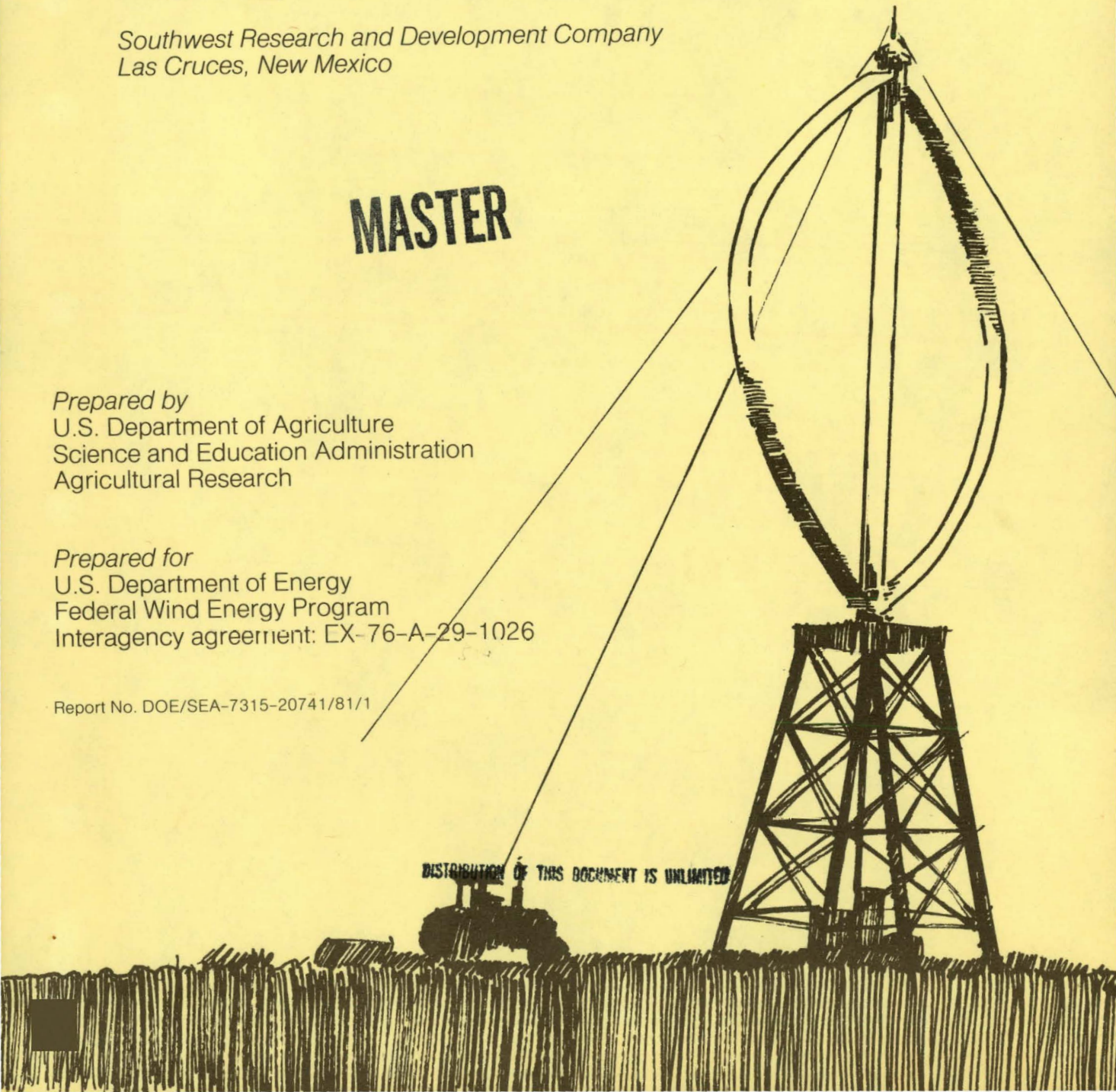
ON-FARM U.S. IRRIGATION PUMPING PLANTS

Final Report
April 30, 1980

James R. Gilley

Southwest Research and Development Company
Las Cruces, New Mexico



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Prepared for:

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ABSTRACT

Over 473,000 on-farm pumping plants are being used to pump and deliver irrigation water in the United States. The distribution of these units by geographic regions and potential wind power zones was determined. Over 60 percent of the pumping units in the U.S. are smaller than 37.3 kw (50 horsepower) in size and only 9.4 percent of the units are larger than 74.6 kw in size (100 horsepower). Over 49 percent of these pumps (231,440) are located in the six Great Plains States of Colorado, Kansas, Nebraska, New Mexico, Oklahoma and Texas. This area also has the largest potential wind power in the U.S. during the primary irrigation season. Over 51 percent of the pumping units are located in wind zones having a potential average wind power greater than 250 W/m^2 at an elevation of 50 meters. However, only 6.5 percent of the units are located in the largest potential average wind power zone (> 400 W/m^2 at 50 meters). In general, those areas which have greater potential wind power, have larger sized pumping units.

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1 INTRODUCTION

Presently, federal and state programs are exploring the feasibility of using wind power, solar power, and fuels from crop residues to replace fossil fuel power sources for pumping irrigation water. An estimate of the size distribution of irrigation pumping plants is needed by public and private organizations developing these alternative power sources. As no reports on the size distribution have previously been published, this study was conducted to meet this need. The data presented in this report may also be useful for other purposes.

Land irrigated with the aid of pumping plants in the United States reached approximately 44 million acres in 1979. This report summarizes the size distribution of some 473,000 pumping plants supplying water to this area, the energy sources used, the water supply source and the duration of seasonal operation. These estimates include the entire country, and are subdivided by farm production regions, individual states, and in some cases, selected subareas within a state (Figure 1). Because wind power varies greatly within the U.S., the pumping plants are further classified by areas having similar average wind power during the primary irrigation season (Figure 2). The wind power values shown in Figure 2 are used only to classify the pumping plants by similar average wind power zones. Figure 2 should not be used to determine the actual wind power available to pump irrigation water.

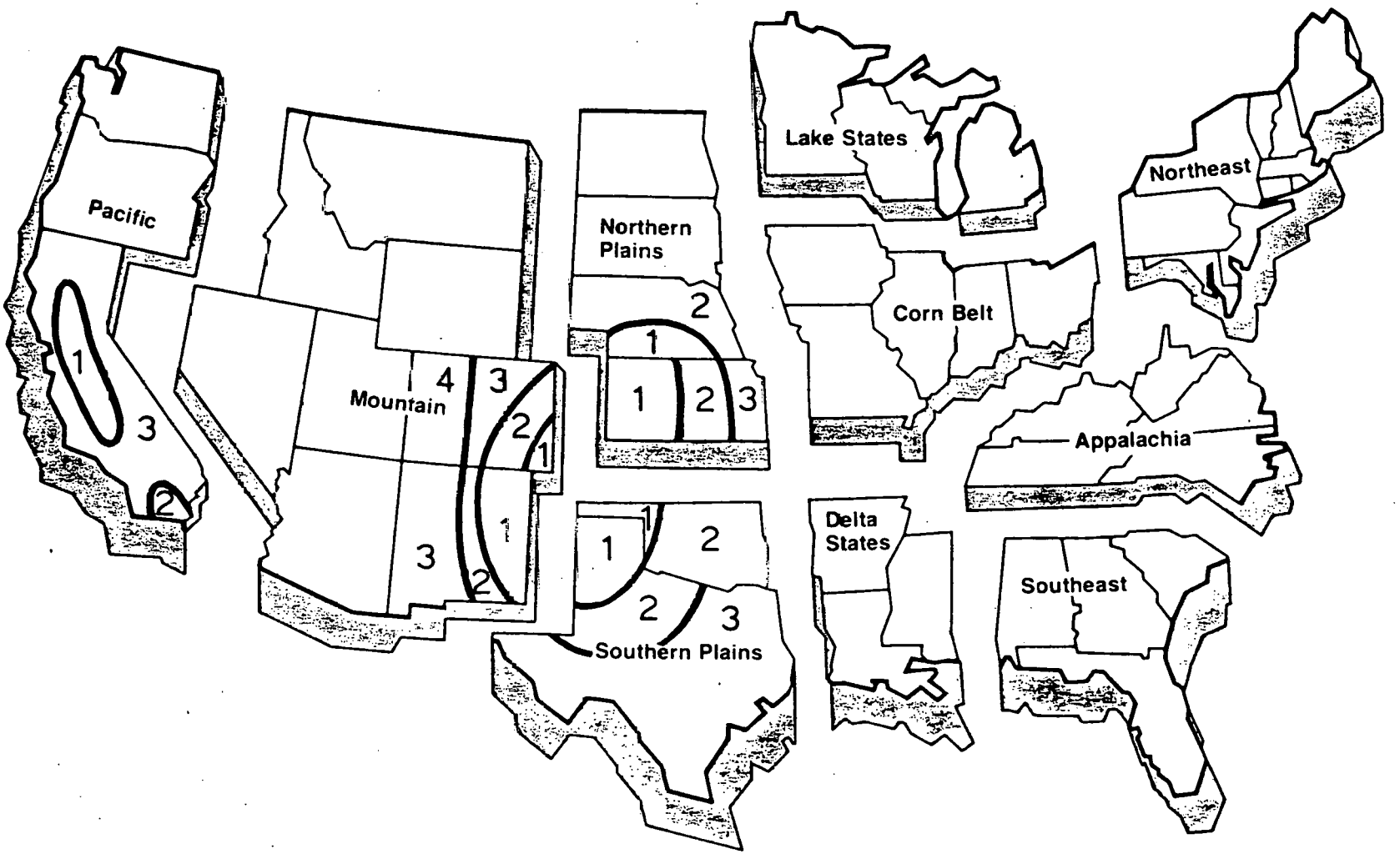


Figure 1. Farm production regions (Sloggett, 1979) and subareas within selected states.

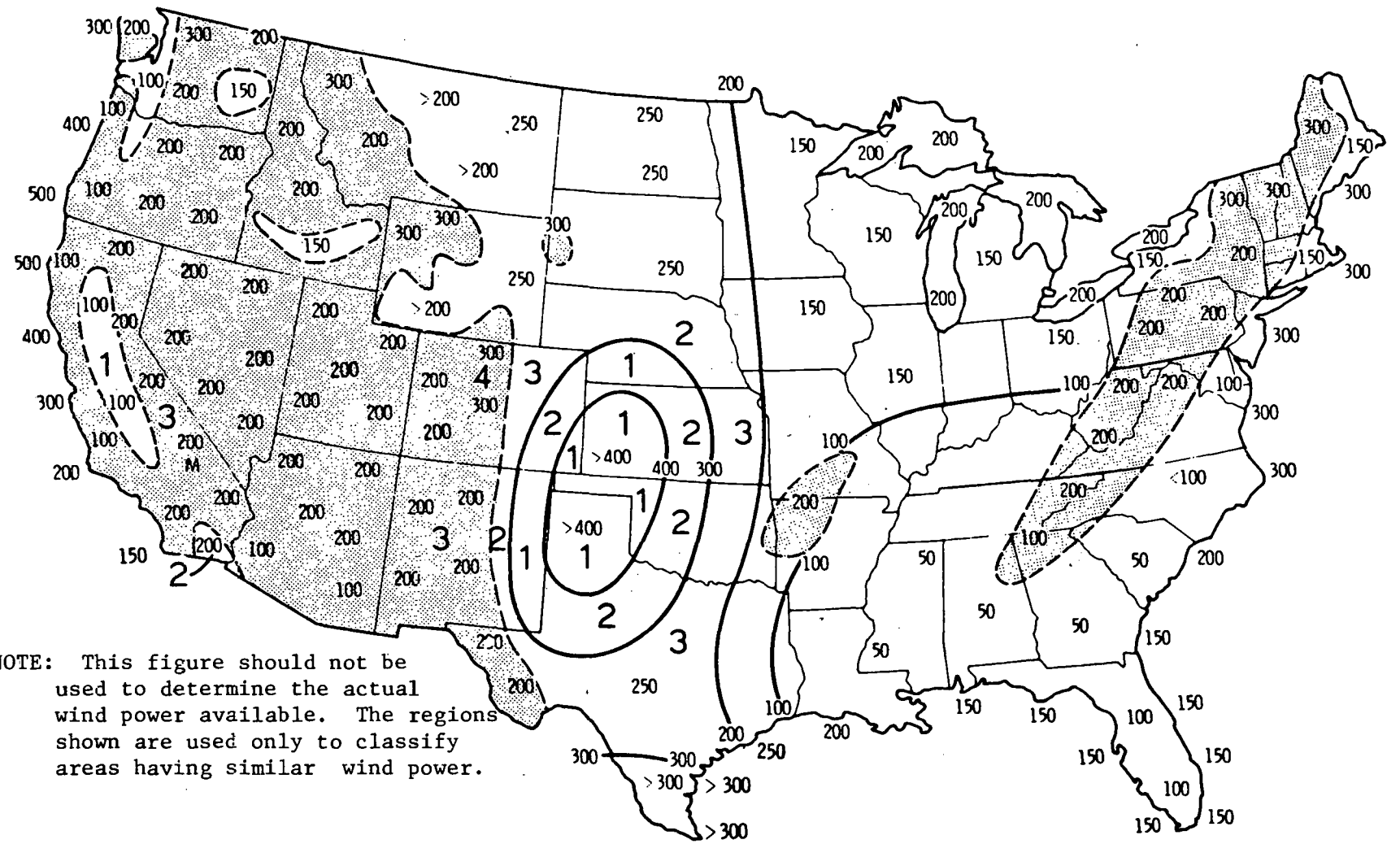


Figure 2. Average summer potential wind power(W/m^2) at 50 m above exposed areas(Elliot, 1977) and subareas within selected states.

To estimate the size of these pumping plants, it was necessary to determine: (1) area irrigated from both groundwater and pumped surface water sources, (2) irrigation flow rate and life, and (3) types of irrigation systems. The procedures used to estimate the distribution of pumping plant size is given in the following section. Seasonal and peak irrigation water requirements were used to estimate the duration of seasonal pumping plant operation. Data necessary for these calculations are shown in Appendix I and were collected from the state irrigation specialists listed in Appendix II. In many cases, additional data sources were used and various assumptions were made to determine the pumping plant size. These data sources and assumptions are given in Appendix III.

2 PROCEDURE

2.1 PUMPING PLANT SIZE

The procedure used to estimate the power requirements of irrigation pumping plants in the United States was based on the power formula:

$$BHP = \frac{Q\ (L + 0.102\ P)}{101.9\ E} \qquad (1)$$

where BHP is the pump brake-power requirements, kilowatts
Q is the pumping plant discharge, liters/second
L is the pumping lift, meters
P is the system pressure requirements, kilopascals
and, E is the pump efficiency.

For purposes of this study, a constant pump efficiency of 75 percent was used. The pumping plant flow rate and pumping lift distribution were obtained from the state irrigation experts given in Appendix II. The flow rates and pumping lifts used in the analysis are given in Table 1.

Assuming a pump efficiency of 75 percent, equation (1) was rewritten:

$$BHP = \frac{Q_i\ (L_j + P_k)}{76.4} \qquad (2)$$

where Q_i are the flow rates given in Table 1,
L_j are the pumping lifts given in Table 1, and
P_k are the assumed irrigation system pressure requirements given in Table 2.

Equation (2) was used to calculate the brake-power requirements for the various combinations of flow rates, pumping lifts and irrigation system pressure requirements.

Table 1. Pumping Plant Flow Rates and Lifts Used in the Study.

Flow rate range, liters/sec	< 25	25-38	38-50	50-63	> 63
Flow rate used in the analysis Q_i, liters/sec	15.8	31.6	44.2	56.8	75.7
Pumping lift range, meters	< 15.2	15.2-30.5	30.5-61.0	61.0-91.4	> 91.4
Pumping lift used in the analysis L_j, meters	7.6	22.9	45.7	76.2	106.7

Table 2. Pressure Requirements for the Irrigation Systems Used in the Study.

Irrigation System	System Pressure kilo Pascal
Sprinkler	
Center-pivot	517
Low Pressure Center-pivot	310
Big Gun or Traveler	758
Other Sprinkler	379
Surface	
Open ditch	30
Gated pipe	60

2.1.1 Units Using Groundwater Sources

Two steps were necessary to estimate the number of pumping plants in the different size categories using groundwater sources: (1) the distribution (expressed as a percentage) of the various pump sizes required for the different irrigation systems given in Table 2 was determined, and (2) the total number of units used for a particular irrigation system was estimated.

The distribution of the pumping plant sizes for the various irrigation systems was determined utilizing the system flow rate and pumping lift data obtained from the irrigation specialists using the following procedure:

1. The well flow rate and pumping lift were assumed to be independent.
2. The well flow rate and pumping lift distribution obtained from the irrigation specialists were assumed to be independent of the type of irrigation system. That is, the well flow and the pumping lift were the same for all irrigation systems.
3. With the above two assumptions, the distribution of pumping plant size was determined by combining the percentages of well flow rates and pumping lifts using the following equation:

$$PER_{ij} = PERQ_i \ (PERL_j) \qquad (3)$$

where PER_{ij} is the percent of units having Q_i and L_j,

$PERQ_i$ is the percent of units having a flow rate of Q_i, and

$PERL_j$ is the percent of units having a pumping lift of L_j.

For a given irrigation system, equation (2) was used to calculate the pump size for a given flow rate, Q_i, and pumping lift, L_j. The percent of units of that size was calculated using equation (3). The pumping plant sizes were combined into the following sizes: < 18.7 kW, 18.7-37.3 kW, 37.3-56.0 kW, 56.0-74.6 kW, 74.6-111.9 kW, and > 111.9 kW. An example of the results of this analysis is shown in Table 3.

The number of groundwater pumping plants used for a particular irrigation system (N_i) was estimated by:

$$N_i = \frac{A_i}{A_t} N_t \qquad (4)$$

where N_i is the number of groundwater pumping plants used for a particular irrigation system (Table 2),

A_i is the area irrigated from groundwater by a particular irrigation system,

A_t is the total area irrigated from groundwater, and

N_t is the total number of groundwater pumping plants.

An example of this procedure is given in Table 3.

The above procedure, in effect, assumes that all systems irrigated from groundwater supplies have the same area per pumping unit. It is recognized that this assumption and the assumption that the well flow rate and pumping lift were the same for all irrigation systems, while necessary because actual data were not available, is not strictly true. The irrigation systems may irrigate different land sizes and will accordingly have different flow rates. The flow rate assumption slightly

Table 3. Distribution of Pumping Plant Size for Various Irrigation Systems Using Groundwater Sources. [1/]

State Example Area within state Example

Flow rate data:	Well flow rate, liters/sec	< 25	25-38	38-50	50-63	> 63
	Units, % of total [2/]	10	20	40	20	10
Pumping lift data:	Lift, meters	< 15.2	15.2-30.5	30.5-61.0	61.0-91.4	> 91.4
	Units, % of total [2/]	20	30	30	10	10

Irrigation System	Groundwater Pumping Plant Size, kilowatts						
	< 18.7	18.7-37.3	37.3-56.0	56.0-74.6	74.6-111.9	> 111.9	Total
	- - - - - - - - - - - - Percent of Pumping Units - - - - - - - - - - - -						
Sprinkler							
Center-Pivot	5	23	30	29	9	4	100
Low-Pressure Center-Pivot	12	38	25	12	12	1	100
Big Gun	2	11	21	36	21	9	100
Other Sprinkler	8	42	22	15	11	2	100
Surface							
Open Ditch	45	36	9	6	4	0	100
Gated Pipe	45	30	15	6	3	1	100

[1/] Calculated using equations 2 and 3.

[2/] Data from irrigation specialists.

narrows the range of pumping plant sizes from that which actually exists. The assumption of equality of area irrigated by type of irrigation system slightly reduces the number of pumping plants below that which actually exists for those systems irrigating areas smaller than the average. The assumption also slightly increases the number of pumping plants above that which actually exists for systems irrigating areas larger than the average. It is estimated, however, that the combined effects of these are fully masked in the results of this study by the necessarily limited number of size classes used, which tends to mask small errors, and the accuracy limits of the other basic data obtained.

The combination of the distribution of pumping plant size for the various irrigation systems (Table 3) and the total number of pumping plants for the irrigation systems (Table 4) results in the number of pumping plants of the given sizes. The pumping plant size distribution for the example state is given in Table 5.

2.1.2 Units Using Surface Water Sources

The procedure used for analyzing those systems using surface water sources was identical to the procedure used for groundwater sources. The irrigation system discharge was assumed to be the same as the well flow rate data given in Table 1, and a constant surface water lift was assumed. An example of this analysis is given in Tables 4, 5 and 6.

Table 4. Number of Pumping Units for Groundwater and Surface Water for Various Irrigation Systems.

State Example Area within state Example

Number of groundwater pumps 10,000 [1] Number of surface water pumps 5,000 [1]

Irrigation System (1)	Area Irrigated, acres [1] (2)	Groundwater Pumps: Area, acres [1] (3)	Groundwater Pumps: % of pumps [2] (4)	Groundwater Pumps: Pumps, number [3] (5)	Surface Water Pumps: Area, acres [1] (6)	Surface Water Pumps: % pumps [4] (7)	Surface Water Pumps: Pumps number [5] (8)
Sprinkler	750,000						
Center-Pivot	500,000						
Regular	400,000	350,000	35.0	3,500	50,000	10.0	500
Low-Pressure	100,000	50,000	5.0	500	50,000	10.0	500
Big Gun	100,000	50,000	5.0	500	50,000	10.0	500
Other	150,000	50,000	5.0	500	100,000	20.0	1,000
Surface	750,000						
Open Ditch	250,000	100,000	10.0	1,000	150,000	30.0	1,500
Gated Pipe	500,000	400,000	40.0	4,000	100,000	20.0	1,000
TOTAL	1,500,000	1,000,000	100	10,000	500,000	100.0	5,000

[1] Data from irrigation specialists.

[2] Calculated from Column (3) and total area irrigated by groundwater.

[3] Calculated from Column (4) and total number of wells.

[4] Calculated from Column (6) and total area irrigated by pumped surface water.

[5] Calculated from Column (7) and total number of surface water units.

Table 5. Number of Pumping Units for Various Irrigation Systems by Size and Water Source. [1/]

State Example Area within state Example

Irrigation System	Water Source	Pumping Plant Size, kilowatts						
		< 18.7	18.7-37.3	37.3-56.0	56.0-74.6	74.6-111.9	> 111.9	Total
		Number of Pumps						
Sprinkler								
Center-Pivot	Groundwater	175	805	1,050	1,015	315	140	3,500
	Surface Water	50	300	100	50	0	0	500
Low-Pressure Center-Pivot	Groundwater	60	190	125	60	60	5	500
	Surface Water	150	300	50	0	0	0	500
Big Gun	Groundwater	10	55	105	180	105	45	500
	Surface Water	50	100	200	100	50	0	500
Other Sprinkler	Groundwater	40	210	110	75	55	10	500
	Surface Water	100	800	100				1,000
Surface								
Open Ditch	Groundwater	450	360	90	60	40	0	1,000
	Surface Water	1,500	0	0	0	0	0	1,500
Gated Pipe	Groundwater	1,800	1,200	600	240	120	40	4,000
	Surface Water	1,000	0	0	0	0	0	1,000
TOTAL		5,383	4,320	2,530	1,780	745	240	15,000

[1/] Calculated using Tables 3, 4 and 6.

Table 6. Distribution of Pumping Plant Size for Various Irrigation Systems Using Surface Water Sources. [1/]

State Example Area within state Example

Flow rate data:	Flow rate, liters/sec	< 25	25-38	38-50	50-63	> 63
	Units, % of total [2/]	10	20	40	20	10
Pumping lift data:	Water lift, meters	25				
	Units, % of total [2/]	100				

Irrigation System	Pumping Plant Size, kilowatts						
	< 18.7	18.7-37.3	37.3-56.0	56.0-74.6	74.6-111.9	> 111.9	Total
	- - - - - - - - - - Percent of Pumping Units - - - - - - - - - - - - - - - -						
Sprinkler							
Center-Pivot	10	60	20	10			100
Low-Pressure Center-Pivot	30	60	10				100
Big Gun	10	20	40	20	10		100
Other Sprinkler	10	80	10				100
Surface							
Open Ditch	100						
Gated Pipe	100						

[1/] Calculated using equations 2 and 3, constant lift assumed.

[2/] Data from irrigation specialists.

2.2 DURATION OF OPERATION FOR IRRIGATION PUMPING

The duration of operation for irrigation pumping was calculated using the seasonal crop irrigation water requirements obtained from the irrigation specialists and irrigation system capacities assumed equal to peak crop water use requirements.

3 RESULTS

The results of the on-farm irrigation pumping plant study are summarized for the U.S. as well as for individual states and geographic regions. In addition, they are summarized by areas having similar average wind power during the summer months (Figure 2).

3.1 WATER AND ENERGY SOURCE

The type of energy source (electric, diesel, natural gas, propane or gasoline) used to supply the pumping plants and the source of irrigation water (groundwater or surface water) are given on a State basis in Table 7.

3.2 PUMPING PLANT SIZE BY GEOGRAPHIC REGION

The number of irrigation pumping plants in the U.S. and their size distribution are given on a State and Regional basis in Table 8 and their regional distribution is shown in Figure 3. Approximately 78 percent of the on-farm irrigation pumping plants are located in four geographic regions: Southern Plains, Northern Plains, Pacific and Mountain. The two regions with the largest number of units, the Southern and Northern Plains, have a combined total of approximately 44 percent of the pumping plants in the U.S. The number of groundwater and surface water units in the geographic regions of the U.S. is shown in Figure 4. Over 75 percent of the on-farm irrigation pumping in the U.S. are supplied from groundwater sources.

Table 7. Water and Energy Source of the U.S. On-Farm Irrigation Pumping Plants in the Various Geographic Regions.

GEOGRAPHIC REGION	STATE & SUBAREA[2]	WIND ZONE[1] W/m^2	WATER SOURCE GROUND WATER,%	WATER SOURCE SURFACE WATER,%	ENERGY SOURCE DISTRIBUTION ELECTRIC %	DIESEL %	NAT. GAS %	LPG %	GASOLINE %
APPALACHIAN	KY	<100	4	96	0	15	0	0	85
	NC	100	6	94	10	48	0	1	41
	TN	<100	29	71	22	31	8	2	37
	VA	150	1	99	8	35	0	1	56
	WV	200	0	100	12	18	0	0	70
CORNBELT	IL	150	91	9	39	33	0	18	10
	IN	150	37	63	37	25	2	20	16
	IA	150	92	8	44	44	0	6	6
	MO	150	84	16	5	48	0	38	9
	OH	150	35	65	35	15	0	10	40
DELTA	AK	100	70	30	45	30	4	15	6
	LA	<100	50	50	15	42	20	3	20
	MS	<100	20	80	28	66	2	3	1
LAKE	MI	150	63	37	42	32	0	2	24
	MN	150	92	8	60	30	2	8	0
	WI	150	53	37	59	31	0	2	8

Table 7. Water and Energy Source of the U.S. On-Farm Irrigation Pumping Plants in the Various Geographic Regions (Continued).

GEOGRAPHIC REGION	STATE & SUBAREA[2]	WIND ZONE[1] W/m^2	WATER SOURCE GROUND WATER, %	WATER SOURCE SURFACE WATER, %	ENERGY SOURCE DISTRIBUTION ELECTRIC %	DIESEL %	NAT. GAS %	LPG %	GASOLINE %
MOUNTAIN	AZ	200	73	27	78	2	20	0	0
	CO 1	>400	100	0	19	2	79	0	0
	CO 2	350	95	5	82	0	0	18	0
	CO 3	250	95	5	98	1	1	0	0
	CO 4	200	95	5	96	1	2	1	0
	ID	200	45	55	97	2	0	0	1
	MT	250	15	85	84	10	0	2	4
	NV	200	83	17	80	20	0	0	0
	NM 1	350	99	1	40	10	40	10	0
	NM 2	250	98	2	50	10	40	0	0
	NM 3	200	96	4	35	7	45	12	1
	UT	200	80	20	88	6	0	3	3
	WY	250	37	63	85	8	4	1	2
NORTHEAST	CT	150	11	89	10	27	0	1	62
	DE	150	77	23	5	75	0	0	20
	ME	150	0	100	10	30	0	0	60
	MD	200	33	67	5	51	0	9	35
	MA	200	3	97	44	2	0	1	53
	NH	250	0	100	5	5	0	0	90
	NJ	150	56	44	10	15	0	5	70
	NY	200	50	50	10	40	0	0	50
	PA	200	11	89	2	40	0	1	58
	RI	150	0	100	50	30	0	0	20
	VT	250	0	100	10	30	0	0	60

Table 7. Water and Energy Source of the U.S. On-Farm Irrigation Pumping Plants in the Various Geographic Regions (Continued).

GEOGRAPHIC REGION	STATE & SUBAREA [2]	WIND ZONE [1] W/m^2	WATER SOURCE		ENERGY SOURCE DISTRIBUTION				
			GROUND WATER,%	SURFACE WATER,%	ELECTRIC %	DIESEL %	NAT. GAS %	LPG %	GASOLINE %
NORTHERN PLAINS	KS 1	>400	96	4	25	18	48	8	1
	KS 2	350	90	10	35	25	20	20	0
	KS 3	250	60	40	30	44	3	23	0
	NE 1	350	97	3	30	36	21	12	1
	NE 2	250	94	6	30	36	21	12	1
	ND	250	77	23	85	12	0	1	2
	SD	250	47	53	62	29	2	5	2
PACIFIC	CA 1	100	83	17	82	3	14	1	0
	CA 2	200	79	21	82	3	14	1	0
	CA 3	150	77	23	82	3	14	1	0
	OR	200	14	86	100	0	0	0	0
	WA	200	27	73	100	0	0	0	0
SOUTHEAST	AB	<100	25	75	7	77	0	7	9
	FL	100	43	57	37	59	0	2	2
	GA	<100	28	72	5	75	0	10	10
	SC	<100	35	65	35	60	0	1	4

Table 7. Water and Energy Source of the U.S. On-Farm Irrigation Pumping Plants in the Various Geographic Regions (Continued).

GEOGRAPHIC REGION	STATE & SUBAREA 2/	WIND ZONE 1/ W/m^2	WATER SOURCE GROUND WATER, %	WATER SOURCE SURFACE WATER, %	ENERGY SOURCE DISTRIBUTION ELECTRIC %	DIESEL %	NAT. GAS %	LPG %	GASOLINE %
SOUTHERN PLAINS	OK 1	>400	99	1	17	5	61	15	2
	OK 2	350	83	17	17	5	61	15	2
	TX 1	>400	100	0	4	6	89	1	0
	TX 2	350	100	0	44	1	54	1	0
	TX 3	250	48	52	61	10	20	9	0
OTHERS	AL	OTHER	50	50	70	5	0	0	25
	HI	OTHER	93	7	99	0	0	0	1

1/ Wind zone areas are defined in Figure 2.

2/ Subareas of selected states are defined in Figures 1 and 2.

Table 8. Size Distribution of the U.S. On-Farm Irrigation Pumping Plants in the Various Geographic Regions.

GEOGRAPHIC REGION	STATE & SUBAREA[2]	WIND ZONE[1] W/m^2	NUMBER OF PUMPS GROUND WATER	SURFACE WATER	TOTAL PUMPS	NUMBER OF PUMPS BY POWER SIZE, kW < 18.7	18.7 - 37.3	37.3 - 56.0	56.0 - 74.6	74.6 - 111.9	>111.9
APPALACHIAN	KY	<100	12	910	922	461	461	0	0	0	0
	NC	100	240	3747	3987	1932	1972	79	4	0	0
	TN	<100	87	213	300	127	151	22	0	0	0
	VA	150	8	2450	2458	1228	1230	0	0	0	0
	WV	200	0	69	69	35	34	0	0	0	0
	TOTAL		347	7389	7736	3783	3848	101	4	0	0
CORNBELT	IL	150	800	80	880	84	300	200	249	39	8
	IN	150	246	418	664	30	197	146	278	13	0
	IA	150	1394	297	1691	280	351	321	456	253	30
	MO	150	1500	360	1860	792	195	233	292	326	22
	OH	150	110	269	379	15	123	147	68	26	0
	TOTAL		4050	1424	5474	1201	1166	1047	1343	657	60
DELTA	AK	100	17315	3815	21130	11250	8050	1490	104	226	10
	LA	<100	6000	6000	12000	6351	5333	87	117	102	0
	MS	<100	2635	500	3135	1793	1243	18	75	6	0
	TOTAL		25950	10315	36265	19404	14626	1595	296	334	10
LAKE	MI	150	1890	1110	3000	358	502	1478	562	0	0
	MN	150	3480	450	3930	317	1170	916	1249	225	53
	WI	150	1677	954	2641	246	1005	621	627	116	26
	TOTAL		7047	2524	9571	921	2777	3015	2438	341	79

Table 8. Size Distribution of the U.S. On-Farm Irrigation Pumping Plants in the Various Geographic Regions (Continued).

GEOGRAPHIC REGION	STATE & SUBAREA[2/]	WIND ZONE[1/] W/m^2	NUMBER OF PUMPS GROUND WATER	SURFACE WATER	TOTAL PUMPS	NUMBER OF PUMPS BY POWER SIZE, kW < 18.7	18.7 - 37.3	37.3 - 56.0	56.0 - 74.6	74.6 - 111.9	>111.9
MOUNTAIN	AZ	200	7000	200	7200	272	546	781	756	4353	492
	CO 1	>400	780	0	780	0	117	328	150	181	4
	CO 2	350	6359	335	6694	1683	1087	1738	1070	1023	93
	CO 3	250	7614	401	8015	5419	1804	558	185	49	0
	CO 4	200	2908	153	3061	1034	786	622	543	57	19
	ID	200	6714	8196	14910	5783	2747	1589	868	1474	2449
	MT	250	940	5438	6378	4114	1736	257	199	69	3
	NV	200	2619	537	3156	966	1281	596	214	89	10
	NM 1	350	5780	50	5830	1152	1487	1793	1191	187	20
	NM 2	250	2060	50	2110	375	1202	286	186	57	4
	NM 3	200	4235	185	4420	1598	1773	776	226	45	2
	UT	200	7926	2022	9948	1208	2440	2207	2369	1639	85
	WY	250	2300	4000	6300	3840	1822	390	175	62	11
	TOTAL		57235	21567	78802	27444	18828	11921	8132	9285	3192
NORTHEAST	CT	150	17	133	150	45	96	8	1	0	0
	DE	150	415	124	539	48	118	188	146	39	0
	ME	150	0	83	83	27	54	2	0	0	0
	MD	200	179	364	543	63	293	126	51	10	0
	MA	200	100	422	522	147	334	38	3	0	0
	NH	250	0	110	110	35	72	3	0	0	0
	NJ	150	1624	1276	2900	348	1410	687	406	49	0
	NY	200	650	650	1300	156	682	279	163	20	0
	PA	200	35	282	317	38	190	79	10	0	0
	RI	150	0	50	50	6	42	2	0	0	0
	VT	250	0	37	37	4	31	2	0	0	0
	TOTAL		3020	3531	6551	917	3322	1414	780	118	0

Table 8. Size Distribution of the U.S. On-Farm Irrigation Pumping Plants in the Various Geographic Regions (Continued).

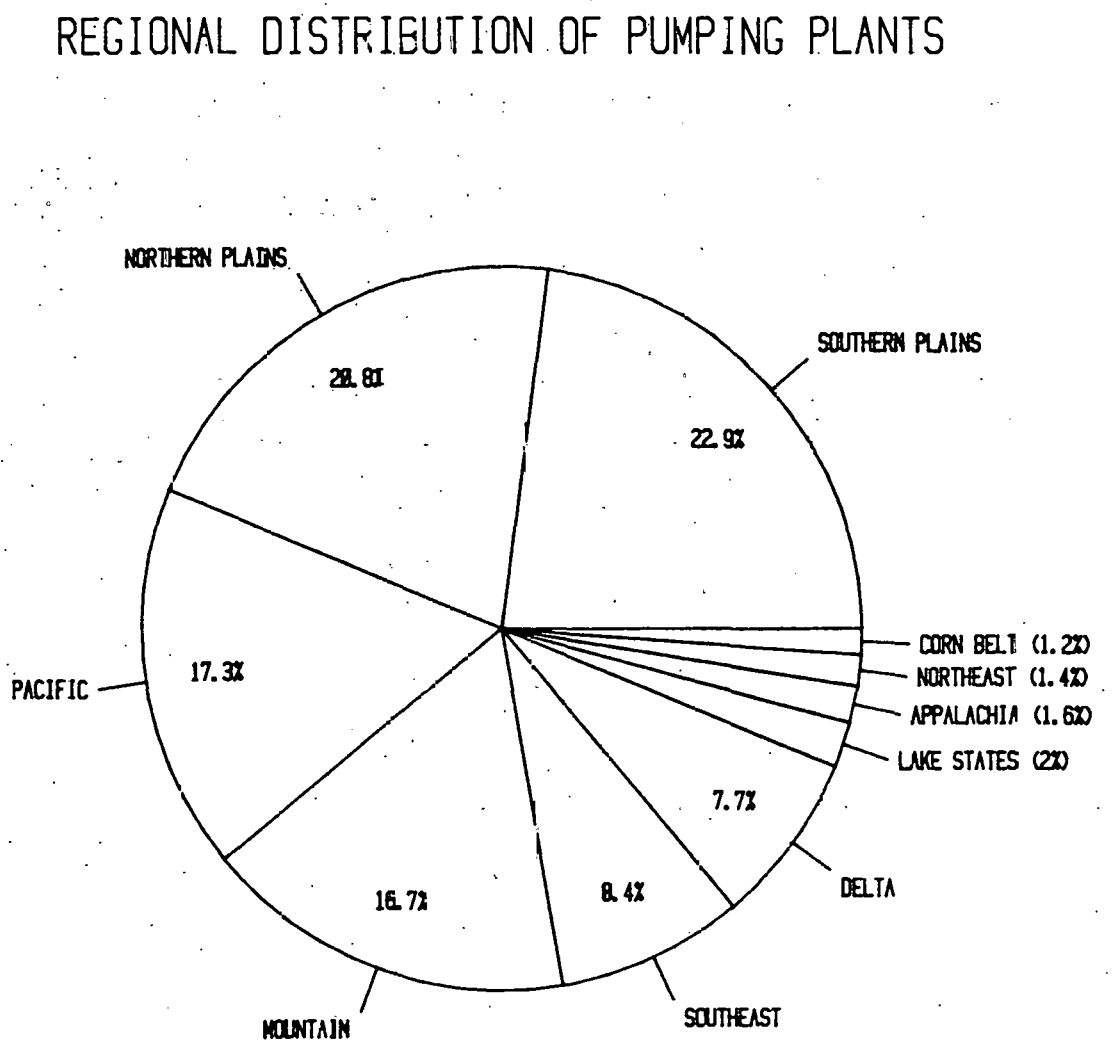
GEOGRAPHIC REGION	STATE & SUBAREA 2/	WIND ZONE 1/ W/m²	NUMBER OF PUMPS GROUND WATER	NUMBER OF PUMPS SURFACE WATER	NUMBER OF PUMPS TOTAL PUMPS	NUMBER OF PUMPS BY POWER SIZE, kW < 18.7	18.7 - 37.3	37.3 - 56.0	56.0 - 74.6	74.6 - 111.9	>111.9
NORTHERN PLAINS	KS 1	>400	19984	647	20631	4763	5930	4695	3110	1729	404
	KS 2	350	2147	231	2378	527	603	841	366	40	1
	KS 3	250	828	558	1386	726	470	146	39	5	0
	NE 1	350	32914	1725	34639	22744	6045	2235	1562	1653	400
	NE 2	250	29857	3593	33450	16385	4337	5983	4376	1860	509
	ND	250	750	250	1000	229	328	238	174	31	0
	SD	250	2394	2359	4753	308	1889	1156	748	652	0
	TOTAL		88874	9363	98237	45682	19602	15294	10375	5970	1314
PACIFIC	CA 1	100	33706	5476	39182	8762	13259	10095	1982	3248	1836
	CA 2	200	190	38	228	50	81	58	11	16	12
	CA 3	150	10623	2652	13275	2951	4160	3922	605	1252	385
	OR	200	1130	10582	11712	1818	6130	2697	680	328	59
	WA	200	3338	13678	17016	3174	8350	3364	1617	507	4
	TOTAL		48987	32426	81413	16755	31980	20136	4895	5351	2296
SOUTHEAST	AB	<100	340	1018	1358	129	108	511	228	310	72
	FL	100	12539	16619	29158	16324	7281	3507	1429	569	48
	GA	<100	2460	6241	8701	869	1791	2552	607	1824	1058
	SC	<100	150	400	550	32	50	159	38	213	8
	TOTAL		15489	24278	39767	17354	9230	6729	2352	2916	1186

Table 8. Size Distribution of the U.S. On-Farm Irrigation Pumping Plants in the Various Geographic Regions (Continued).

GEOGRAPHIC REGION	STATE & SUBAREA[2]	WIND ZONE[1] W/m^2	NUMBER OF PUMPS GROUND WATER	NUMBER OF PUMPS SURFACE WATER	NUMBER OF PUMPS TOTAL PUMS	NUMBER OF PUMPS BY POWER SIZE, kW < 18.7	18.7 - 37.3	37.3 - 56.0	56.0 - 74.6	74.6 - 111.9	>111.9
SOUTHERN PLAINS	OK 1	>400	2741	20	2761	46	345	659	852	672	187
	OK 2	350	4210	575	4785	1248	1902	1038	490	94	13
	TX 1	>400	6400	0	6400	142	932	1350	1739	1678	559
	TX 2	350	68000	0	68000	15850	24784	13827	8092	4615	832
	TX 3	250	20600	5500	26100	14590	6051	2150	1184	1503	622
	TOTAL		101951	6095	108046	31876	34014	19024	12357	8562	2213
OTHERS	AL	OTHER	20	20	40	20	20	0	0	0	0
	HI	OTHER	1600	120	1720	110	259	285	478	452	136
	TOTAL		1620	140	1760	130	279	285	478	452	136
NATIONAL TOTALS			354570	119052	473622	165467	139672	80561	43450	33986	10486

1/ Wind zone areas are defined in Figure 2.

2/ Subareas of selected states are defined in Figures 1 and 2.



igure 3. Distribution of U. S. on-farm irrigatien pumping plants by geographic region.

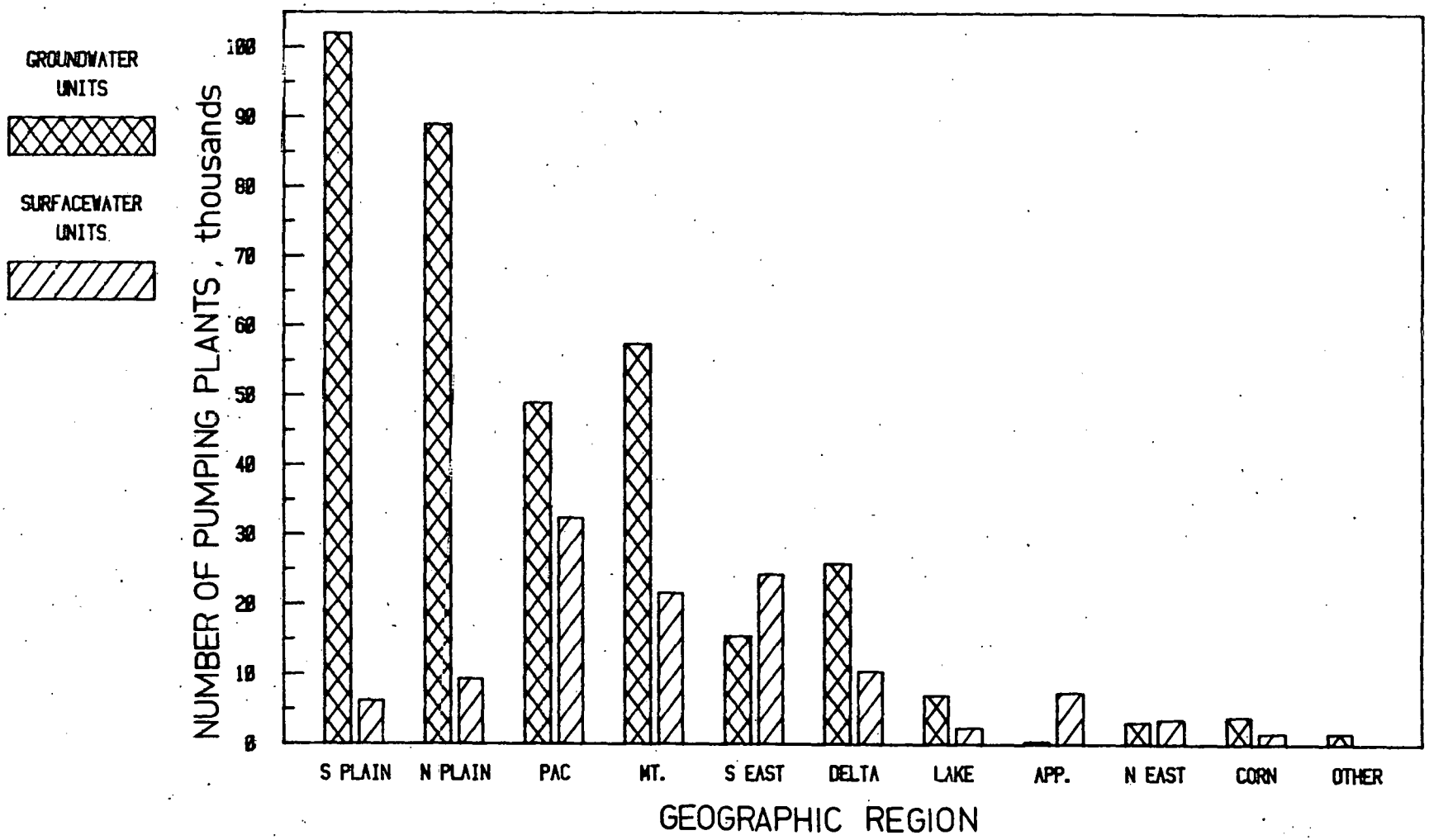


Figure 4. Distribution of irrigation pumping plants by geographic region and water supply.

The national size distribution of on-farm irrigation pumping plants is shown in Figure 5. Over 64 percent of the units are smaller than 37.3 kW in size and only 9.4 percent of the units are larger than 74.6 kW in size.

The accumulative distribution of the on-farm irrigation pumping plants on a national basis and the 50, 75 and 90 percentile sizes are shown in Figure 6. The 50 percentile size is approximately 28 kW , the 75 percentile size is approximately 48 kW and the 90 percentile size is approximately 73 kW.

The size distribution of the six regions having the greatest number of pumping plants is shown in Figure 7. The northern plains has the largest number of units less than 18.7 kW in size with 45,682 units. The southern plains has the largest number of units between 18.7 and 37.3 kW (34,014) and the largest number of units between 56.0 and 74.6 kW (12,357). The pacific area has the largest number of units between 37.3 and 56 kW (20,136) and the mountain region has the largest number of units greater than 74.6 kW in size (12,477).

3.3 PUMPING PLANT SIZE BY WIND ZONE

The number of pumping plants for the various sizes grouped by zones having the same average wind power during the principle irrigation season is given in Table 9 and Figure 8. The 350 W/m^2 wind zone has the largest number of pumping plants (122,326 units or 25.8 percent of the national total). The two wind zones having the largest potential wind power (>400 W/m^2 and

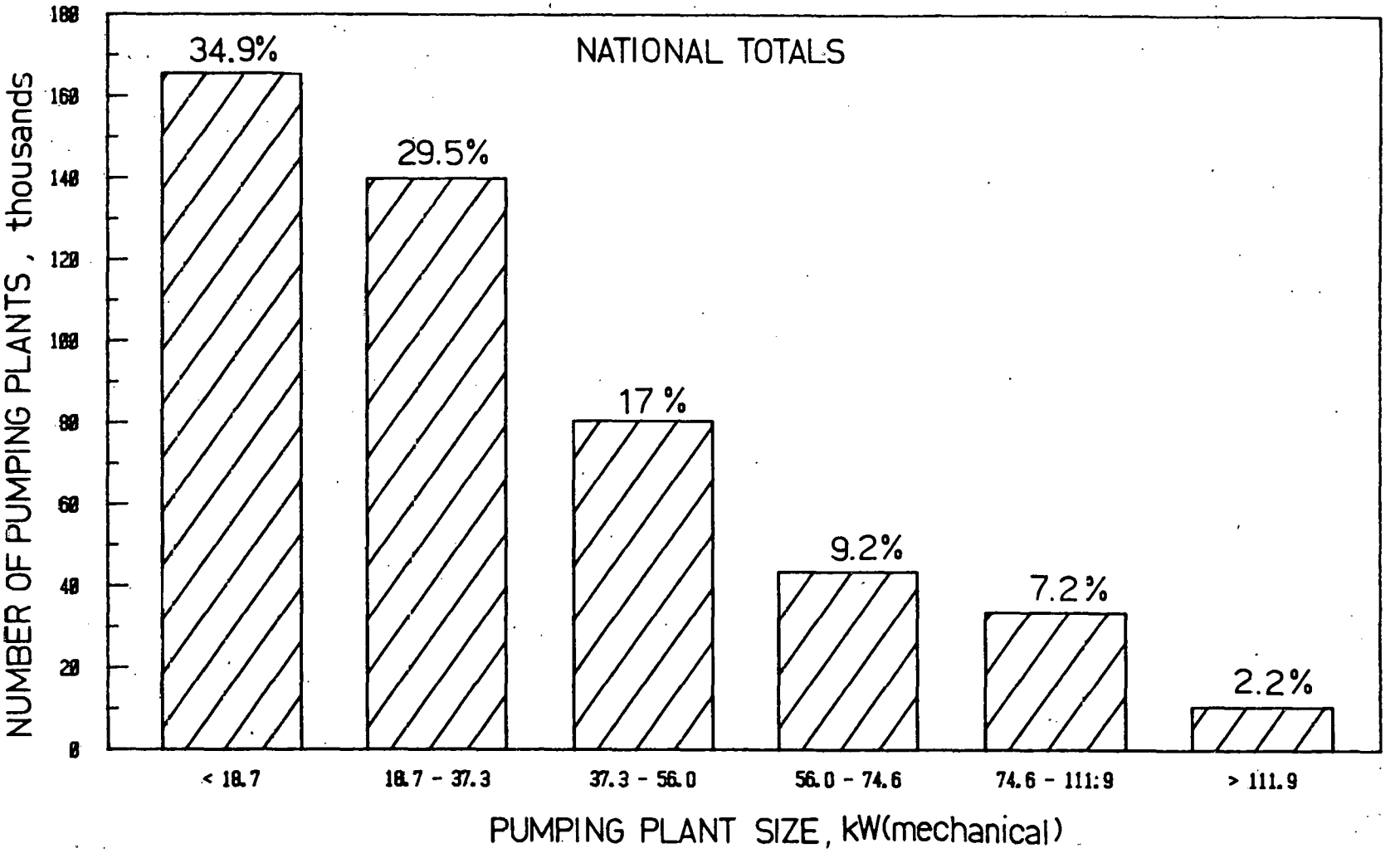


Figure 5. Distribution of the on-farm irrigation pumping plants, national totals and percent of national totals in each size class.

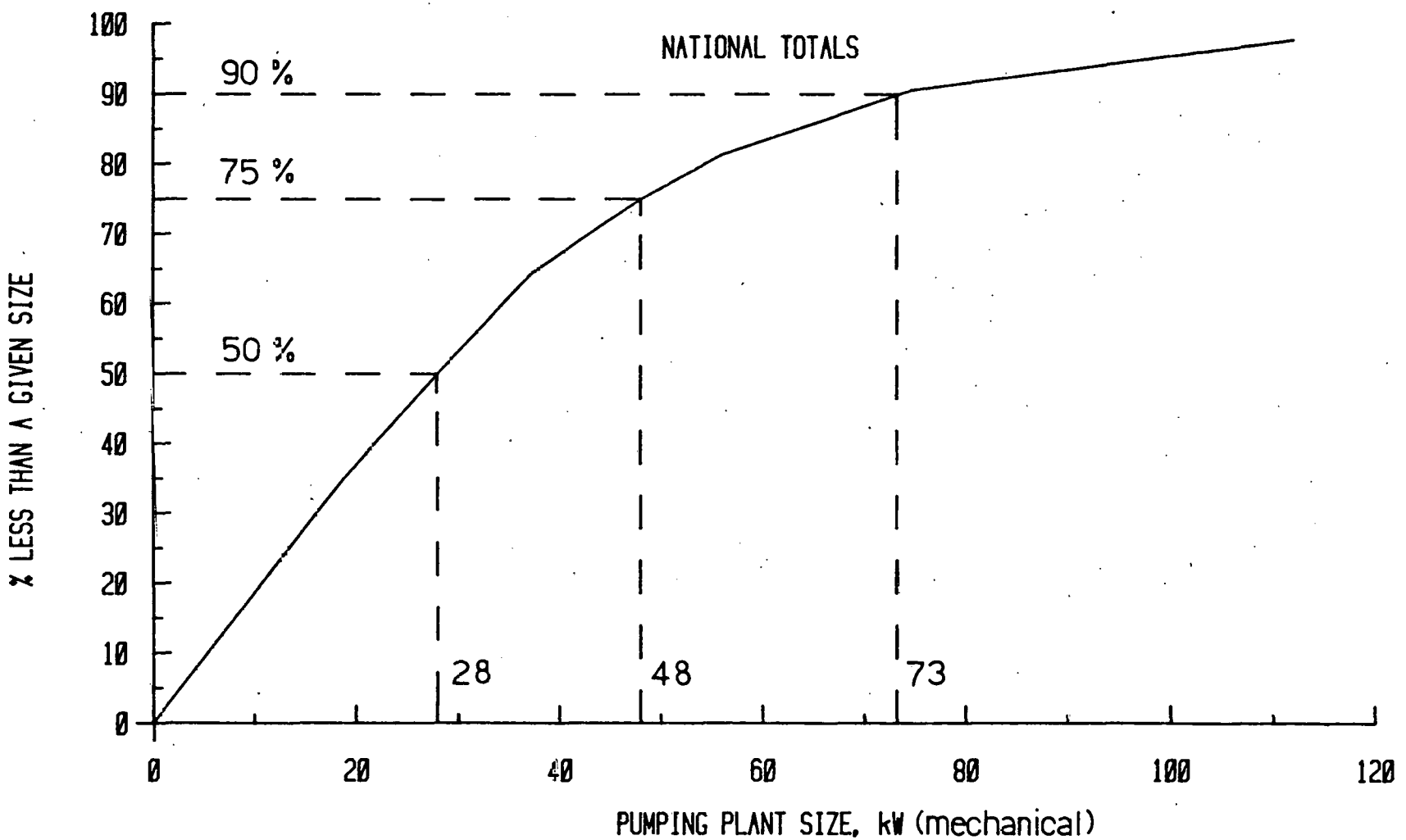


Figure 6. Distribution of the on-farm irrigation pumping plants, national totals less than a specific size.

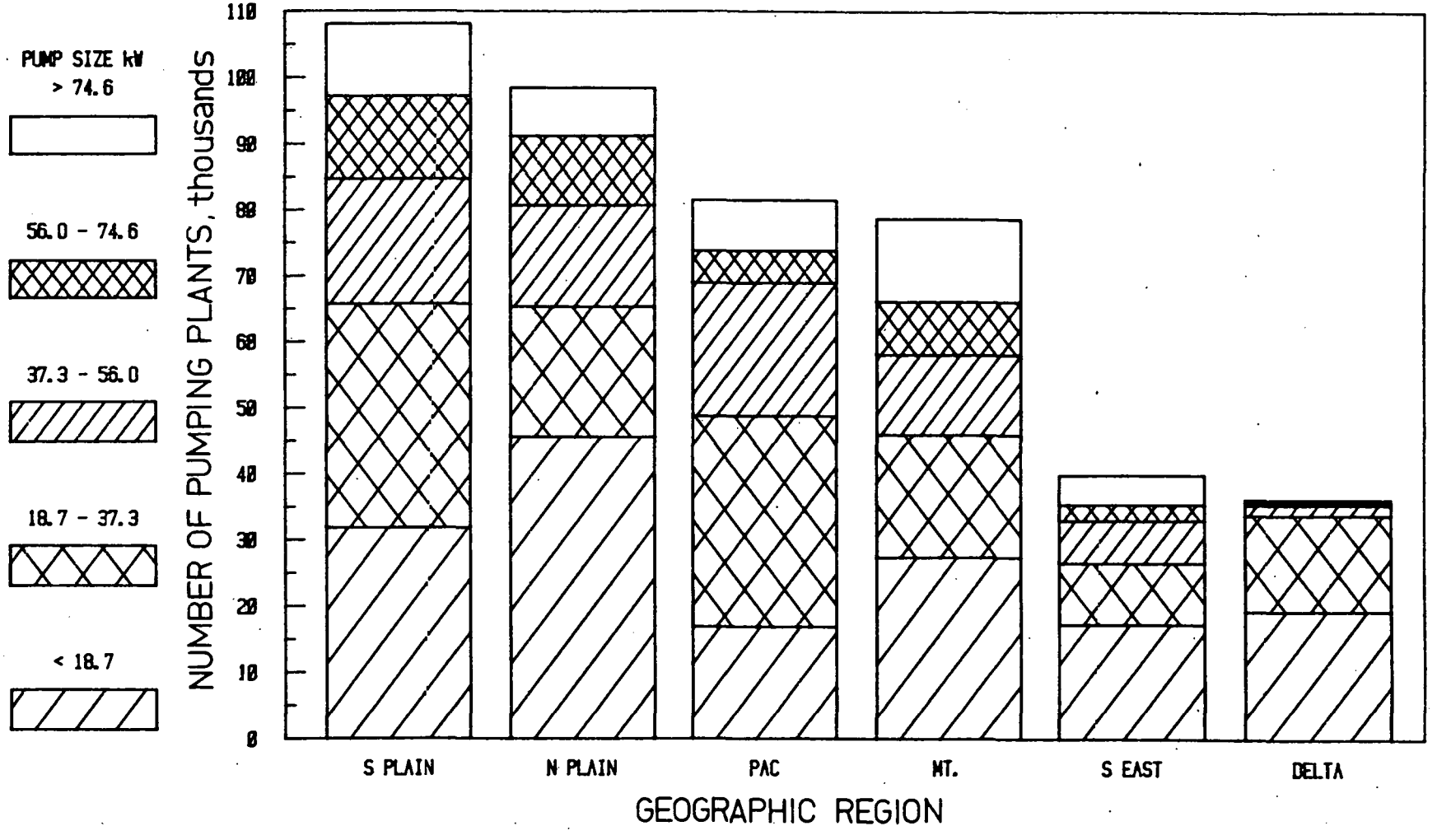


Figure 7. Size distribution of the on-farm irrigation pumping plants for the six regions having the greatest number of units.

Table 9. Size Distribution of U.S. On-Farm Irrigation Pumping Plants in the Various Wind Zones.

WIND ZONE[1] W/m²	STATE & SUBAREA[2]	NUMBER OF PUMPS GROUND WATER	SURFACE WATER	TOTAL PUMPS	NUMBER OF PUMPS BY POWER SIZE, kW < 18.7	18.7 - 37.3	37.3 - 56.0	56.0 - 74.6	74.6 - 111.9	>111.9
>400	CO 1	780	0	780	0	117	328	150	181	4
	KS 1	19984	647	20631	4763	5930	4695	3110	1729	404
	OK 1	2741	20	2761	46	345	659	852	672	187
	TX 1	6400	0	6400	142	932	1350	1739	1678	559
	TOTAL	29905	667	30572	4951	7324	7032	5851	4260	1154
350	CO 2	6359	335	6694	1683	1087	1738	1070	1023	93
	KS 2	2147	231	2378	527	603	841	366	40	1
	NE 1	32914	1725	34639	22744	6045	2235	1562	1653	400
	NM 1	5780	50	5830	1152	1487	1793	1191	187	20
	OK 2	4210	575	4785	1248	1902	1038	490	94	13
	TX 2	68000	0	68000	15850	24784	13827	8092	4615	832
	TOTAL	119410	2916	122326	43204	35908	21472	12771	7612	1359
250	CO 3	7614	401	8015	5419	1804	558	185	49	0
	KS 3	828	558	1386	726	470	146	39	5	0
	MT	940	5438	6378	4114	1736	257	199	69	3
	NE 2	29857	3593	33450	16385	4337	5983	4376	1860	509
	NH	0	110	110	35	72	3	0	0	0
	NM 2	2060	50	2110	375	1202	286	186	57	4
	ND	750	250	1000	229	328	238	174	31	0
	SD	2394	2359	4753	308	1889	1156	748	652	0
	TX 3	20600	5500	26100	14590	6051	2150	1184	1503	622
	VT	0	37	37	4	31	2	0	0	0
	WY	2300	4000	6300	3840	1822	390	175	62	11
	TOTAL	67343	22296	89639	46025	19742	11169	7266	4288	1149

Table 9. Size Distribution of U.S. On-Farm Irrigation Pumping Plants in the Various Wind Zones (Continued).

WIND ZONE[1] W/m^2	STATE & SUBAREA[2]	NUMBER OF PUMPS GROUND WATER	SURFACE WATER	TOTAL PUMPS	NUMBER OF PUMPS BY POWER SIZE, kW < 18.7	18.7 - 37.3	37.3 - 56.0	56.0 - 74.6	74.6 - 111.9	>111.9
200	AZ	7000	200	7200	272	546	781	756	4353	492
	CA 2	190	38	228	50	81	58	11	16	12
	CO 4	2908	153	3061	1034	786	622	543	57	19
	ID	6714	8196	14910	5783	2747	1589	868	1474	2449
	MD	179	364	543	63	293	126	51	10	0
	MA	100	422	522	147	334	38	3	0	0
	NV	2619	537	3156	966	1281	596	214	89	10
	NM 3	4235	185	4420	1598	1773	776	226	45	2
	NY	650	650	1300	156	682	279	163	20	0
	OR	1130	10582	11712	1818	6130	2697	680	328	59
	PA	35	282	317	38	190	79	10	0	0
	UT	7926	2022	9948	1208	2440	2207	2369	1639	85
	WA	3338	13678	17016	3174	8350	3364	1617	507	4
	WV	0	69	69	35	34	0	0	0	0
	TOTAL	37024	37378	74402	16342	25667	13212	7511	8538	3132
150	CA 3	10623	2652	13275	2951	4160	3922	605	1252	385
	CT	17	133	150	45	96	8	1	0	0
	DE	415	124	539	48	118	188	146	39	0
	IL	800	80	880	84	300	200	249	39	8
	IN	246	418	664	30	197	146	278	13	0
	IA	1394	297	1691	280	351	321	456	253	30
	ME	0	83	83	27	54	2	0	0	0
	MI	1890	1110	3000	358	602	1478	562	0	0

Table 9. Size Distribution of U.S. On-Farm Irrigation Pumping Plants in the Various Wind Zones (Continued).

WIND ZONE[1] W/m^2	STATE & SUBAREA[2]	NUMBER OF PUMPS GROUND WATER	SURFACE WATER	TOTAL PUMPS	NUMBER OF PUMPS BY POWER SIZE, kW < 18.7	18.7 - 37.3	37.3 - 56.0	56.0 - 74.6	74.6 - 111.9	>111.9
150	MN	3480	450	3930	317	1170	916	1249	225	53
cont	MO	1500	360	1860	792	195	233	292	326	22
	NJ	1624	1276	2900	348	1410	687	406	49	0
	OH	110	269	379	15	123	147	68	26	0
	RI	0	50	50	6	42	2	0	0	0
	VA	8	2450	2458	1228	1230	0	0	0	0
	WI	1677	964	2641	246	1005	621	627	116	26
	TOTAL	23784	10716	34500	6775	11053	8871	4939	2338	524
100	AK	17315	3815	21130	11250	8050	1490	104	226	10
	CA 1	33706	5476	39182	8762	13259	10095	1982	3248	1836
	FL	12539	16619	29158	16324	7281	3507	1429	569	48
	NC	240	3747	3987	1932	1972	79	4	0	0
	TOTAL	63800	29657	93457	38268	30562	15171	3519	4043	1894
<100	AB	340	1018	1358	129	108	511	228	310	72
	GA	2460	6241	8701	869	1791	2552	607	1824	1058
	KY	12	910	922	461	461	0	0	0	0
	LA	6000	6000	12000	6361	5333	87	117	102	0
	MS	2635	500	3135	1793	1243	18	75	6	0
	SC	150	400	550	32	50	159	88	213	8
	TN	87	213	300	127	151	22	0	0	0
	TOTAL	11684	15282	26966	9772	9137	3349	1115	2455	1138

Table 9. Size Distribution of U.S. On-Farm Irrigation Pumping Plants in the Various Wind Zones

WIND ZONE[1] W/m²	STATE & SUBAREA[2]	NUMBER OF PUMPS GROUND WATER	SURFACE WATER	TOTAL PUMPS	NUMBER OF PUMPS BY POWER SIZE, kW < 18.7	18.7 - 37.3	37.3 - 56.0	56.0 - 74.6	74.6 - 111.9	>111.9
OTHER	AL	20	20	40	20	20	0	0	0	0
	HI	1600	120	1720	110	259	285	478	452	136
	TOTAL	1620	140	1760	130	279	285	478	452	136
NATIONAL TOTALS		354570	119052	473622	165467	139672	80561	43450	33986	10486

[1] Wind zones are defined in Figure 2.

[2] Subareas of selected states are defined in Figures 1 and 2.

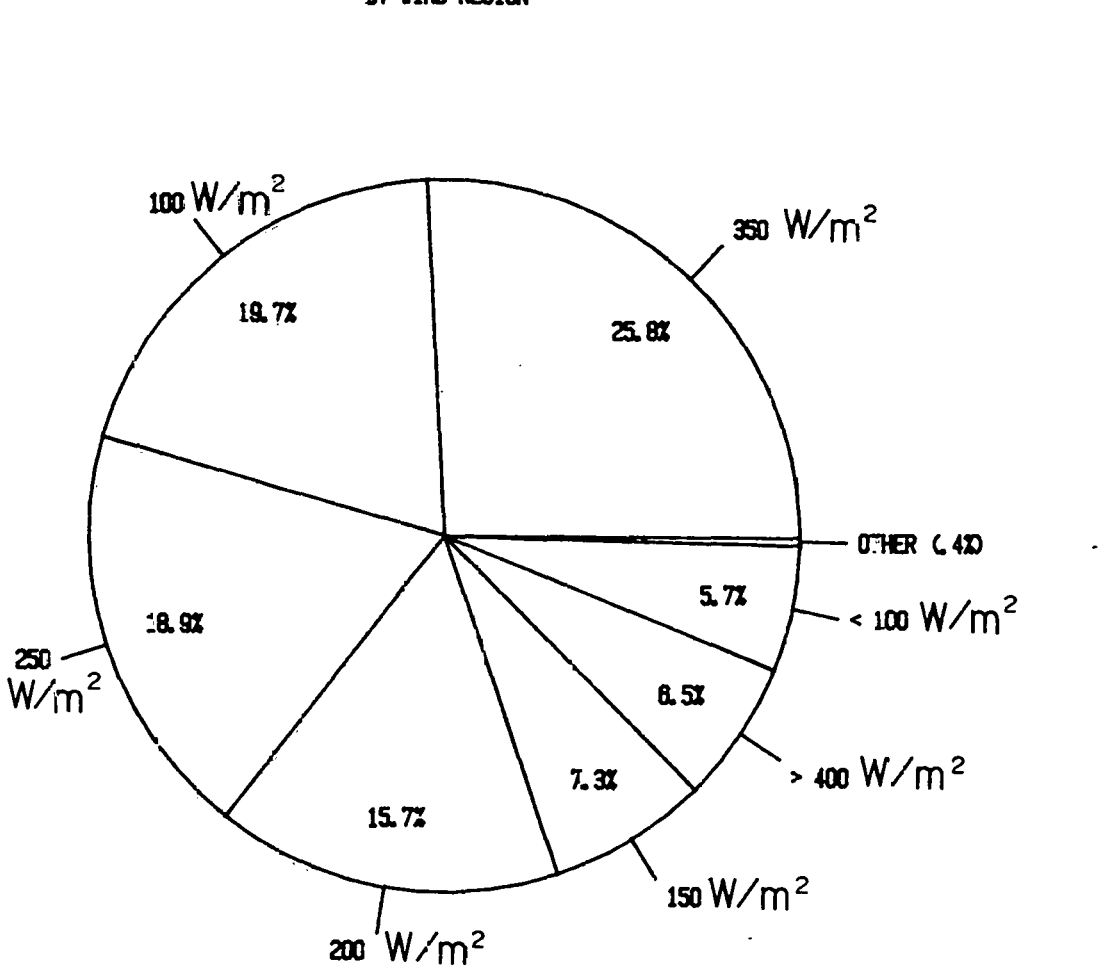


Figure 8. Distribution of U. S. on-farm irrigation pumping plants grouped by zones having similar potential wind power during the primary irrigation season.

350 W/m^2, the mid and southern Great Plains area) have a combined total of over 32 percent of the nations pumping units.

The size distribution of the units in the various wind power zones is shown on a percentage basis in Figure 9. All wind power zones with the exception of the 400 W/m^2 zone have over 50 percent of their units smaller than 37.3 Kw in size. The 400 W/m^2 wind power zone has a more uniform distribution of pump sizes.

The location of the various sizes of pumps by wind power zone is shown in Figure 10. Three wind power zones (200 W/m^2, 250 W/m^2 and 350 W/m^2) have approximately 60 percent of the pumps in all size categories. The lower wind power zones have a predominance of their units in the smaller sizes.

The 50, 75 and 90 percentile sizes for the various wind power zones is illustrated in Figure 11. In general, the larger irrigation pumping units are associated with the higher wind power zones. The 200 W/m^2 and <100W/m^2 wind power zones have larger 90 percentile pump sizes because of the large number of units in the 74.6-111.9 kW range. It is unlikely that wind turbine manufacturers planning sizes of wind machines to meet irrigation needs would need to change the sizes of wind turbines manufactured as the market for them spreads from the highest wind zones to the lower wind zones.

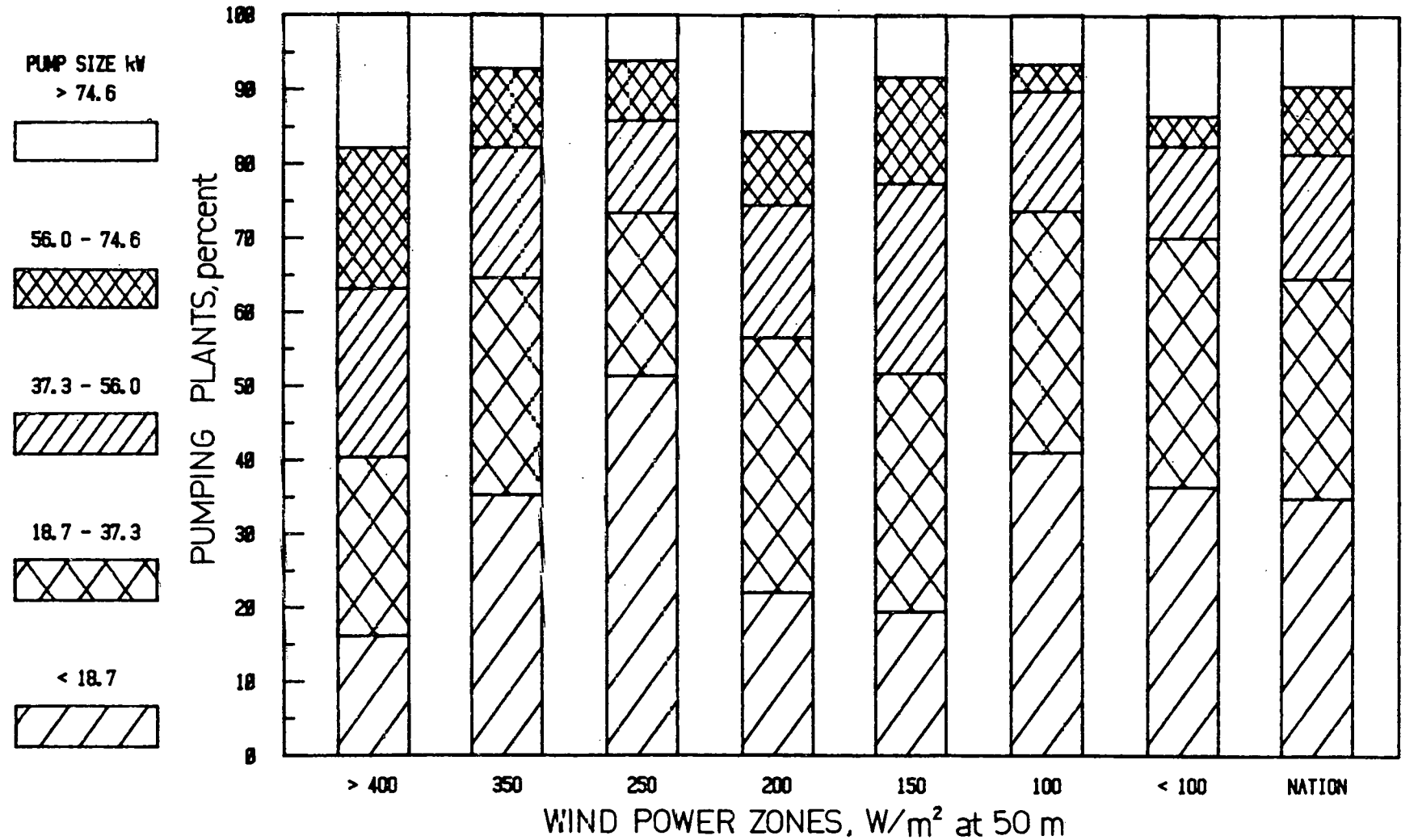


Figure 9. Size distribution of U. S. on-farm irrigation pumping plants for the various wind power zones.

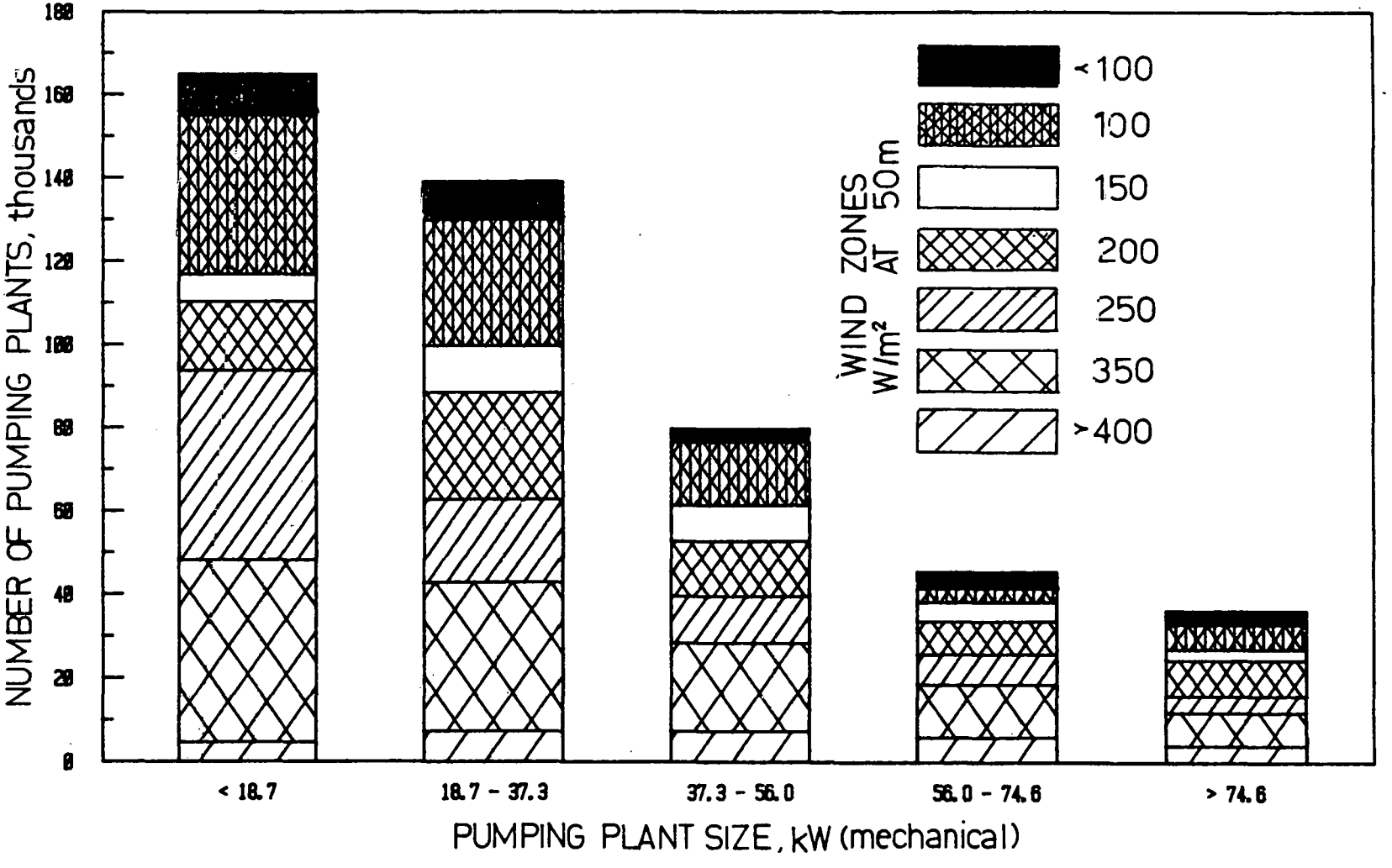


Figure 10. The location of the various sizes of U. S. on-farm irrigation pumping plants by wind power zones.

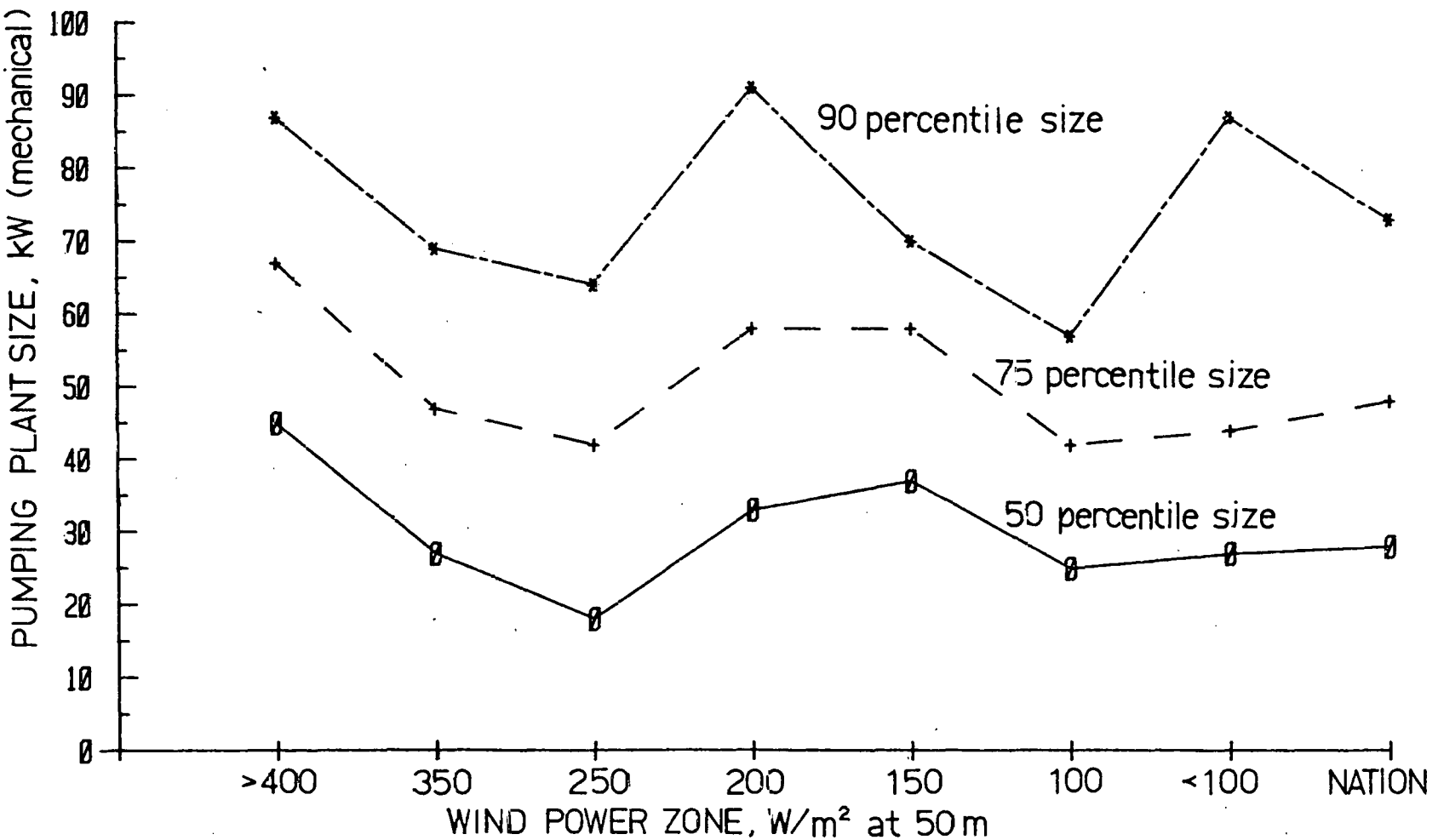


Figure 11. The 50, 75, and 90 percentile pump sizes for the various wind power zones.

3.4 DURATION OF SEASON OPERATION

The duration of seasonal operation for wind-powered irrigation pumping plants is given in Table 10. As expected, the length of seasonal operation is greatest in the southern portions of the U.S. and is highly variable depending upon the crop being irrigated (net irrigation water requirement), the peak water use rate, and the irrigation system capacity.

Table 10. Duration of Irrigation Season Operation. [1/]

Region	State	Irrigation Season	Peak Water Use Weekly Basis mm/day	Seasonal Net Irrigation, mm	Duration of Operation, hrs
Northeast	ALL	June - Aug.	5.0 - 6.5	100 - 200	380 - 1000
Appalachia	North Carolina	May - July	5.0 - 7.5	150 - 300	500 - 1200
	Virginia	May - Aug.	5.0 - 7.6	150 - 250	500 - 1000
	Rest	May - Aug.	5.0 - 7.6	150 - 250	500 - 1000
Southeast	Alabama	June - Aug.	5.5 - 7.6	100 - 200	350 - 650
	Florida	Jan. - Dec.	5.0 - 7.6	150 - 1500	700 - 4700
	Georgia	June - Aug.	5.0 - 7.6	100 - 200	300 - 800
	South Carolina	Apr. - Aug.	5.0 - 7.6	76 - 200	300 - 800
Delta	Arkansas	May - Sept.	5.0 - 7.6	150 - 850	600 - 2700
	Louisiana	May - Sept.	5.0 - 7.6	150 - 1000	500 - 3200
	Mississippi	May - Sept.	5.0 - 7.6	100 - 1050	300 - 3400
Corn Belt	ALL	June - Aug.	5.0 - 8.1	100 - 250	300 - 1000
Lake States	ALL	June - Aug.	5.0 - 7.0	200 - 400	700 - 1300
N. Plains	Kansas	Apr. - Oct.	5.0 - 8.1	350 - 750	800 - 2400
	Nebraska	Apr. - Oct.	6.4 - 8.1	400 - 750	600 - 2100
	North Dakota	May - Sept.	6.4 - 8.1	200 - 450	750 - 1400
	South Dakota	Apr. - Sept.	6.4 - 8.1	150 - 450	600 - 1500
S. Plains	Oklahoma	Apr. - Sept.	6.4 - 8.9	300 - 700	1000 - 2200
	Texas	Apr. - Sept.	5.1 - 8.9	200 - 900	600 - 3000

Table 10. Duration of Irrigation Season Operation (Continued). [1/]

Region	State	Irrigation Season	Peak Water Use Weekly Basis mm/day	Seasonal Net Irrigation, mm	Duration of Operation, hrs
Mountain	Arizona	Feb. - Oct.	7.6 - 11.4	600 - 1500	1800 - 4700
	Colorado	May - Sept.	5.0 - 8.1	300 - 800	800 - 2500
	Idaho	Apr. - Oct.	5.0 - 7.6	330 - 650	900 - 1900
	Montana	Apr. - Sept.	5.0 - 6.4	300 - 650	900 - 2000
	Nevada	Mar. - Sept.	5.0 - 8.1	300 - 750	1100 - 2500
	New Mexico	Apr. - Oct.	5.6 - 8.9	350 - 800	1200 - 2500
	Utah	Apr. - Sept.	5.6 - 7.6	300 - 800	1000 - 2500
	Wyoming	May - Aug.	5.0 - 7.6	300 - 760	1000 - 2400
Pacific	California	Feb. - Sept.	5.0 - 8.9	300 - 1200	1100 - 3800
	Oregon	Apr. - Oct.	5.0 - 8.9	150 - 900	300 - 2800
	Washington	Apr. - Oct.	5.0 - 8.0	400 - 1100	1400 - 3500
Other	ALL	Apr. - Sept.	6.3 - 9.1	500 - 1100	1000 - 3000

[1/] Estimated from state irrigation specialists which provided crop and seasonal irrigation water requirements; and other sources of data for peak water use rates.

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APPENDICES

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APPENDIX I

IRRIGATION DATA COLLECTED

I. Irrigated area and source of water

A. Area irrigated
1. Total irrigated area
2. Area irrigated with pumped water

B. Source of pumped water
1. Percent of the area irrigated with surface water supplies
2. Percent of the area irrigated with groundwater supplies
3. Number of wells
4. Number of pumping plants using surface water supplies

II. Well information

A. Distribution of well flow rate: ranges are given in Table 1

B. Distribution of pumping lift: ranges are given in Table 1

III. Irrigation method

A. Sprinkler - area irrigated by sprinklers
1. Center-pivot; area irrigated, percentage low pressure system and percentage irrigated with surface water supplies
2. Traveler or big gun; area irrigated and percentage irrigated with surface water supplies
3. Other sprinkler; area irrigated and percentage irrigated with surface water supplies

B. Surface - area irrigated by surface systems
1. Open ditch; area irrigated, percentages irrigated with groundwater and surface water, and percentages of reuse systems
2. Gated pipe; area irrigated, percentages irrigated with groundwater and surface water, and percentages of reuse systems

IV. Energy source; percent of power units using electric, diesel, natural gas, propane or gasoline

V. Crops irrigated; crop, area irrigated, seasonal irrigation water requirements

APPENDIX II

STATE IRRIGATION INFORMATION SOURCES

Alabama:	Larry Curtis, Extension Agricultural Engineer, Auburn University, Auburn
Arizona:	Allan Halderman, Extension Agricultural Engineer, University of Arizona, Tucson
Arkansas:	Richard Estes, University of Arkansas, Fayetteville
Colorado:	Robert Logenbaugh, Colorado State University, Ft. Collins
Florida:	Dalton S. Harrison, Extension Agricultural Engineer, University of Florida, Gainesville
Idaho:	John Busch, Agricultural Engineer, University of Idaho, Mosco
Illinois:	Paul Walker, Agricultural Engineer, University of Illinois, Urbana
Iowa:	Stewart W. Melvin, Extension Agricultural Engineer, Iowa State University, Ames
Kansas:	Delynn R. Hay, Extension Agricultural Engineer, Kansas State University, Manhattan
Michigan:	Ronald Van Til, Water Management Division, Michigan Department of Natural Resources, Lansing
Minnesota:	Roger E. Machmeier, Extension Agricultural Engineer, University of Minnesota, St. Paul
Mississippi:	John McVey, Agricultural Engineer, Mississippi State University, State College
Missouri:	Robert Shottman, Agricultural Engineer, University of Missouri, Columbia
Montana:	Philip Threlkeld, Department of Natural Resources and Conservation, Helena
New Mexico:	Robert Lansford, Department of Agricultural Economics, New Mexico State University, Las Cruces

North Carolina:	Ronald E. Sneed, Agricultural Engineer, North Carolina State University, Raleigh
North Dakota:	Darnell Lundstrom, Extension Agricultural Engineer, North Dakota State University, Fargo
Oklahoma:	Delbert Schwab, Agricultural Engineer, Oklahoma State University, Clemson
Oregon:	Marvin N. Shearer, Extension Irrigation Specialist, Oregon State University, Corvallis
South Carolina:	Charles V. Privette, Agricultural Engineer, Clemson University, Clemson
South Dakota:	LeRoy W. Cluever, Extension Agricultural Engineer, South Dakota State University, Brookings
Texas:	Leon New, Texas A & M University, Lubbock
Utah:	Kern Sputler, Agricultural and Irrigation Engineering Department, Utah State University, Logan
Virginia:	E. B. Hale, Extension Agricultural Engineer, Virginia Polytechnic Institute and State University, Blacksburg
Washington:	Gene Thompson, Extension Irrigation Engineer, Washington State University, Prosser
Wisconsin:	Leonard R. Massie, Extension Agricultural Engineer, University of Wisconsin, Madison
Wyoming:	Donald J. Brosz, Extension Irrigation Engineer, University of Wyoming, Laramie

APPENDIX III

DATA SOURCES AND ASSUMPTIONS

The determination of the number of pumping plants and their size required several assumptions in some of the states, particularly those states for which no direct information was obtained. If the irrigated area given in the Irrigation Survey (1979) was less than 50,000 acres, the irrigation expert in that state was not contacted, and other sources of data were used. The data sources and the assumptions made in estimating pumping plant number and size are listed in Table III-1.

Table III-1. Data Sources and Assumptions Used in Determining Pumping Plant Size.

Region	State	Data Source [1] Energy Source	Water Source	Irrigated Area	Irrigation Systems	Lift
Northeast [2]	Connecticut [3]	b	b	a	b	b
	Delaware [3] [4]	a	b	a	a	b
	Maine [3]	b	b	a	b	b
	Maryland [3]	b	b	a	a	b
	Massachusetts [3]	a	b	a	a	b
	New Hampshire [3]	b	b	a	b	b
	New Jersey [3]	b	b	a	b	b
	New York [3] [4]	a	b	a	a	b
	Pennsylvania [3]	b	b	a	b	b
	Rhode Island [3]	b	b	a	b	b
	Vermont [3]	b	b	a	b	b
Appalachia	Kentucky [3] [5]	a	b	a	b	b
	North Carolina [3] [4]	a	b	a	a	b
	Tennessee [3] [4] [5]	b	b	a	b	b
	Virginia	c	c	c	c	c
	West Virginia [3] [5]	a	b	a	a	b
Southeast	Alabama [6]	c	c	c	c	b

Table III-1. Data Sources and Assumptions Used in Determining Pumping Plant Size (Continued).

Region	State	Data Source [1] Energy Source	Water Source	Irrigated Area	Irrigation Systems	Lift
	Florida [9]	c	c	c	c	c
	Georgia [3] [4] [8]	a	a, b	a	a	b
	South Carolina	c	c	c	c	c
Delta	Arkansas	c	c	c	c	c
	Louisiana [3] [8]	b	b	a	a	b
	Mississippi	c	c	c	c	c
Corn Belt	Illinois	c	c	c	c	c
	Indiana [3] [9]	a	b	a	a	b
	Iowa	c	c	c	c	c
	Missouri	c	c	c	c	c
	Ohio [3] [4] [8]	b	b	a	b	b
Lake States	Michigan [9]	c	c	c	c	b
	Minnesota	c	c	c	c	c
	Wisconsin [9]	c	c	c	c	b
N. Plains	Kansas	c	c	c	c	c
	Nebraska [10]	c	c	c	c	b, c
	North Dakota	c	c	c	c	c

Table III-1. Data Sources and Assumptions Used in Determining Pumping Plant Size (Continued).

Region	State	Data Source 1/ Energy Source	Water Source	Irrigated Area	Irrigation Systems	Lift
	Scuth Dakota	c	c	c	c	c
S. Plains	Oklahoma	c	c	c	c	c
	Texas	c	c	c	c	c
Mountain	Arizona	c	c	c	c	c
	Colorado 11/	c	b	a, b	a	b
	Idaho 12/	c	c	c	c	c
	Montana 13/	c	b	c	c	b
	Nevada 3/ 9/	b	b	b	b	b
	New Mexico	c	c	c	c	c
	Utah 14/	c	c	c	c	c
	Wyoming	c	c	c	c	c
Pacific	California 15/	f	e	a, g	e	e
	Oregon 3/ 16/	a	d	c	c	d
	Washington	c	c	c	c	c
Other	Alaska 3/	a	b	a	a	b
	Hawaii 3/ 17/	b	b	b	b	b

FOOTNOTES FOR TABLE III-1

1/ Data Sources

a - Irrigation Survey (1979)
b - Sloggett (1979)
c - State expert
d - King et al. (1979)
e - Knutson et al. (1977)
f - Cervinka et al. (1974)
g - Stewart (1975)

2/ Used a regional average area per unit based on Irrigation Journal data for Delaware and New York. Used average flow rate data from Lake states and average lift for ground water and surface water from Sloggett.

3/ Estimated pumping plant number and/or size from various sources of data. State was not surveyed or survey was not returned.

4/ Number of wells from Irrigation Survey (1979).

5/ Flow rates, lifts and area irrigated per unit from Virginia were used.

6/ Used flow rates from South Carolina.

7/ Used 130 acres/unit for center-pivot, 90 acres/unit for gun, 50 acres/unit for other sprinkler, and 100 acres/unit for surface systems to estimate number of units.

8/ Used regional values for flow rates and on estimates of lift distribution.

9/ Used regional values for flow rates and an estimate of lift. Regional average area per unit was used.

10/ Pumping plant size of well units was estimated from distribution of electrical units from survey of power companies.

11/ Pumping plant size was estimated by Robert Logenbaugh from a survey of electrical power companies.

12/ Pumping Plant size distribution was estimated by John Busch.

13/ Flow rate and lift distribution from Wyoming was used. Used regional area per unit to determine number of units.

14/ Used regional area per unit to determine number of units.

FOOTNOTES FOR TABLE III-1 (continued)

15/ Used 120 acres/unit for sprinkler systems and 90 acres/unit for surface systems. Pumping plant size was estimated from Knutson et al. (1977).

16/ Well flow rates and lifts from Washington were used. 128 acres per well and 84 acres per surface unit were used to estimate number of units.

17/ Used estimated distribution of lift and flow rates. Assumed 50 acres per unit.

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