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ABSTRACT

Procedures for analyzing the potential of solar photovoltaic collectors to meet energy requirements in a metropolitan region are described and a modelling effort is applied to the San Fernando Valley region of Los Angeles. The procedure involves a series of steps designed to produce maps and tabulations revealing the amount of rooftop area available for establishing solar collectors and the proportion of energy requirement that could be potentially supplied by solar photovoltaics within each of the 533 mainline feeder service areas in the study area. For the sixty-five square-mile study area, the results showed that, with half the available flat and south-facing roofs used and assuming the availability of energy storage, 52.7 percent of the actual kWh energy requirements could have been met in 1978 using photovoltaic collectors. The report discusses hourly, daily, weekly, and monthly fluctuations in potential supply and actual loads and recommends avenues for further research. In the final section, some further potential applications of the modelling technique are suggested.

EXECUTIVE SUMMARY

The potential of solar photovoltaic collectors to displace energy requirements supplied by fossil fuels has to date been determined only for the individual building. Procedures for estimating the potential energy that solar power can supply for each energy service area in a metropolitan region have been recently developed at the Jet Propulsion Laboratory. The application of specialized technology for spatial data integration was required for the study because diverse sets of data, each with unique properties of spatial resolution and information generalization, needed to be merged and compared on a location-by-location basis if a valid analysis was to be achieved. To have directly measured the amount of flat and south-facing rooftop available for solar collectors was impractical for such a large area (the San Fernando Valley is 65 square miles in area). Furthermore, the data on energy demand was available by one set of administrative units (mainline feeder service area) while land use statistics, from which it would be possible to approximate suitable rooftop area, were readily available only in another administrative unit (census tracts). Using image processing technology and statistically valid sampling strategies, a series of steps was performed to produce maps, tabulations, and graphs revealing rooftop area figures and the proportion of current energy consumed that could be collector-supplied for each power service area.

The process was originally demonstrated for the western portion of the San Fernando Valley in Los Angeles.[1] That study gave promising results, a net surplus in kilowatt hour production from solar panels, when compared with actual consumption data gathered by the Los Angeles City Department of Water and Power in 1976 for all utility users except industrial sites. More precise information, founded on more complete power consumption data, and a more comprehensive survey of rooftop availability needed to be generated before it became practical to evaluate the technical potential.

The results of this study are generally encouraging with regards to the potential of distributed photovoltaic systems in the urban area studied. For urban areas like Los Angeles, where electrical load is rising with the use of air-conditioners and more electrified households, distributed photovoltaics could probably meet projected increases in energy requirements, thereby reducing the amount of electrical energy required from conventional energy sources. In addition, the results show that, should photovoltaic collectors presently be installed under the modelling assumptions (i.e., half of the flat and south-facing rooftop areas where collector sites and energy storage existed), during 1978, 52.7 percent of the energy requirements could have been met. However, because of modelled assumptions noted in the body of the report, more definitive utilities systems studies need to be done to assure the viability of the concept. Again, there is a need for more precise data, both with regard to actual solar insolation and electricity use. The present study, with its estimate of utilizing only half the area of usable rooftops, indicates that solar photovoltaics could make a major contribution to aggregate energy requirements. It also indicates that electricity storage at the mainline feeder and substation levels may be required, or that major transports of electricity out

of a surplus substation region to a deficit substation region for the midday hours will be required.

Recommendations. As with most exploratory studies, more questions were raised than answered. The use of a geographic information system to aggregate the spatially distributed information has brought to mind the potential for incorporating other kinds of data to refine the modelling effort. These include the following:

a) Model the use of storage capabilities to level out the surplus and deficit associated with the intermittent photovoltaic energy source.

b) Model the interaction and trade-offs associated with alternative solar energy systems (e.g., solar thermal).

c) Model a variety of socioeconomic impacts that may affect the potential use of solar photovoltaic systems installation and energy requirements.

d) Use the system to model alternative cost allocations and system planning strategies.

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INTRODUCTION

The potential of solar photovoltaic collectors to displace energy requirements supplied by fossil fuels has to date been determined only for the individual building. Procedures for estimating the potential energy that solar power can supply for each energy service area in a metropolitan region have been recently developed at the Jet Propulsion Laboratory. The application of specialized technology for spatial data integration was required for the study because diverse sets of data, each with unique properties of spatial resolution and information generalization, needed to be merged and compared on a location-by-location basis if a valid analysis was to be achieved. To have directly measured the amount of flat and south-facing rooftop available for solar collectors was impractical for such a large area (the San Fernando Valley is 65 square miles in area). Furthermore, the data on energy demand was available by one set of administrative units (mainline feeder service area), while land use statistics, from which it would be possible to approximate suitable rooftop area, were readily available only in another administrative unit (census tracts). It was necessary to go to the original mapped information and initial solar insolation and energy consumption tabulations to spatially merge and suitably prepare these diverse data sets prior to making comparisons of photovoltaic potential. Using image processing technology and statistically valid sampling strategies, a series of steps were performed to produce maps, tabulations, and graphs revealing rooftop area figures and the proportion of current energy consumed that could be collector-supplied for each power service area.

The process was originally demonstrated for the western portion of the San Fernando Valley in Los Angeles.[1] That study gave promising results, a net surplus in kilowatt hour production from solar panels when compared with actual consumption data gathered by the Los Angeles City Department of Water and Power in 1976 for all utility users except industrial sites. More precise information, founded on more complete power consumption data, and a more comprehensive survey of rooftop availability needed to be generated before it became practical to evaluate the technical potential.

The present study differed from the original in several aspects. Firstly, the industrial feeder stations, thought to contribute up to one third the energy demand in some substation regions, were included in the total consumption figures for each substation and feeder line service area. Secondly, energy consumption statistics at each feeder line service area for each month, and bi-hourly consumption statistics for selected months for each distribution substation service area, were gathered to obtain a knowledge of the system's load profile. Finally, more comprehensive primary data for the solar potential estimations were incorporated. A more detailed land use data base was used, a more comprehensive sampling scheme was applied to calculate potentially available rooftop area, and a revised estimate of solar photovoltaic potential based on recent experiments was used.[2]

DATA CHARACTERISTICS

The data used for the study were all collected at the highest level of detail and finest temporal and spatial resolution known to be available for the study area. The characteristics of each data set used are discussed below, thus enabling the reader to gauge the degree of precision associated with the analysis.

Power Districting Procedure. The Los Angeles Department of Water and Power (DWP) has precise maps of each of 35 distribution substation service areas, but has been concerned primarily with the location of individual feeder lines rather than the exact area each line serves. Therefore, maps such as that displayed in Figure 1, located the boundaries for each of the 512 main line feeder areas by referring to the DWP feeder line map books and transferring an approximation of the midpoint line between two feeder lines manually to a detailed street map. An accurate, highly detailed delineation would require the use of DWP installation plot maps which specify precisely which building is served by which main line feeder and was beyond the scope of this effort. The main line feeder area boundaries were then digitized and stored on computer compatible tape. In addition, each of the 484 industrial service line terminals was allocated to a mainline feeder area through matching its address with the street map reference base.

Calculating Electrical Load. The DWP, as with all utility companies, has been primarily concerned with meeting peak power demand for a mainline feeder, determined by monitoring amperes, as opposed to aggregate energy produced to meet requirements over a period of time. Thus, for the purposes of this study, it was necessary to compute from peak amperage demand readings the monthly and bi-hourly aggregate demand expressed in kilowatt hours (kWh). The computation of monthly kWh for each mainline feeder service area was accomplished by averaging weekly peak amperage figures for each feeder and using that as an apportioning coefficient to the power substation total kWh demand (data which existed). Table I illustrates the procedure for calculating monthly kWh statistics for each mainline feeder service area during the summer months using the September load profiles. A separate coefficient was calculated for the winter months using the December load profile. May through October were considered to be typically summer months, while November through April were considered winter months. The apportioning coefficients were then applied to the kWh statistics gathered each month for each of the thirty-five substations within the San Fernando Valley.

To make the aggregate monthly consumption figures for aggregate load within a prescribed area complete, a separate file of Industrial Substation monthly energy consumption statistics was merged with the mainline feeder statistics. This was accomplished by determining, by visual inspection, in which of the 533 feeder areas each of the 484 industrial substations resided, and adding those corresponding files.

The calculation of bi-hourly kWh consumptions for each of the 35 distribution substations during the months of September and December was accomplished by applying known constants to the bi-hourly peak amperage figures. Bi-hourly peak amperage readings for power substations are the most precise temporal divisions systematically collected by the DWP. While they may fail to give utility systems engineers the level of specificity required for a comprehensive utility systems engineering trade-off study for solar photovoltaics, the data

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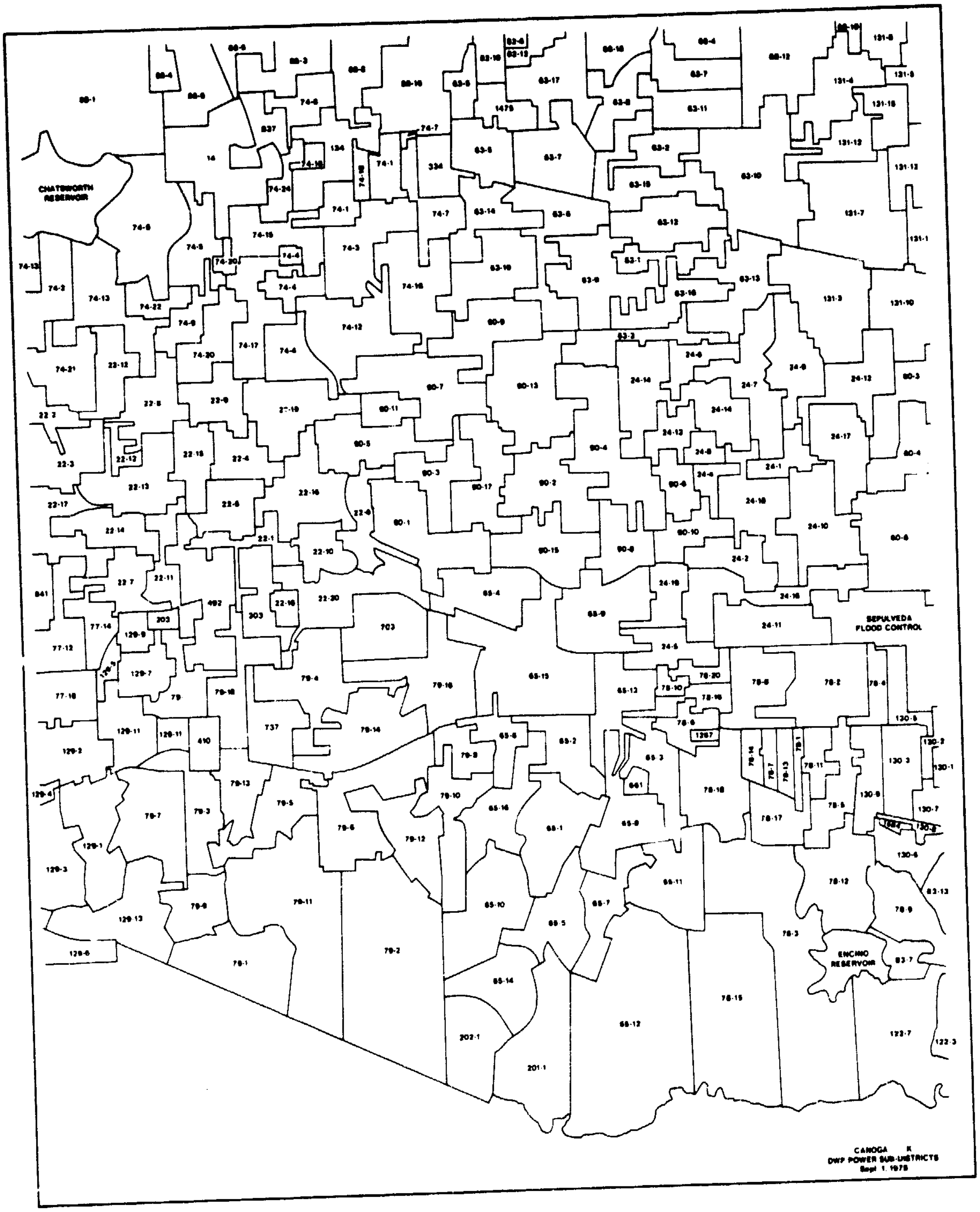

Figure 1. Power Substation and Main Line Feeder Service Areas in the Canoga Park Quadrangle of the San Fernando Valley, Los Angeles.

Table I. Calculation of Aggregate Monthly Energy Demand in kWh for Each Mainline Feeder Service Area in Distribution Substation Region 65 of the San Fernando Valley During September 1978.

Feeder I.D.	Weekly Amp Peaks in September 1st	2nd	3rd	4th	Average	Ave/Total+	kWh/Feeder
65-1	270	200	310	310	272.5	0.074	696,333
65-2	240	160	220	270	225.5	.061	574,004
65-3	250	160	310	310	257.5	.070	658,693
65-4	270	150	273	343	259.0	.070	658,693
65-5	240	110	220	280	212.5	.058	545,774
65-6	210	190	230	313	235.8	.064	602,234
65-7	180	80	190	210	165.0	.045	423,446
65-8	160	140	170	170	160.0	.043	404,626
65-9	240	180	320	320	265.0	.072	677,513
65-10	280	100	250	330	240.0	.065	611,644
65-11	350	170	320	370	302.5	.082	771,612
65-12	160	100	160	200	155.0	.042	395,216
65-13	180	160	200	247	196.8	.053	498,725
65-14	220	100	210	250	195.0	.053	498,725
65-15	347	220	293	407	316.8	.086	809,251
65-16	230	157	220	280	221.8	.062	583,414
					3680.5		9,409,000* (kWh)

Note: The Industrial Substation kWh figures are added _after_ these calculations.

* Obtained from monthly Power Substation Files.

\+ All summer category months (May - October) used these September apportioning coefficients.

may help bound the problem more precisely. The formulation designed to obtain aggregate kilowatt hours for each two-hour period is shown below:

$$(1) \quad kVAh = \frac{(\sqrt{3})\ (40)\ (V)\ (A)\ (h)}{1000}$$

where: kVAh is kilovolt amp hours.
V = 125 volts.
h = number of hours between reading.
A = Distribution substation amperage reading (variable).

The square root of 3 and division of 1000 are used to achieve the conversion to amperage over time as opposed to peak loading, while the number 40 is used to reflect the fact that the primary distribution from distribution substations is via 5 kilovolt lines (i.e., (40) (V) = 40 x 125 = 5000). By substituting all constants we find that:

$$(2) \quad kVAh = \frac{(\sqrt{3})\ (40)\ (125)\ (2)}{1000}$$

$$\simeq 17.32(A)$$

After factoring in an approximation for the power use factor, the constant multiplier to convert amperage to kilowatt hours over a two-hour period at a distribution substation is:

$$(3) \quad kWh = 17.32(A)\ 0.9$$

$$= 15.59(A)$$

<u>Land Use Maps</u>. The land use data base used for the subsequent calculation of rooftop area available to solar collectors was taken from the California Department of Water Resources land use inventory of south Los Angeles County.[2] The inventory was performed by photo interpretation of low altitude photography with high altitude photography updates to 1973. As illustrated in Figure 2, the interpreted land use map was transferred to the U.S. Geological Survey 1:24,000 map series. Land use for the entire San Fernando Valley is displayed in Figure 3. It is important to note that the land use classes used by the Department of Water Resources in their mapping were designed to help assess potential water demand, with the result that some classes appear superfluous (e.g., cropland types) while others could have been more specific. The full tabulation of land use acreages by type for each mainline feeder service area provided a level of detail sufficiently accurate and complete to serve the requirements for estimating available rooftop area in a region the size of the San Fernando Valley (i.e., 65 square miles).

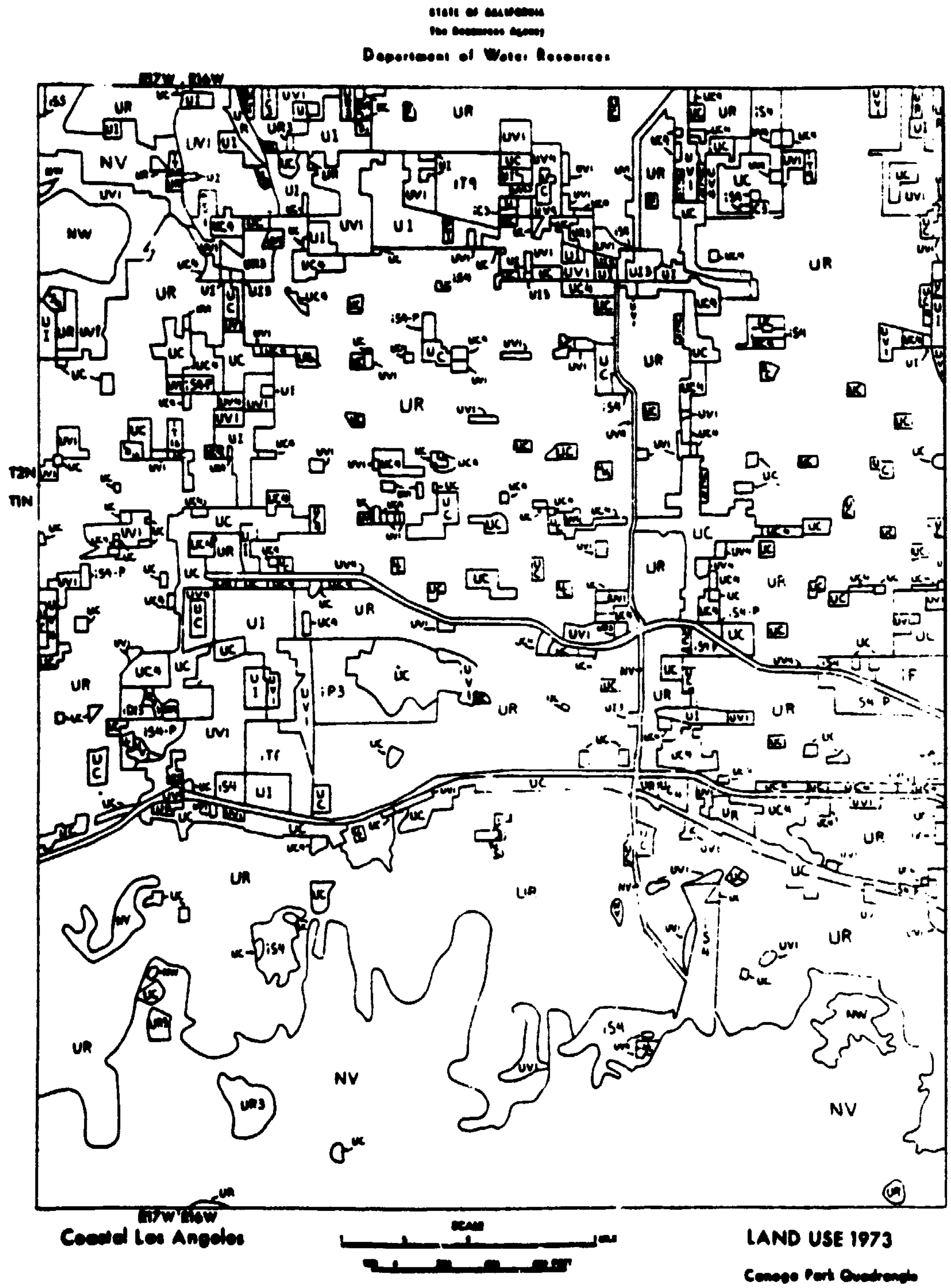

Figure 2. Land Use Map Compiled in 1973 by the California Department of Water Resources for the Canoga Park Quadrangle of the San Fernando Valley, Los Angeles.

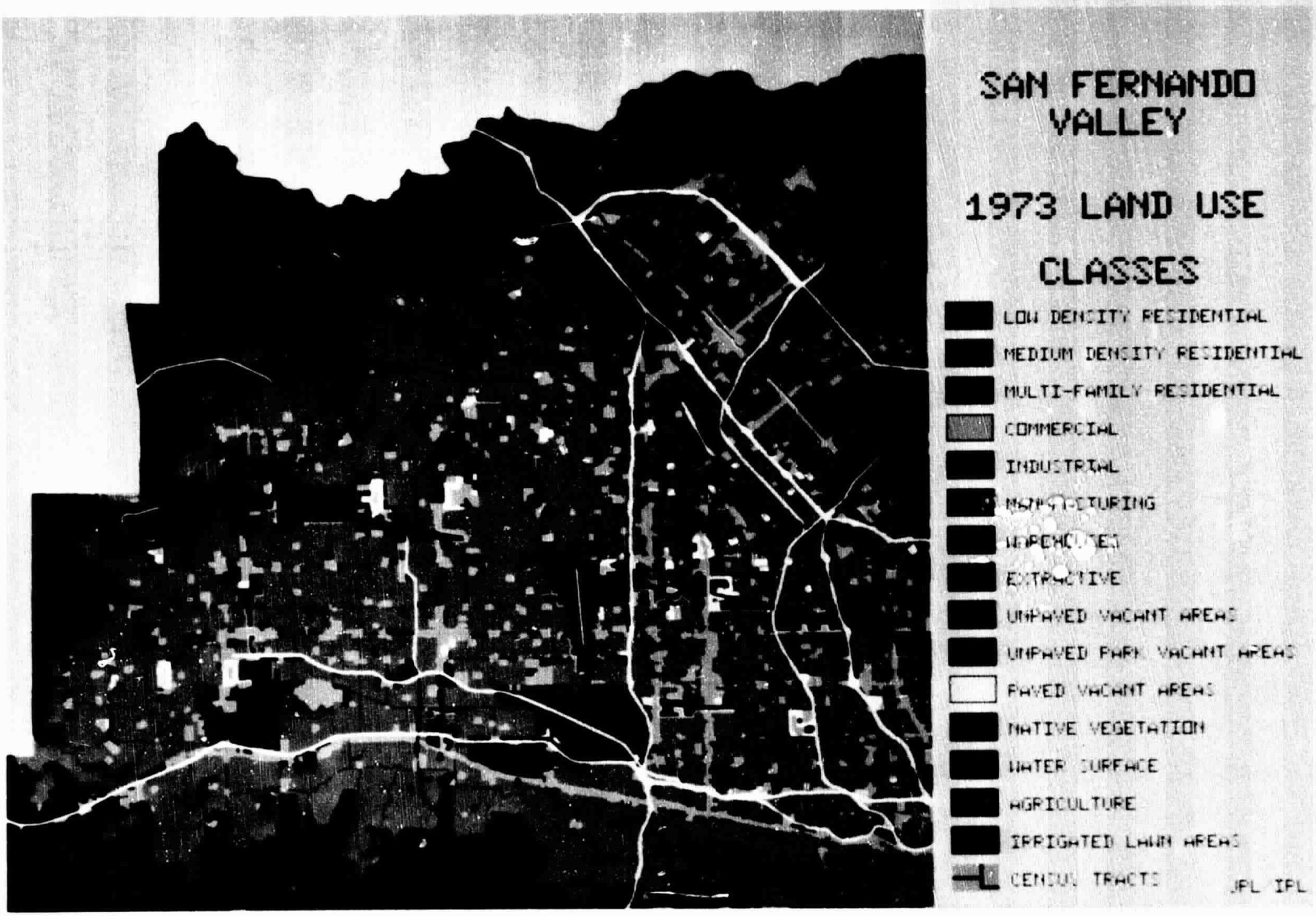

Figure 3. Composite Land Use Maps of the San Fernando Valley, Los Angeles, Compiled from California Department of Water Resources Surveys in 1973 and Processed to be Computer Compatible.

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Specifically, the minimum mapping unit of ten acres used for delineation of any discrete land use type, and the error associated with positioning of land use boundaries meets the USGS map accuracy standards for maps of the scale 1:24,000.

DATA BASE PREPARATION

An overview of the procedures involved in preparing the data bases of solar photovoltaic potential and actual electric energy consumption in the San Fernando Valley test case is shown in Figure 4. The process involved the use of an image based spatial data integration technology developed at the Jet Propulsion Laboratory called the Image Based Information System (IBIS). IBIS is a subset of the VICAR (Video Image Communication and Retrieval) image processing system which can permit the efficient integration of a variety of spatially distributed and sampled data sets, such as those required for the application here. The salient characteristics of the IBIS data integration technology are discussed below, as are the procedures used to estimate available rooftop area, solar photovoltaic potential statistics, and comparison statistics for energy demand.

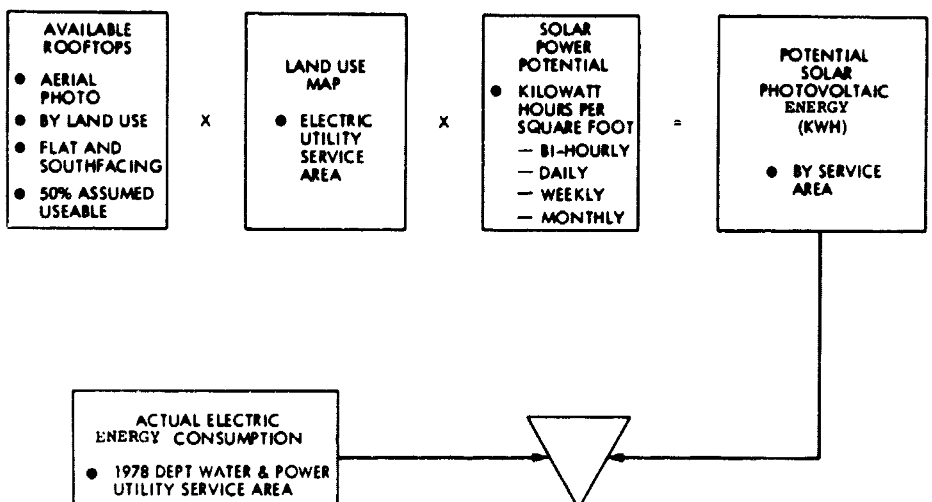

Figure 4. Schematic Overview of Analysis Procedure to Determine Urban Solar Photovoltaics Potential.

Data Integration Technology. In 1975, Billingsley and Bryant[4] proposed that image processing technology could be utilized for the registration and processing of multiple data planes over a geographic area. A motive was the utilization of Landsat digital imagery to provide information on land use or ground cover in the general setting of geographic analysis. In 1976 this proposal was realized in a more general fashion by creating a comprehensive geographic information system that performs operations on image, tabular, and graphical data sets called IBIS.[5]

IBIS is a computer-based approach to the analysis of geographical situations. By grouping selected IBIS programs into processing operations, a variety of spatial phenomena can be investigated. The basic concepts of data management and data processing within IBIS are covered in this section. IBIS is considered to be a raster base information system. Most data entered into IBIS will be in raster (image based) format. However, the system is configured in such a manner that other data types such as graphical and tabular data may be used in analysis as well. Logical and mathematical interfaces have been provided to link all data files in an IBIS data base superstructure (Figure 5). By utilizing these interfaces, information may be derived from simple associations to, or comparisons between two or more, data files stored in an IBIS data base. More complex procedures including polygon overlay and cross-tabulation can also be investigated through IBIS technology.

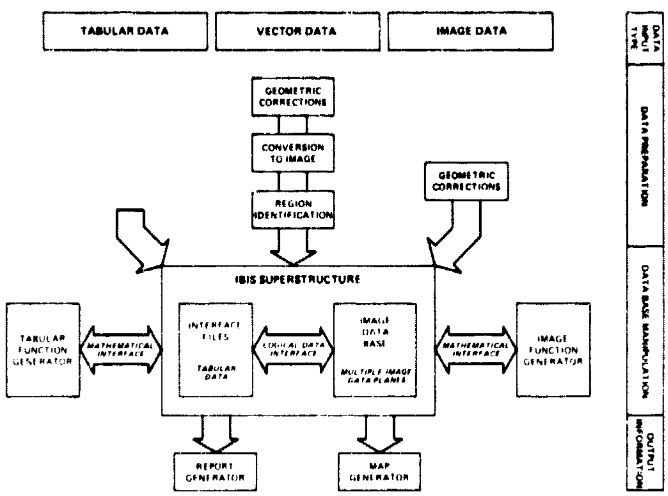

Figure 5. A Configuration Diagram of the Image Based Information System (IBIS)

The image formatted data plane is the primary data type utilized in IBIS processing. IBIS data planes may be obtained directly in image form, as in Landsat imagery, or they may be derived from the data compiled by sources such as the U.S. Geological Survey, the U.S. Bureau of the Census, and the Defense Mapping Agency. Regardless of data type and origin, all data planes are incorporated into a data set which is referred to as the IBIS data base (Figure 6). When investigating a specific problem, a data plane may be included in, excluded from, or modified before an IBIS processing step. New data planes may be constructed with the system and may be used in subsequent processing steps.

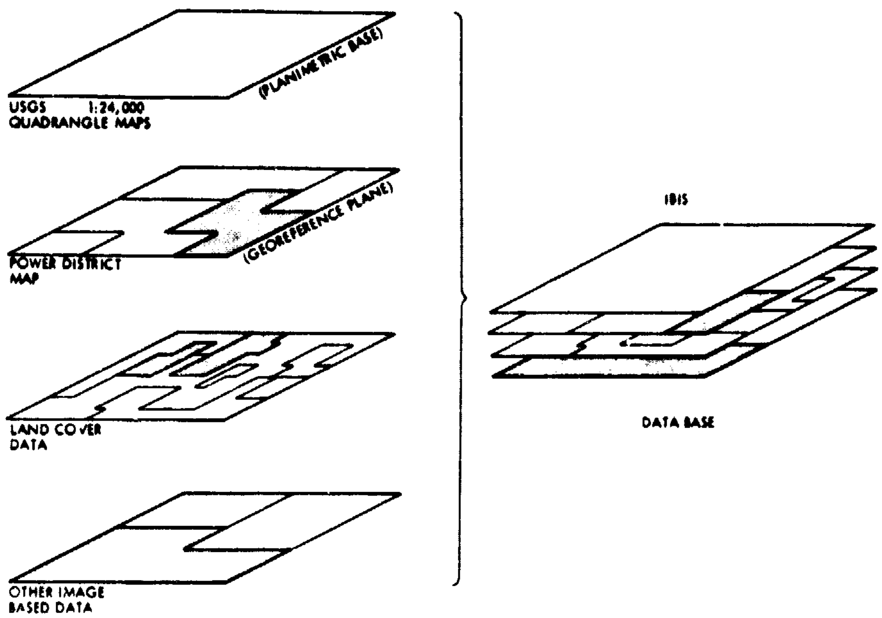

Figure 6. Conceptualized Formation of an IBIS Data Base.

One of the more important graphical data files entered onto the IBIS data base is the geo-reference plane. The geo-reference plane is a polygon file which is used in data aggregation and map generation procedures. In this case, the geo-reference plane has been constructed from the mainline feeder service area derived from DWP Maps (Figure 1). Once the geo-reference plane is transformed into image space, each polygon or region must be identified. The region identification process involves the assignment of a unique value (or image gray tone) to each individual region. After region identification, the geo-reference plane may be used in several higher order IBIS procedures. For example, polygon overlay of the geo-reference plane with some other image data plane can be initiated to derive tabulations. Or, the gray values of each polygon in the geo-reference base may be modified to produce a map depicting the results of a modelling application with data stored in an interface file. Several geo-reference planes may be included in an IBIS data base. For example, a data base may contain a census tract geo-reference plane and a congressional district geo-reference plane. The maximum number of regions that can be included in one geo-reference plane is virtually unlimited. Currently, up to 20,000 regions can be identified by gray value for an individual geo-reference plane.

All tabular files (interface files) are linked to at least one of the geo-reference planes included in the IBIS data base. The specific link is obtained by storing the numerical value (gray tone) representing each region of the geo-reference plane with tabular data describing attributes of that region (Figure 7). Attribute data may be statistical in origin, an identification code, or may be the result of an image plane comparison routine such as polygon overlay or cross-tabulation. Data stored in either the data base or an interface file can be modified or manipulated with IBIS software. New data planes and interface files are easily generated. Four basic data manipulation procedures are currently available: 1) Data manipulation between image planes: new image data planes are generated as a function of two or more image data planes. Chiefly the procedures implemented to derive such data planes are VICAR routines, although some IBIS routines are also used. Simple transformations such as image addition, subtraction, multiplication, and division are easily obtained. Complex functions are handled nearly as easily, and precise mathematical formulas may be specified. Image enhancement routines are available, as are several data classification and stratification routines. 2) Data manipulation within the interface file: most functions available in the image domain are also available for analysis of tabular data. Resultant from such operations, new tabular data entries are generated. Complex mathematical functions may be used to derive higher order properties of data stored in an interface file. 3) Data manipulation of image data into tabular data: by implementing certain IBIS routines, data originally stored in image format may be summarized and copied into a tabular file. The majority of these routines are aggregation functions, an example of which is histogramming. IBIS procedures for polygon overlay and cross-tabulation are within this realm of data transfer programs. 4) Data manipulation of tabular data into image data: the representation of tabular data in image form is primarily used as an output aid. By the implementation of a map generating routine, any geo-reference base can be modified as a function of an interface file. Modelling of data is performed similarly. Data planes produced in this manner can be entered into the IBIS data base for subsequent operations.

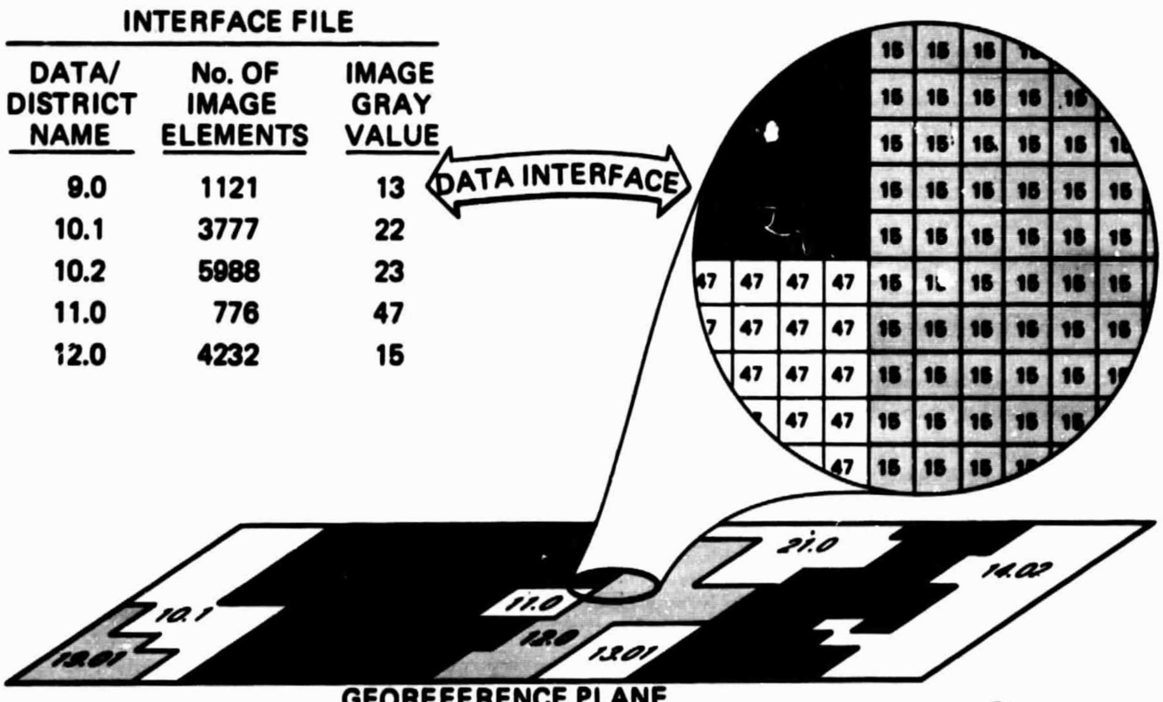

Figure 7. The IBIS Interface File Data Interface.

The various modes of data entry, data manipulation, and data output provide the researcher with complete flexibility to structure a unique data base specifically designed for a particular problem or investigation. IBIS is merely a framework for analysis of spatial data. The actual information system is constructed with the selection of specific image and tabular data.

Rooftop Area Estimation Procedure. An overview of the procedure used to estimate the area of rooftops available for the installation of solar collectors within each mainline feeder service area is given in the block diagram in Figure 8. One series of steps involves the derivation of land use acreages by mainline feeder service area and has been discussed in the section on data characteristics. The procedures used to estimate the amount of rooftop area available for locating solar photovoltaic collector arrays involved the use of a multistage sampling approach similar to that used in forestry applications.[6] Statistics on the proportionate area of flat and south-facing rooftops available within each type of land use were obtained from a four-step procedure. Firstly, a stratified random sampling procedure was used to locate sixty-two sample sites. The position of each sample site relative to the USGS 1:24,000 map series quadrangles is shown in Figure 9, while Figure 10 gives an example of one of the sample sites with an overlay of the Department of Water Resources land use classification applied. Figure 11 displays the same sample site region as that in Figure 10 but with the flat and south-facing rooftops delineated by a photo interpreter. By using a dot planimeter, the area of available rooftops was calculated within land use types which occurred, as was the area of each land use type occurring in each sample site. The values were then aggregated by land use for all sixty-two sample sites and an average value of available roof area was computed. The results are given in bar graph form in Figure 12. A subsecting of the total population of sample sites by USGS quadrangle (see Figure 9) showed no significant deviations from the overall statistics shown in Figure 12. The derived coefficients for percentage available roof area were then multiplied by the total area of each land use occurring in each DWP mainline feeder service area and distribution substation service area. A representative map for the San Fernando Valley region shown in Figure 13 provides a general understanding of the variability that exists throughout the study region.

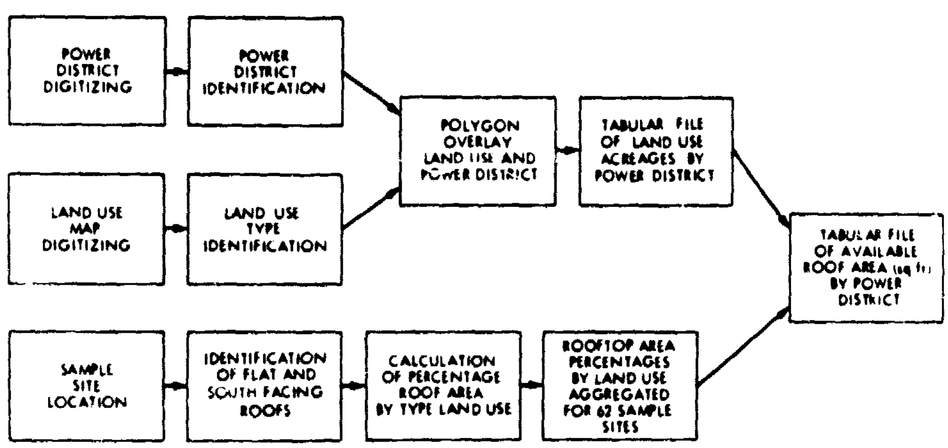

Figure 8. Rooftop Area Tabulation Procedure.

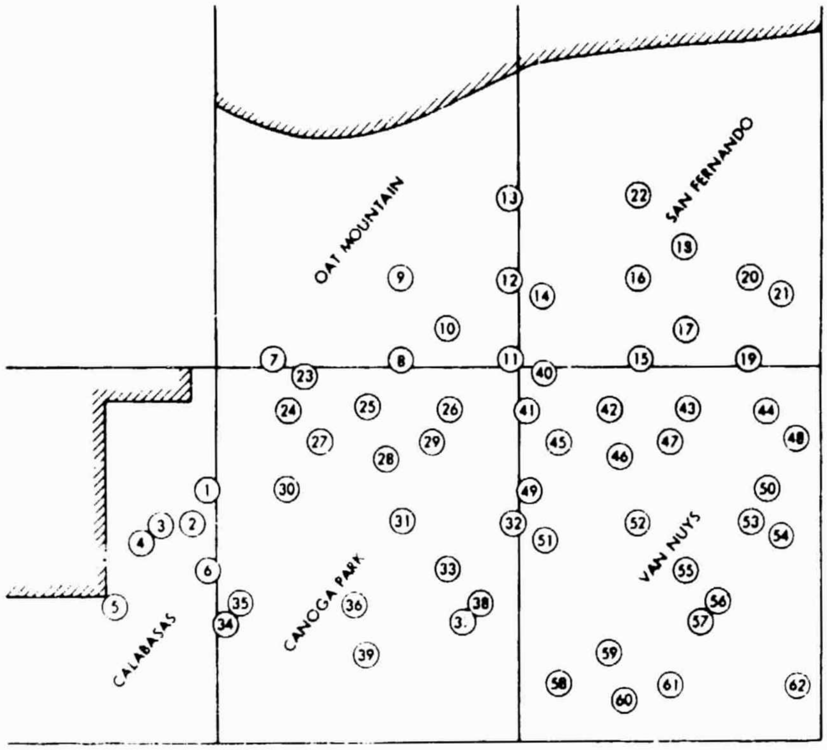

Figure 9. Location of 62 Ground Sample Sites Used for Rooftop Area Estimation in the San Fernando Valley, Los Angeles.

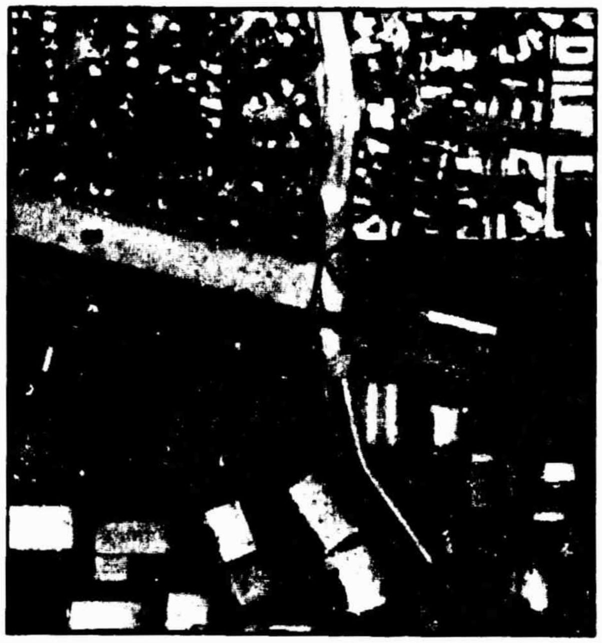

Figure 10. Example of Sample Site with Land Use Boundaries Overlay.

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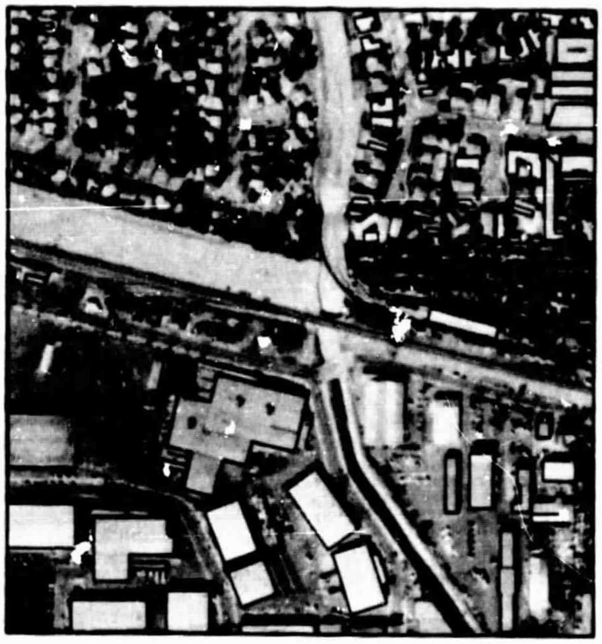


Figure 11. Example of Sample Site with Roof Areas Available to Solar Collectors Delineated.

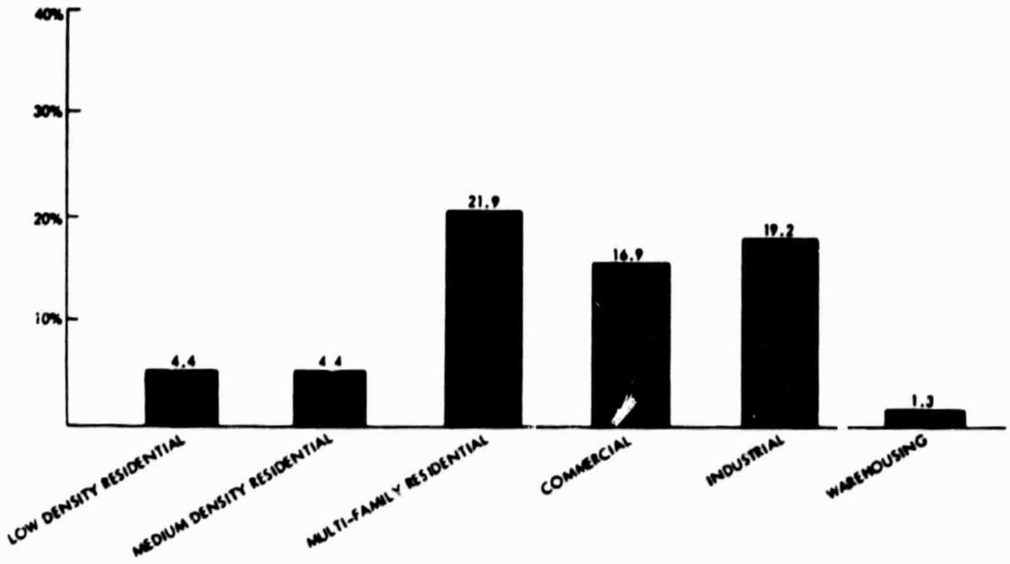


Figure 12. Percentage of Total Area Within Each Land Use Class Available for Rooftop Solar Collectors in the San Fernando Valley, Los Angeles.

AVAILABLE ROOFTOP

(PERCENT OF MAIN LINE FEEDER)

- LESS THAN 1%
- 1 – 1.9%
- 2 – 3.9 %
- 4 – 7.9%
- 8 + %

Figure 13. Rooftop Area Available to Solar Collectors Within Each Main Line Feeder Service Area of the San Fernando Valley, Los Angeles.

Modelling Solar Photovoltaic Potential. The modelling of solar photovoltaic potential within a power district involved three steps. Incoming solar radiation was estimated, then the efficiency of the collectors was factored, and finally the aggregate productivity on the available roof in a power district was calculated. The incoming radiation estimates were taken from the field test and modelling data derived by the JPL Solar Photovoltaics Project.[2] The information provided was in kWh per square meter of collector surface area for a median day in each month of the year. Cloudiness and haze interference components were considered by their being included as the average daily condition during several years weather station measurements for the greater Los Angeles region. The total daily radiation figures were multiplied by 0.0929 to convert the collector area measurement to square feet and then by 0.1 to accommodate the assumption that the solar panels had 10 percent efficient cells in transforming solar radiation into photovoltaic electricity. Table II gives the modelled potential incoming solar radiation as it would strike a collector tilted 35 degrees and the resultant kWh output for a nominal day during each month. Hourly incoming radiation estimates were aggregated to bi-hourly time segments for the months of September and December and presented in the graphs of Figures 18-21 in the Data Analysis section of this report.

TABLE II. Solar Incoming Radiation and Photovoltaic Cell Potential for Nominal Days in Each Month in Los Angeles.

Month	Nominal Day Incoming Radiation (kWh/m^2)	Photovoltaic Potential (kWh/ft^2)
Jan	4.57	0.042455[illegible]
Feb	5.49	0.0510021
Mar	6.34	0.0588986
Apr	6.16	0.0572264
May	6.08	0.0564832
Jun	6.22	0.0577838
Jul	6.65	0.0617785
Aug	6.63	0.0615927
Sept	6.50	0.060385
Oct	5.42	0.0503518
Nov	4.95	0.0459855
Dec	4.52	0.0419908

The calculation of aggregate productivity of solar cells on the available rooftops in a power district was then computed on a monthly, weekly, daily and bi-hourly basis (as needed). The computation was performed by combining the tabular files of available roof area by power districts (see Figure 8) with the computed solar cell productivity values for each time period under analysis. One further basic assumption was made that only half of the available rooftops would in fact be used for solar panel installation, as many of the rooftops probably had ventilators and other obstructions which would reduce the usable area of rooftops. The reduction of the rooftop area figure by fifty percent also assured that all estimates of a photovoltaic power source were conservative; that is, the resultant values more closely approximate an engineered potential rather than theoretical potential. A representative sample of the data for the entire San Fernando Valley is presented in Figure 14. A comparison with Figure 14, rooftop area, shows its close correlation with solar potential except where most of the region is characterized by low density residential land use.

Integrating Electrical Load Statistics. The integration of electrical load and potential photovoltaic supply statistics was performed in a series of IBIS interface file manipulations (refer to Figure 4). The map image of all mainline feeder service areas (Figure 15) contains a pointer to each tabular listing for energy requirement and for potential supply during each time frame under analysis. Energy demand values for a sample month are displayed in choropleth map form in Figure 16, and percentage potentially supplyable statistics are given in Figure 17 for the month of September 1978. While the maps give a sense of the regional variability in these statistics, a clearer view is presented in Figures 18-21 in the next section, Data Analysis, where a graphing of the data provides the reader with an appreciation of the temporal fluctuations that occur.

DATA ANALYSIS

To a large extent, the graphs that accompany this section speak for themselves. The graphs present in summary and representative form display the analysis results. Although they do not present the entire case study in its complexity they will give the reader a reference base that will help explain the analysis presented and provide background material on the recommendations made in the final section.

Monthly Loads vs. Potential Supply. The monthly statistics are presented in Figures 18 and 19 as graphs of representative districts. In Figure 18 the percentage of electricity that can offset present sources and be supplied by photovoltaic collectors is given for six representative distribution substations (D.S.). While the curves show differences on the order of fifteen percent between substation service areas for any given month in 1978, the general trend is for relatively high potential supply in the spring and fall, and lower potential in winter and summer. The relatively low potential in winter is a direct result of the low sun angle and fewer daylight hours, but the lower potential in the summer reflects the high energy use for air-conditioning. The differences among distribution substations for the percent potentially supplied by solar photovoltaics in any given month is related to the kind of land use in a region. Those distribution substations that have a relatively large percentage of industrial and commercial land use acreage, DS 21, DS 67, DS 100, and DS 101, exhibit fluctuations in demand corresponding to seasonality in manufacturing and sales. The predominantly residential distribution substations, DS 77 and 82, present curves which more closely approximate the seasonal pattern of potential supply from photovoltaics. Figure 19, which gives the absolute monthly kWh for electric energy use and potential photovoltaic supply by mainline feeder service area illustrates the relationship between land use

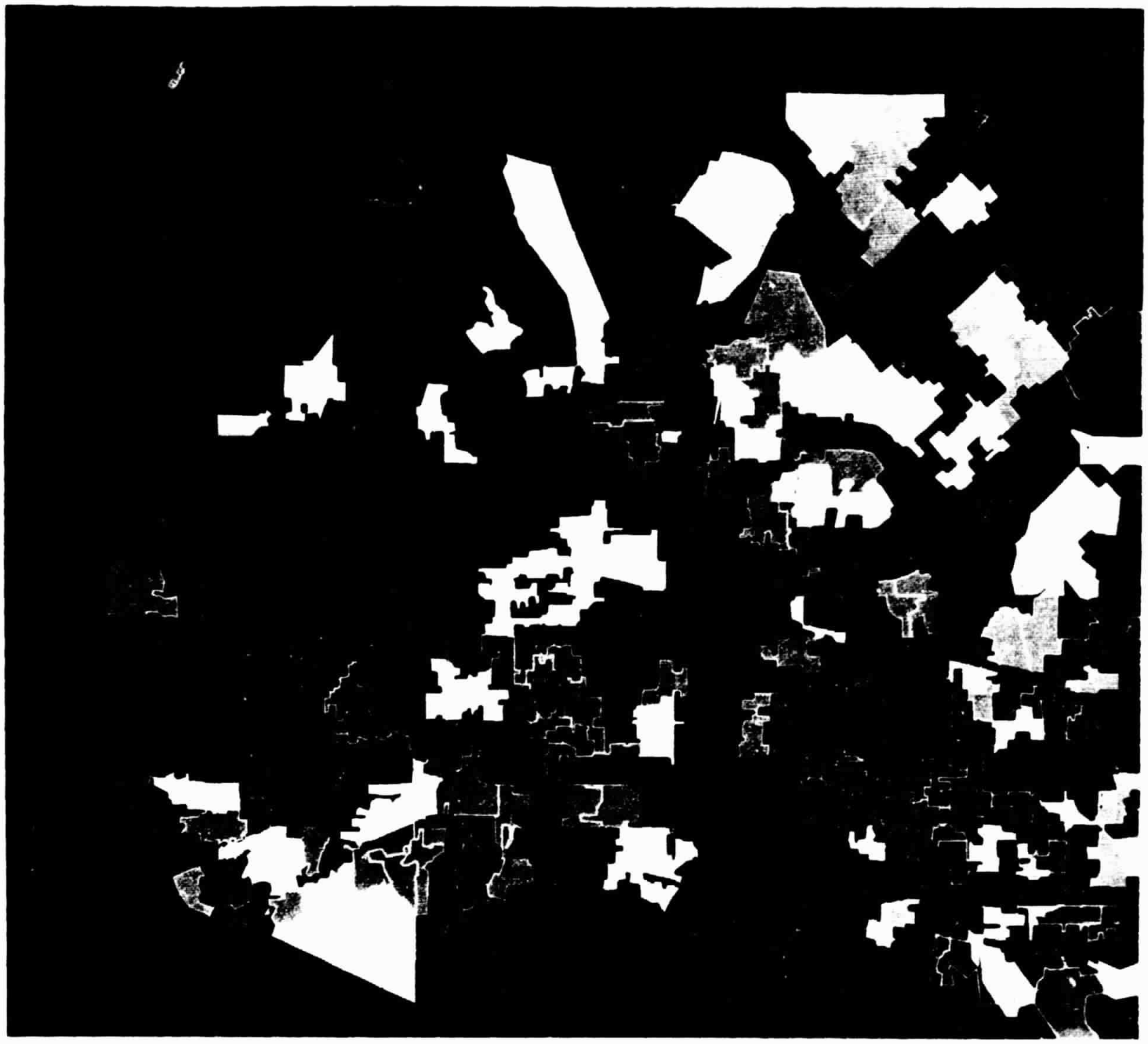
TOTAL INCOMING SOLAR RADIATION
(MWh EQUIVALENCE)

- LESS THAN 1
- 1 – 250
- 251 – 450
- 451 – 650
- 651 – 850
- 850 + %

Figure 14. Potential Photovoltaic Energy (MWh) Within Each Main Line Feeder Service Area of the San Fernando Valley, Los Angeles, During Month of September.

Figure 15. Main Line Feeder Service Areas Within the San Fernando Valley, Los Angeles.

Figure 16. Energy Use (kWh) Within Each Main Line Feeder Service Area of the San Fernando Valley, Los Angeles, During September 1978.



SOLAR POTENTIAL

SEPTEMBER 1978

- 0 – 19%
- 20 – 39%
- 40 – 79%
- 80 – 99%
- 100 – %

Figure 17. Percentage of Load Potentially Supplied by Solar Photovoltaics, for Each Main Line Feeder Service Area of the San Fernando Valley, Los Angeles, During September 1978.

and land more closely. The curves in Figure 19 also show the greater potential for utility autonomy within predominantly residential mainline feeder service areas and the highly fluctuating loads associated with industrial plants and some types of commercial use.

Daily and Bi-Hourly Comparisons. Figure 20 presents the same six distribution substations shown in Figure 18, graphing the daily percent potentially supplied by photovoltaics. It is important to note that these daily figures do not include industrial feeder substations, with the result that most curves are artificially high. September 1978 was the highest electrical energy use month experienced to date by the DWP, and December is a fairly representative profile for an "average" month. On a daily basis, it becomes apparent that those distribution substation areas with high proportions of industrial and commercial land uses have considerably lower loads over the weekends as opposed to the predominantly residential substation areas. Furthermore, the load profile appears to be more closely related to the air temperature and corresponding loads for air-conditioners in residential areas. To illustrate this point, during the last ten days of September 1978, a record heat wave was experienced in Los Angeles with temperatures exceeding $100^{\circ}F$ each day. Figure 21 gives absolute kWh load and potential supply statistics on a bi-hourly basis for each day in September 1978 for Distribution Substation 21. It should be noted that the utility load curves do not include industrial substation statistics and that the bi-hourly solar potential curve is a mean value day profile for the entire month of September and does not include actual sunshine statistics for the days in September 1978. Regardless of these limitations, several important points can be noted. Firstly, the loading profile throughout the day shows that there is usually a potential surplus during the midday hours but a deficit during breakfast and dinner times (6-8 AM and 4-8 PM). This would imply the need for storage and/or flexibility in generation operations to match the supply and demand loads throughout the daylight hours and, where sufficient photovoltaic potential exists, meet the nighttime energy requirements. There is the potential to achieve a surplus during nearly every midday hour (10 AM - 4 PM) during what was a very high demand month.

SUMMARY AND RECOMMENDATIONS

Summary. The results of this study are generally encouraging with regards to the potential of distributed photovoltaic systems in the urban area studied. For urban areas like Los Angeles, where electrical load is rising with the use of air-conditioners and more electrified households, distributed photovoltaics could probably meet projected increases in energy requirements, thereby reducing the amount of electrical energy required from conventional energy sources. In addition, the results show that should photovoltaic collectors presently be installed under the modelling assumptions (i.e., half of the flat and south-facing rooftop areas where collector sites and energy storage existed), during 1978, 52.7 percent of the energy requirements could have been met. Table III summarizes the monthly conditions. However, because of modelled assumptions noted in the previous sections, more definitive utilities systems studies need to be done to assure the viability of the concept. As the previous study (1) also noted, there is a need for more precise data, both with regard to actual solar insolation and electricity use. The present study, with its estimate of utilizing only half the area of usable rooftops, indicates that solar photovoltaics could make a major contribution to aggregate energy requirements. It also indicates that electricity storage at the mainline feeder and substation levels may be required, or that major transports of electricity out of a surplus substation region to a deficit substation region for the midday hours will be required.

TABLE III. Monthly Summary of Modelled Photovoltaic Potential in the San Fernando Valley, Los Angeles.

Month	Solar Potential (kWh)	Actual 1978 Demand (kWh)	Percent Supplyable From Photovoltaics
January	165,320,256 kWh	403,431,168 kWh	41.0%
February	179,381,904	358,191,360	50.1
March	229,350,416	382,626,816	59.9
April	215,650,528	368,013,312	58.6
May	219,944,848	413,149,696	53.2
June	217,750,992	467,941,632	46.5
July	240,564,704	532,511,744	45.2
August	239,841,216	502,435,328	47.7
September	227,553,376	471,772,160	48.2
October	196,069,200	435,819,520	45.0
November	173,290,576	402,258,432	43.1
December	163,511,568	411,375,360	39.7
Year	2,468,228,100	4,681,584,460	52.7

Recommendations. As with most exploratory studies, more questions were raised than answered. The use of a geographic information system to aggregate the spatially distributed information has brought to mind the potential for incorporating other kinds of data to refine the modelling effort. These include the following:

(a) Model the location of potential District and Feeder Line storage capabilities and their effect on leveling out the surplus and deficit curve associated with potential supply and actual demand over a 24-hour period, thereby improving the general load profile for the region. Such measures could give engineers an approximation of the potential autonomy of service areas from the utility net and give a system-wide estimation of the potential reduction in central power generation capacity. It should also provide data for assessing the ability of the total system to accept energy from an intermittent source without the addition of storage.

(b) It should be possible, given a complete land use inventory of each DWP service area, to incorporate into a model the use of alternative solar power systems that may be better sited on vacant lands. Similarly, it should be possible to address a variety of energy technologies and determine the more optimal mixes for the case study region. Solar thermal collectors would compete for available roof areas but significantly reduce natural gas consumption and, to a lesser extent, electrical used for space and water heating. Both natural gas and electric utility bills could be address-matched to District Substations and Main Feeder service areas to compute trade-offs. Similarly, knowing the kind of land use and the typical daily profile for each, it should be possible to overlay the demand and surplus supply profiles of each to further determine district autonomy and regional load matching.

(c) One could model a variety of socioeconomic impacts that may affect the potential use of solar photovoltaics. It should not only be possible to break down the potential productivity/demand mix by land use type, but tie ownership and use more closely to power loadings. For example, schools have a coincidence of peak use and peak solar potential, but no summer use, while theaters have a peak use at night and virtually none during the day. It should be possible to model the economics of production and buy back through the regional net for such facilities. In addition, it should be possible to calculate future demand given a complete demographic and land use profile for a region. Finally, it should be possible to develop scenarios of building a solar photovoltaic supply capability in a region, wherein specific land uses are chosen first because of their large amounts of available roof area or ease of maintenance by utility companies (i.e., industrial plants or government-owned buildings).

(d) Finally, the model could be used in the process of determining cost allocations (and aid in the determination of tariffs) and in system planning.

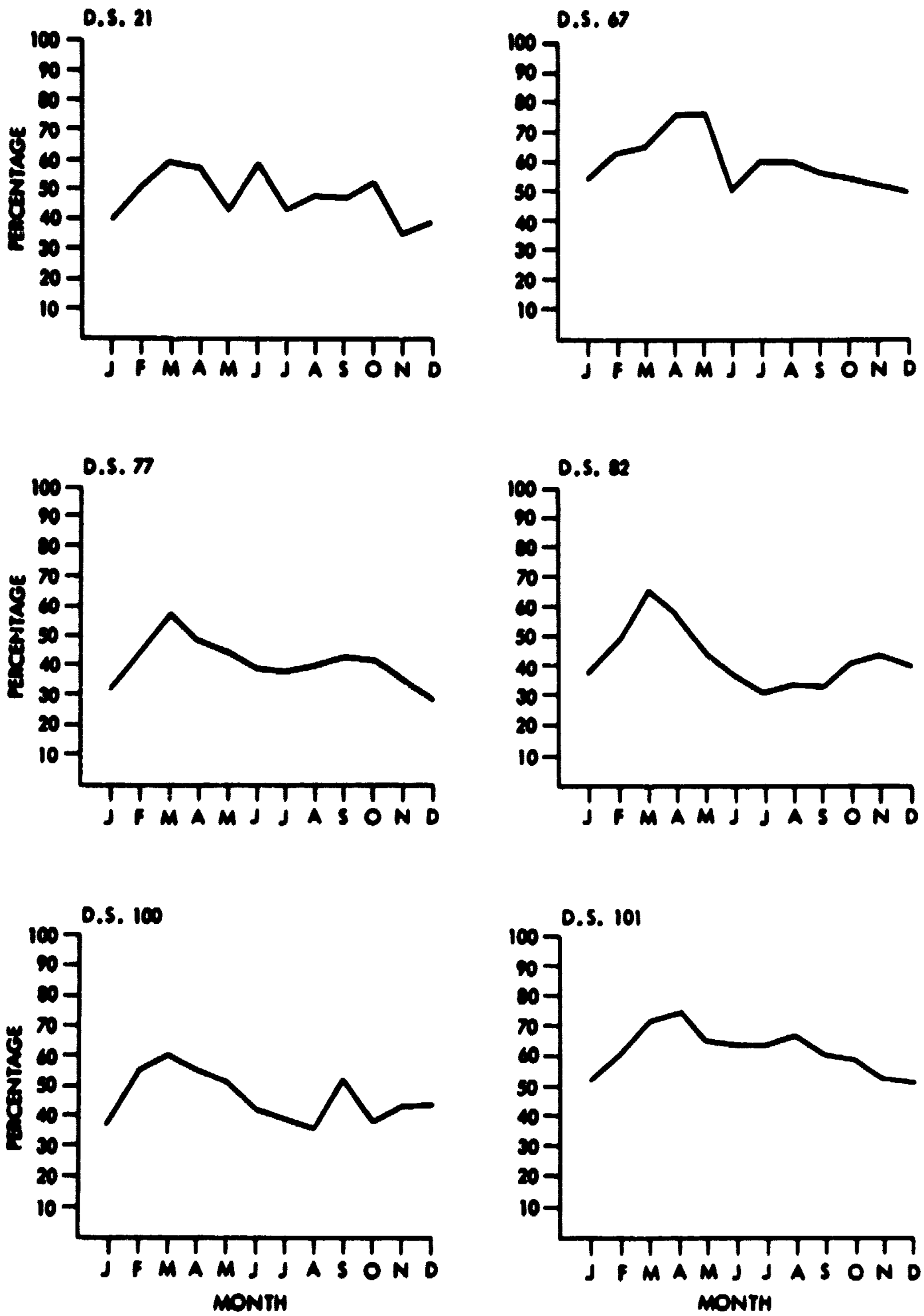


Figure 18. Percentage of Load Potentially Supplied by Solar Photovoltaics for Selected Distribution Substations in the San Fernando Valley, Los Angeles, for Each Month During 1978.

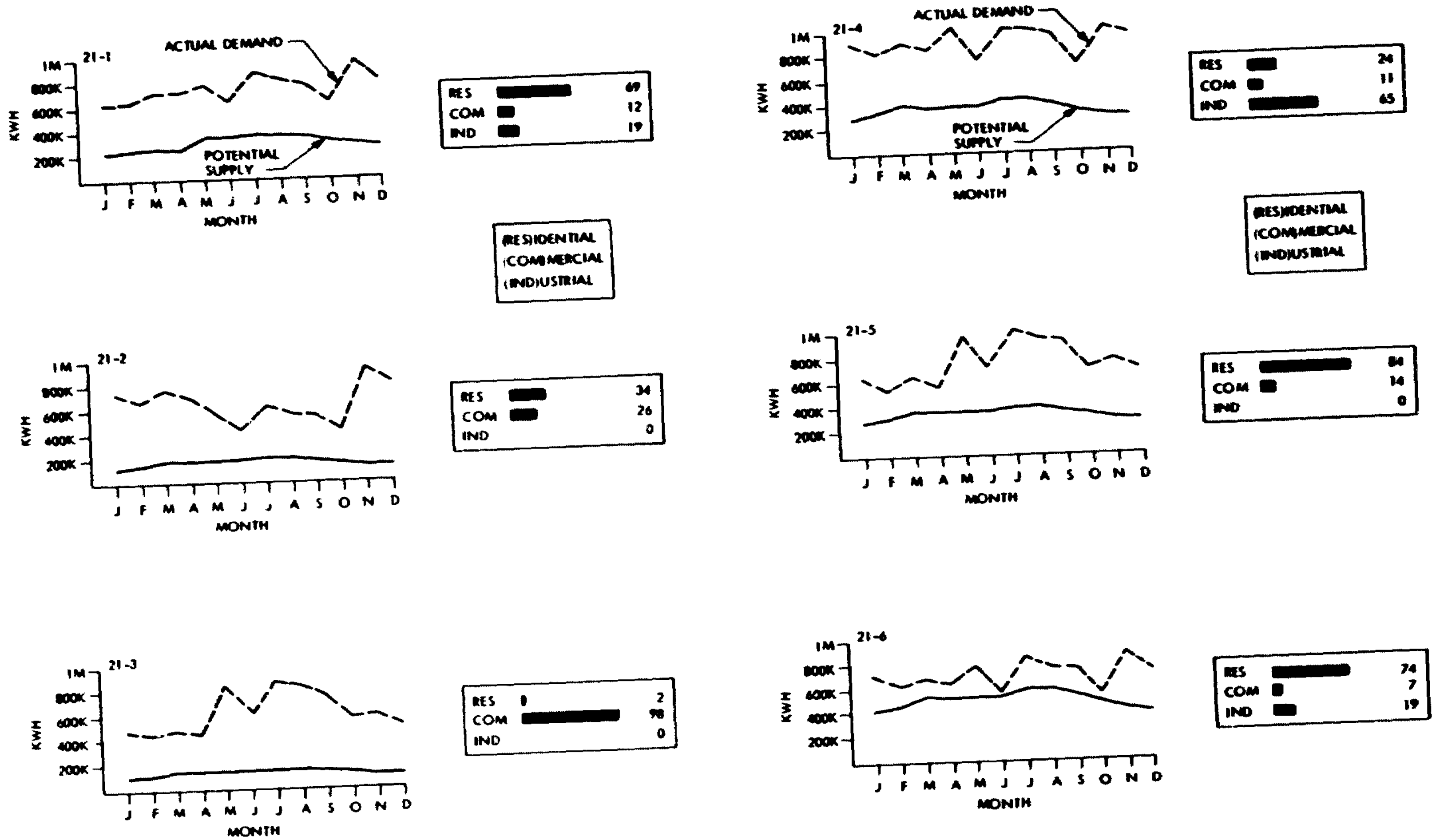


Figure 19. Total Monthly Load (kWh) and Potential Photovoltaic Energy (kWh) Within Each Main Line Feeder Service Area of Distribution Substation 21 in the San Fernando Valley, Los Angeles, 1978. (1 of 3)

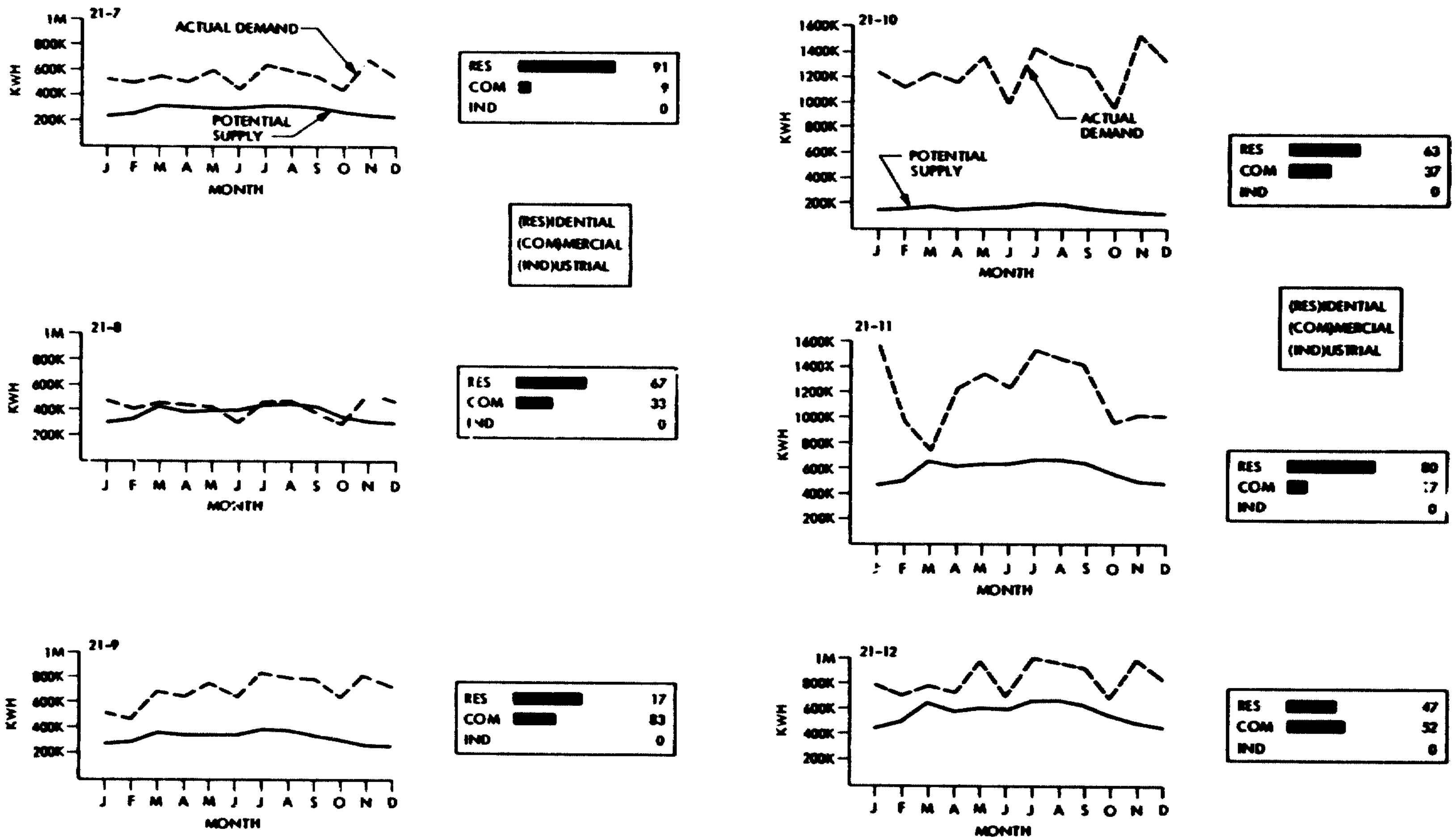


Figure 19. Total Monthly Load (kWh) and Potential Photovoltaic Energy (kWh) Within Each Main Line Feeder Service Area of Distribution Substation 21 in the San Fernando Valley, Los Angeles, 1978. (2 of 3)

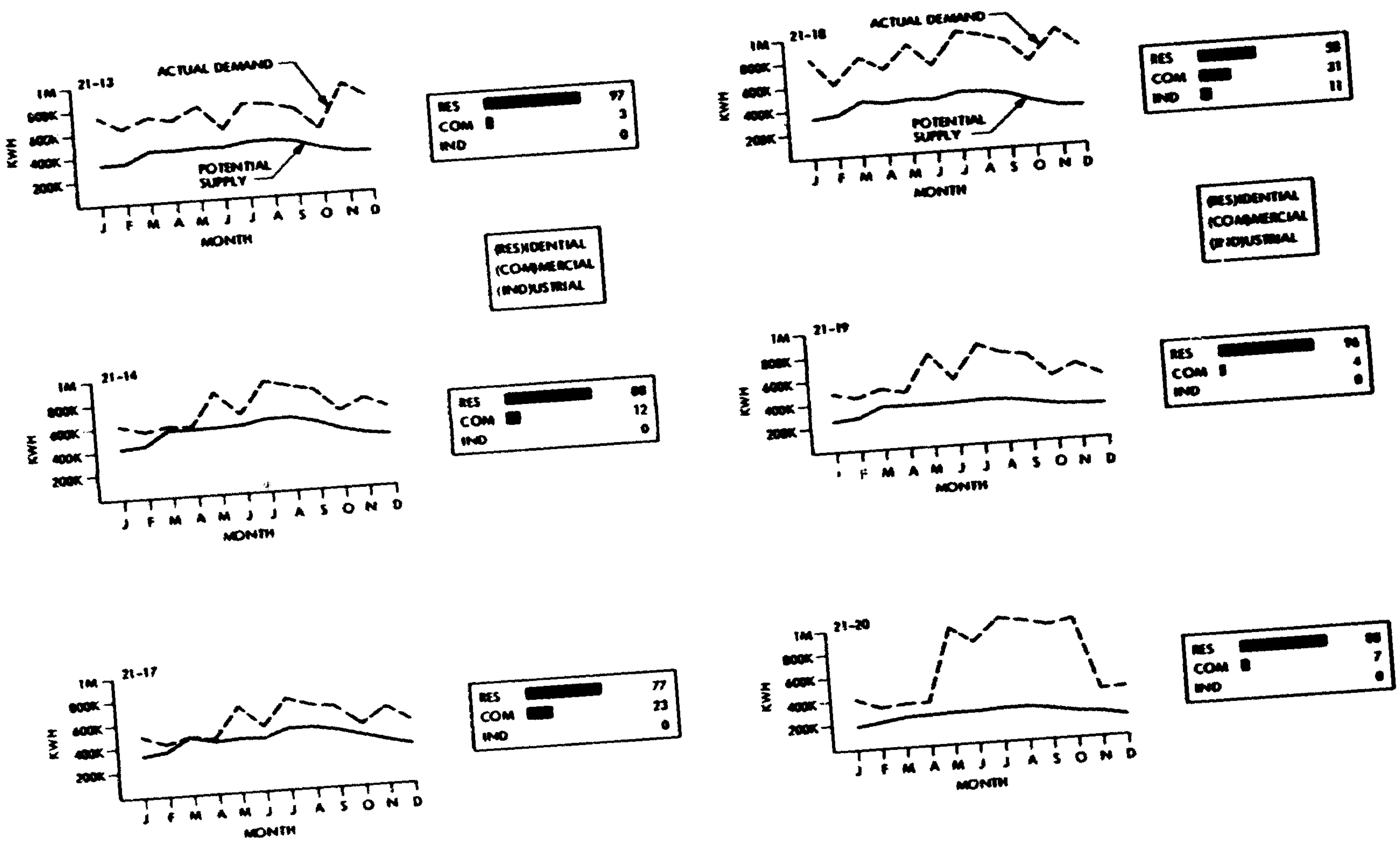


Figure 19. Total Monthly Load (kWh) and Potential Photovoltaic Energy (kWh) Within Each Main Line Feeder Service Area of Distribution Substation 21 in the San Fernando Valley, Los Angeles, 1978. (3 of 3)

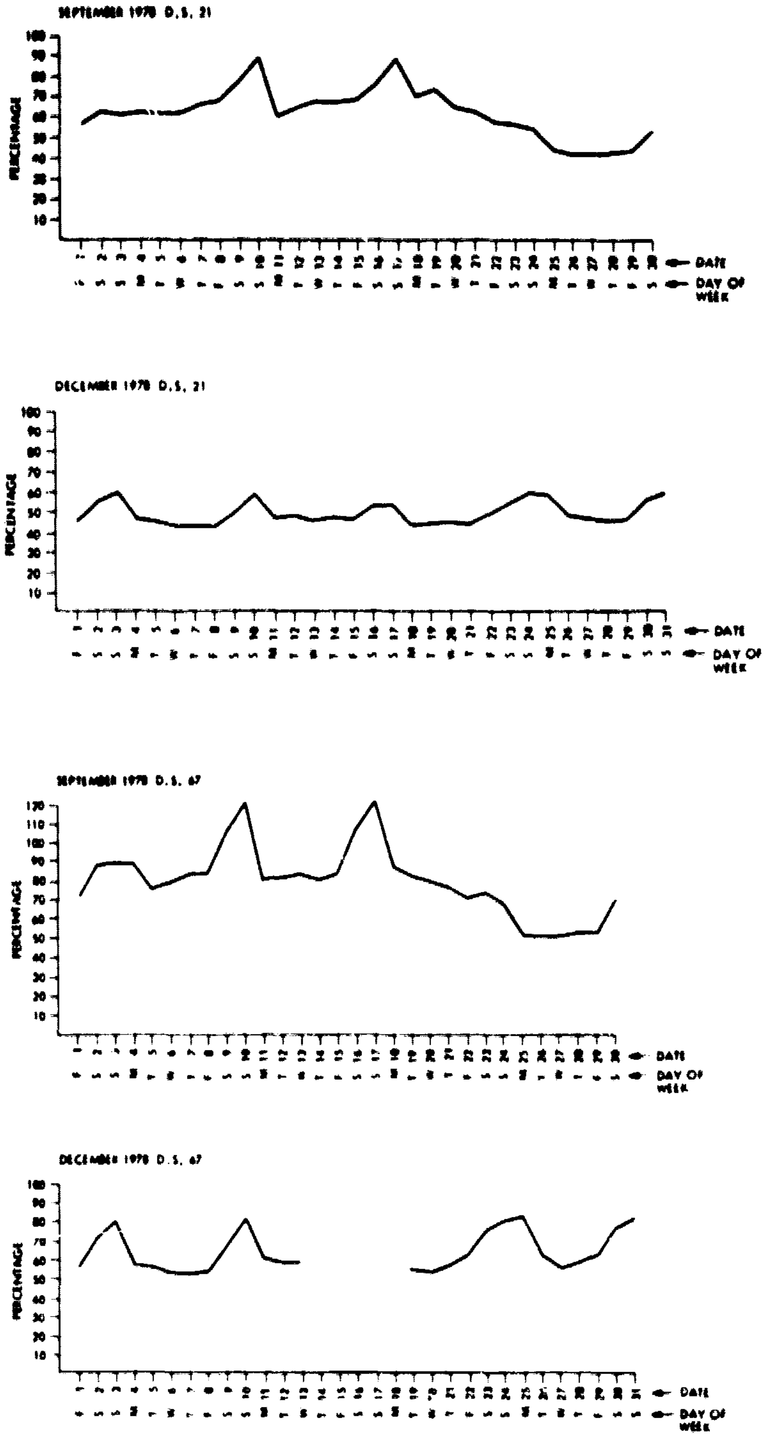


Figure 20. Percentage of Load Potentially Supplied by Solar Photovoltaics for Selected Distribution Substations in the San Fernando Valley, Los Angeles, for Each Day During the Months of September and December 1978. (1 of 3)

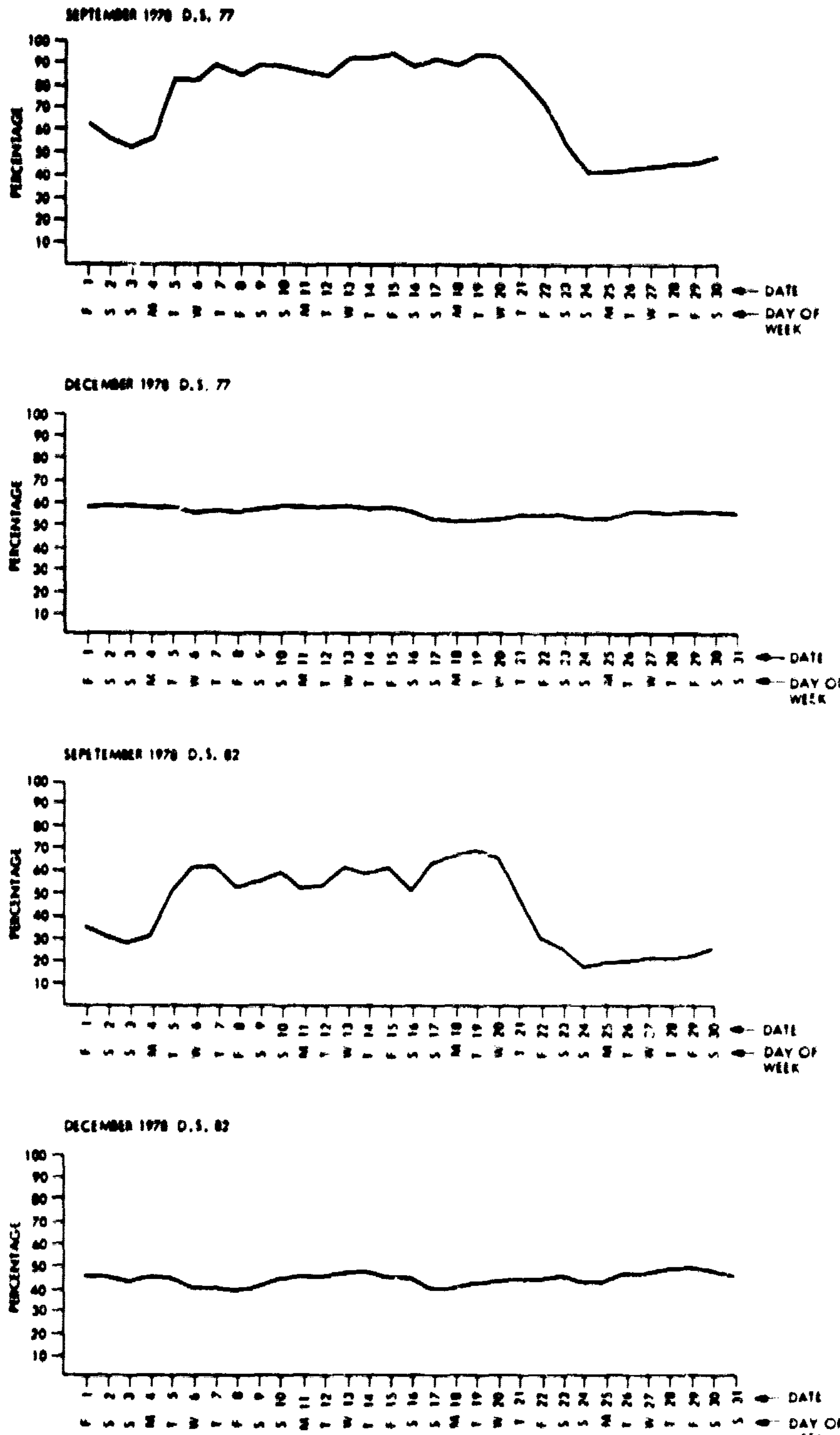


Figure 20. Percentage of Load Potentially Supplied by Solar Photovoltaics for Selected Distribution Substations in the San Fernando Valley, Los Angeles, for Each Day During the Months of September and December 1978. (2 of 3)

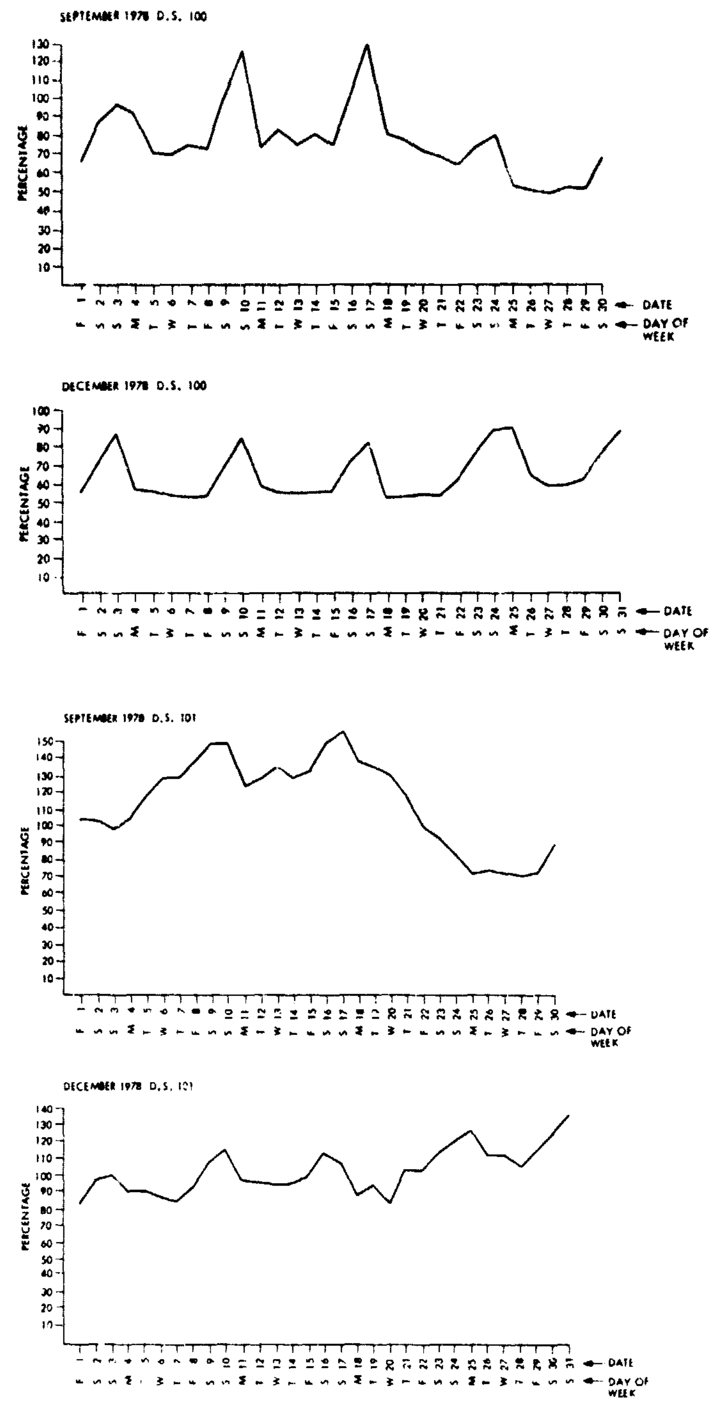


Figure 20. Percentage of Load Potentially Supplied by Solar Photovoltaics for Selected Distribution Substations in the San Fernando Valley, Los Angeles, for Each Day During the Months of September and December 1978. (3 of 3)

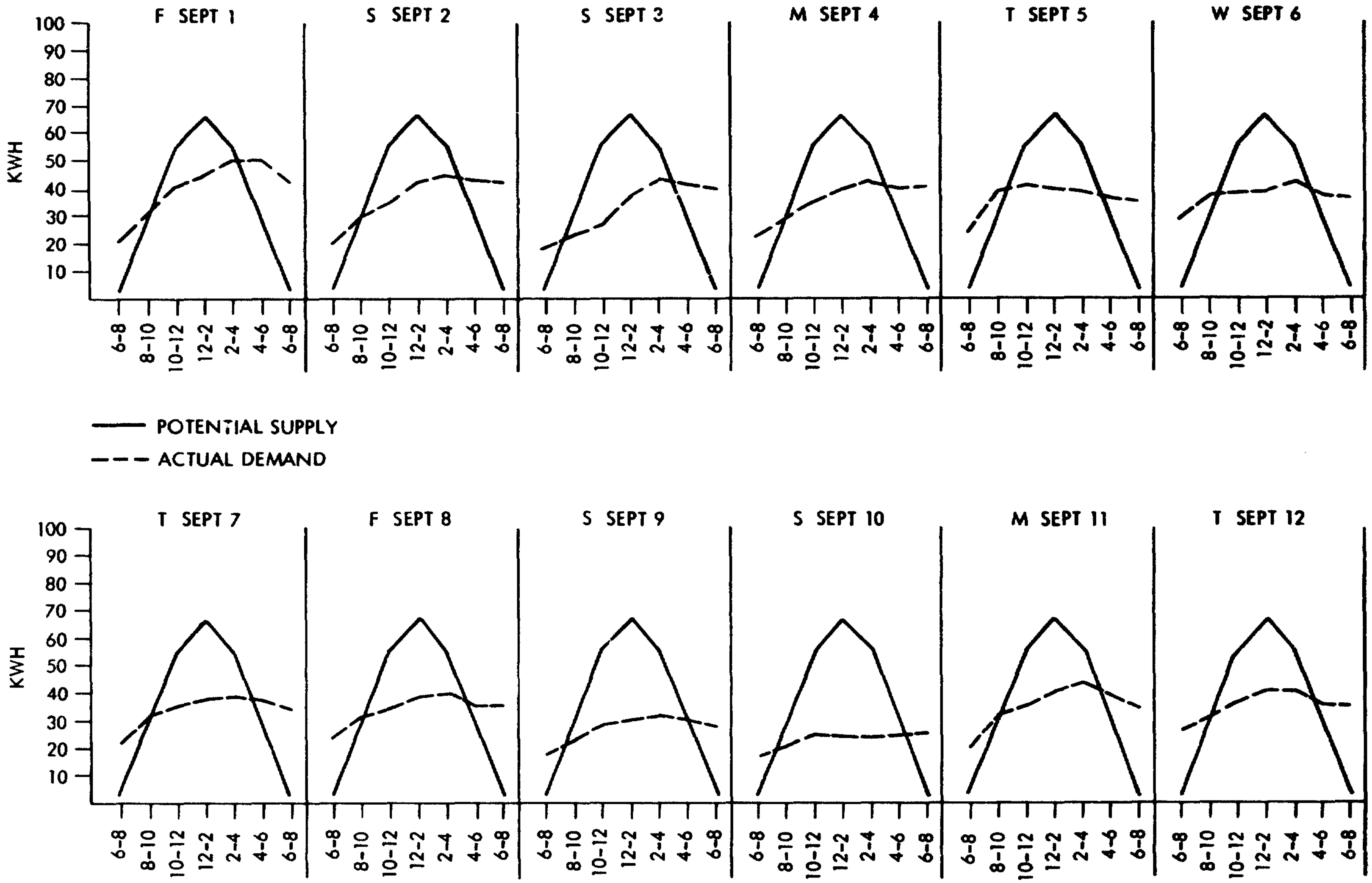


Figure 21. Bi-Hourly Load (kWh) and Potential Photovoltaic Energy (kWh) For Each Day During the Month of September 1978, Within Distribution Substation 21 of the San Fernando Valley, Los Angeles. (1 of 3)

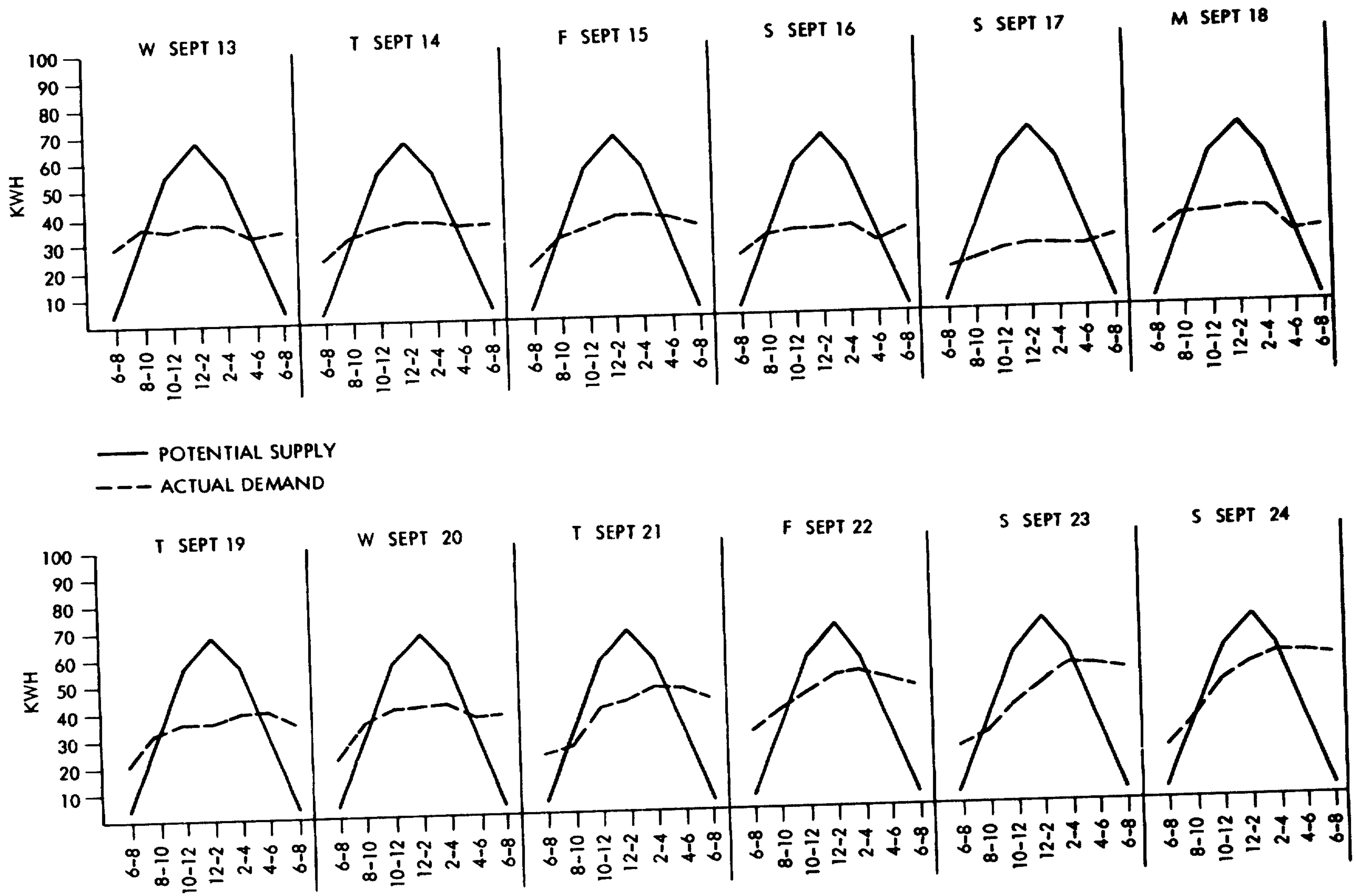


Figure 21. Bi-Hourly Load (kWh) and Potential Photovoltaic Energy (kWh) for Each Day During the Month of September 1978, Within Distribution Substation 21 of the San Fernando Valley, Los Angeles. (2 of 3)

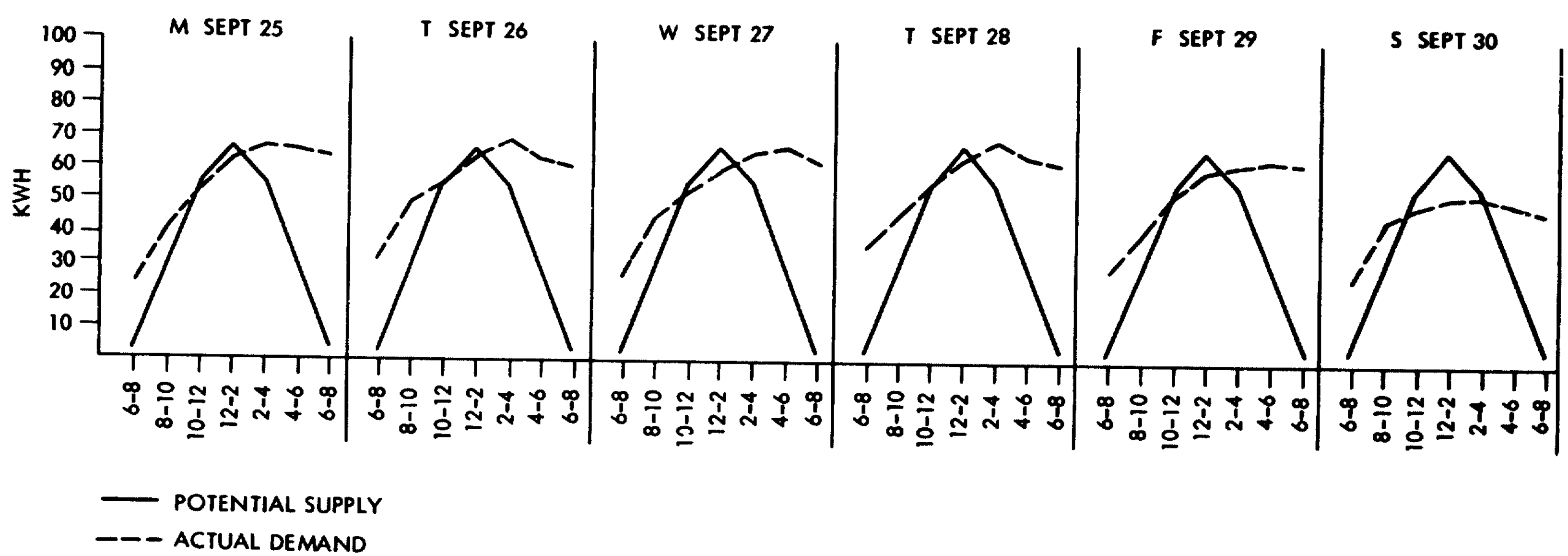


Figure 21. Bi-Hourly Load (kWh) and Potential Photovoltaic Energy (kWh) for Each Day During the Month of September 1978, Within Distribution Substation 21 of the San Fernando Valley, Los Angeles. (3 of 3)

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