the Counties
Selected as Geothermal Prospects
(modified from Ref. 8)

Fig. A-1 Alabama.

Fig. A-2 Arkansas.

Fig. A-4 Illinois.

- 39 -

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-6 Kansas.

- 41 -

Fig. A-8 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-9 Missouri.

Fig. A-10 New Jersey.

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-12 North Carolina.

- ☒ 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

- 47 -

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

SCALE
0 10 20 30 40 50 MILES

Fig. A-14 Pennsylvania.

Fig. A-15 South Carolina.

APPENDIX B

Ranked Prospects under Different Criteria

1944-1945

1944-1945

1944-1945

States/Countries	Overall	Residential	Commercial	Industrial	States/Countries	Overall	Residential	Commercial	Industrial
ALABAMA					CUMBERLAND	134	116	116	144
BALDWIN	48	84	72	21	DE WITT	73	66	64	75
BLOUNT	130	145	138	119	DOUGLAS	58	61	59	44
CULLMAN	62	97	75	38	EDGAR	95	99	96	106
LAMAR	144	150	149	116	EDWARDS	139	136	137	124
LAWRENCE	148	146	142	151	EFFINGHAM	76	70	69	100
LIMESTONE	132	141	130	149	FAYETTE	86	77	79	105
LOWNDES	162	162	162	148	LAWRENCE	88	93	95	73
MARENGO	120	148	147	62	LOGAN	50	55	54	53
MORGAN	63	96	85	35	MACOUPIN	37	34	33	64
PIKE	141	158	153	113	MADISON	8	26	25	1
WALKER	44	78	63	25	MASON	105	86	88	141
WINSTON	124	144	140	92	MENARD	102	85	89	104
ARKANSAS					MONTGOMERY	53	49	49	66
CALHOUN	158	159	159	123	MOULTRIE	104	102	102	112
CLARK	100	132	125	57	PIATT	81	73	73	72
CLEBURNE	146	149	148	117	RICHLAND	123	121	120	132
CROSS	108	131	126	71	SANGAMON	6	9	9	7
DREW	128	151	151	91	SHELBY	69	50	48	83
FRANKLIN	149	147	150	131	VERMILLION	10	20	18	8
HOWARD	121	139	139	70	WABASH	143	138	141	135
JACKSON	93	110	107	52	WAYNE	113	118	117	126
JEFFERSON	55	81	74	19	WHITE	111	109	111	130
LINCOLN	131	143	144	94	INDIANA				
LITTLE RIVER	142	154	154	96	BOONE	38	40	41	50
LONOKE	101	119	113	89	CARROLL	92	74	80	101
OUCHITA	77	114	110	40	CASS	36	43	43	51
PIKE	155	152	152	134	CLAY	72	51	53	79
POINSETT	70	92	86	30	CLINTON	39	37	40	48
SEVIER	136	142	143	98	DAVIESS	96	105	106	97
VANBUREN	159	157	158	138	DUBOIS	64	79	84	45
GEORGIA					GIBSON	57	63	65	49
EVANS	161	161	161	150	GREENE	66	52	52	63
LONG	163	163	163	161	HENDRICKS	45	30	31	99
MONTGOMERY	160	156	157	146	JOHNSON	26	35	34	27
TATTNALL	156	153	155	136	KNOX	35	45	47	31
TOOMBS	152	155	156	120	MARION	5	12	12	4
WAYNE	150	160	160	109	MARTIN	107	115	118	84
ILLINOIS					MONROE	68	82	83	61
BOND	106	107	108	111	MONTGOMERY	29	32	36	20
CHAMPAIGN	14	16	16	17	MORGAN	49	42	42	76
CLARK	94	88	93	93	OWEN	140	122	123	154
CLAY	125	123	121	143	PARKE	122	106	109	139
COLES	33	38	38	28	PIKE	154	140	145	156
CRAWFORD	75	83	87	54	POSEY	84	104	105	68

States/Counties	Overall	Residential	Commercial	Industrial	States/Counties	Overall	Residential	Commercial	Industrial
PULASKI	110	94	100	129	TIOGA	32	21	21	69
PUTNAM	65	60	62	58	WYOMING	34	25	23	65
SHELBY	79	89	97	95	YATES	115	95	91	155
SULLIVAN	80	67	70	86	NORTH CAROLINA				
TIPPECANOE	24	27	27	16	OHIO				
VANDERBURGH	71	100	98	74	BELMONT	22	28	29	18
VIGO	43	53	51	47	CARROLL	90	68	78	121
WARRICK	52	65	67	37	HARRISON	97	72	82	110
WHITE	41	48	50	22	MONTGOMERY	126	124	132	127
KANSAS					PENNSYLVANIA				
MICHIGAN					BEDFORD	60	46	45	82
ALCOMA	147	112	114	162	BLAIR	13	14	15	11
BAY	40	47	46	81	CAMBRIA	4	8	7	5
CLARE	85	56	56	125	CAMERON	157	129	131	163
IOSCO	83	54	55	145	CENTRE	15	11	11	14
MISSAUKEE	138	103	104	158	CLEARFIELD	18	19	19	24
NEWAYGO	47	39	39	77	CRAWFORD	9	6	6	9
OGEAN	117	90	92	153	ELK	67	59	58	88
OSCEOLA	89	69	68	115	FOREST	151	125	124	159
ROSCOMON	127	98	99	160	GREENE	109	101	101	157
TUSCOLA	21	10	10	42	HUNTINGDON	56	44	44	59
MISSISSIPPI					INDIANA	28	31	30	46
GRENADA	98	126	129	87	JEFFERSON	27	24	26	32
HOLMES	74	91	94	85	LAWRENCE	16	23	24	13
LAFAYETTE	112	117	115	147	LYCOMING	11	15	14	10
MADISON	61	87	90	41	MCKEAN	19	18	20	15
MONTGOMERY	46	75	76	26	MIFFLIN	59	62	61	55
MONROE	116	135	136	108	POTTER	87	57	57	107
NOXUBEE	118	127	127	118	SNYDER	51	36	37	56
PONTOTOC	114	128	128	128	SOMERSET	23	22	22	33
MISSOURI					UNION	82	71	66	103
DUNKLIN	99	108	103	67	WARREN	31	33	32	34
NEW MADRID	119	111	112	102	WASHINGTON	2	2	3	2
PEMISCOT	137	133	133	114	WESTMORELAND	3	7	8	3
NEW JERSEY					SOUTH CAROLINA				
OCEAN	17	17	17	36	WEST VIRGINIA				
NEW YORK					BARBOUR	133	113	119	133
ALLEGANY	25	13	13	60	BRAXTON	145	130	134	142
CATTARAUGUS	12	4	4	29	MARSHALL	42	58	60	23
CAYUGA	20	5	5	39	NICHOLAS	129	120	122	137
CHEMUNG	30	29	28	43	PRESTON	78	64	71	80
ONONDAGA	1	1	1	6	RANDOLPH	91	76	81	90
SCHUYLER	103	80	77	140	TAYLOR	153	137	146	152
SENECA	54	41	35	78	UPSHUR	135	134	135	122
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