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ENVIRONMENTAL EFFECTS OF SOLAR THERMAL POWER SYSTEMS

ECOLOGICAL OBSERVATIONS AT THE SITE OF THE 10 MWe SOLAR THERMAL POWER SYSTEM (1978–1984)

SEPTEMBER 1984

PREPARED FOR

SANDIA NATIONAL LABORATORIES

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LABORATORY OF BIOMEDICAL AND ENVIRONMENTAL SCIENCES
UNIVERSITY OF CALIFORNIA, LOS ANGELES

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Editors
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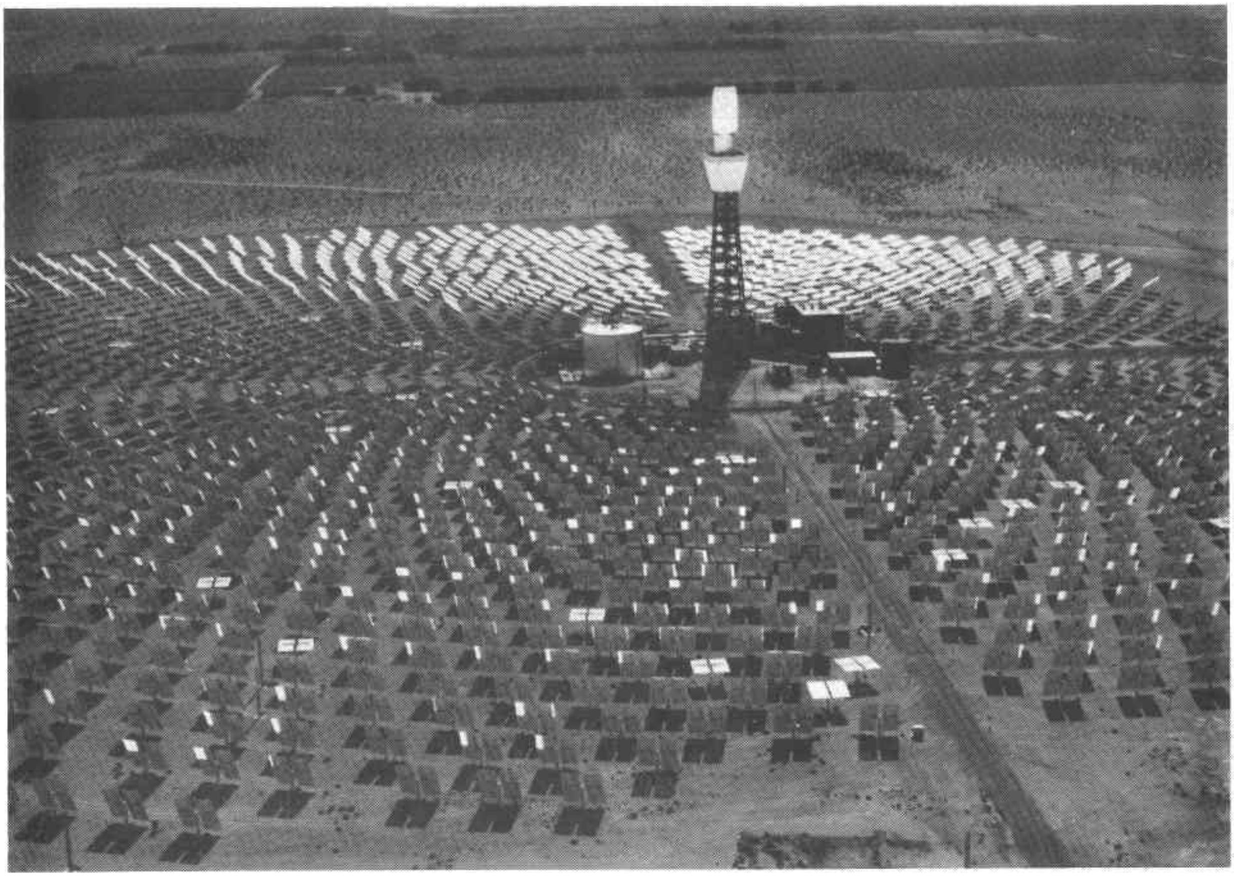

SOLAR ONE

The plant has 1,818 heliostats, each with an area of 39.3 square meters. The plant can deliver 10 megawatts of net electrical power under design conditions. Water-steam is the heat transport fluid in the receiver, which consists of boiler tubes mounted around its entire circumference. The receiver is mounted on a steel tower 80 meters tall. Energy can be stored in a single tank containing heat transfer oil and 6,798 tons of rock. A conventional steam turbine is operated from steam generated using the heat stored in the oil. Alternatively, steam from the receiver can be used directly, or both sources can be used simultaneously. The plant can operate at 7 megawatt output for up to 4 hours using the stored heat.

EXECUTIVE SUMMARY

The Laboratory of Biomedical and Environmental Sciences (LBES), acting for USDOE, was assigned responsibility in 1978 for assessing the ecological consequences of constructing, testing, and operating Solar One. In addition, the Southern California Edison Company (SCE) sponsored parallel studies which included wildlife interactions with the facility by the Los Angeles County Museum Foundation (May 1982 - May 1983); and air quality monitoring by the Statewide Air Pollution Research Center, UCR (1979 - present). This report is a summary of observations made by LBES between July 1978 and July 1984 citing where appropriate findings of the complementary studies.

LBES undertook to answer five general questions.

1. What would be the effects of construction on the surrounding ecosystem?

2. Would the facility itself represent an attractive nuisance or hazard to the indigenous wildlife?

3. Would the facility have an indirect effect on the surrounding ecosystem?

4. Would revegetation of the graded heliostat field be useful to control erosion or replace lost habitat?

5. Could the environmental observations made at Solar One be extrapolated to larger future central receiver systems?

Our efforts to answer these questions were divided into three phases: Preconstruction (1978-79), Construction (1979-81), Testing and Operation (1982-84).

Preconstruction

Physical and chemical analyses of the soil and determination of the plants and animals occupying the area were done in 1978 and 1979 to i) provide a baseline against which to compare changes during facility construction and operation, and ii) prepare for restoration of the site following facility decommissioning. This environmental characterization was used to define a monitoring plan for the construction and operation phases.

In general, the Coolwater property contains a variety of habitats ranging from alfalfa fields to relatively undisturbed desert ecosystems, and from sand dunes bordering the typically dry Mojave River bed to a 53-ha evaporation pond near the southwest border of the site. Each habitat has its characteristic assemblage of species which overlap onto adjacent nontypical habitats. The area is frequented by winds with the general air flow moving from west to east. We assumed that ecological effects of Solar One would be mostly manifest downwind of the site, and since the downwind area to the east consisted of a relatively undisturbed desert ecosystem, we chose to concentrate our studies in that area. However, bird populations were monitored in other habitats adjacent to the site as well as on the site itself.

Our program of biological monitoring did not embrace the total ecosystem, but was tailored to a few particular organisms which included common plants and animals distributed with reasonable uniformity over the area adjoining the heliostat field. A major problem in interpreting biological observations is that populations of desert organisms experience natural changes from one year to the next owing to differences in rainfall and temperature. Such changes include growth and production of shrubs, numbers and kinds of annual plants germinated, and densities of various populations of animals. Therefore, a series of observations in a single area would have shed little light on possible influences of Solar One because such effects are confounded by natural fluctuation. This problem was met by making comparisons over time in paired plots shown to be similar before construction. Such a design assumed that, if construction and operation of the facility effected conditions beyond the heliostat field, the effects would be more strongly expressed in areas near the field than in those at a distance. The detection and interpretation of divergences in paired areas was the basic rationale of the off-field monitoring program.

Construction

Construction of the power plant began in the fall of 1979. The effects of clearing, grading and compacting were obvious and predictable. Clearing and grading completely denuded the site. The pilot plant surface is a compacted bare soil covered with light gravel. The soil surface appears to be stabilizing, but new windblown material continues to be deposited offsite. Whether the source is the heliostat field or redistribution of old material is uncertain.

It was less clear what to expect in areas adjoining the site. We suspected that large amounts of dust and sand would be blown into areas east (downwind) of the prospective heliostat field when the area was cleared and graded. Special collecting devices were placed on the ground at six sites east of the field. These devices measured fluxes of windblown sand at five levels above the ground (from 1 to 36 cm). The meter at the northeastern corner of the field, was unable to capture all windblown material during the first phases of grading. The flux was much reduced 200 m farther north. If we assume the diameter of the heliostat field to be 800 m, the measured loss rates indicate that roughly 160 metric tons of sand were removed from the field between mid-October 1979 and March 1980. Sand deposited downwind of the field was not uniformly dispersed, but formed mounds in wind shadows of shrubs. Mean increase in mound height was 21.5 cm between 35 and 50 m downwind of the field, but less than 1 cm between 90 and 100 m downwind. These observations are consistent with aerial photographs which show a corona of newly deposited sand extending about 100 m from the edge of the field.

The new sand affected germination of some kinds of annual plants, but those which did grow attained larger sizes than those in unaffected areas. No effects on vertebrate populations or shrubs occupying downwind areas have been observed. The fate of the displaced sand was followed closely, but interpretation was confounded by other sources of fugitive dust arising from blading of access roads, cleaning of drainage channels, wind blown material from the Mojave River bed, and development of nearby land for other purposes. Therefore, while there was some evidence that the original material blown from the field was very gradually ablating to the east, efforts to document the fate of the original material blown from the field during early construction were discontinued in 1982.

Testing and Operation

Monitoring of off-site biota was continued through July 1984. The major emphasis during this phase of study, however, was devoted to characterizing micrometeorological effects both within the heliostat array and the downwind study area to the east. We were concerned principally with the environment the biota experience, and thus the properties of air (from the soil surface to only 2 m height), rainfall, soil moisture relations, and evapotranspiration. Our studies might better be termed bioclimatological. Two sets of monitoring arrays were operated simultaneously at different locations (50-200 m apart) within the heliostat field, adjacent to it, and at varying distances and positions downwind of the site. Air temperature, and wind speed profiles were obtained from sensors mounted on a 2-m mast at different times of day and general wind conditions. Evaporation rates were determined from evaporation pans. These activities were augmented by AeroVironment Inc. which conducted a five-day study of flow field measurement using TALA kite anemometers upwind and at varying distances downwind of Solar One. Wind profiles were taken to a height of 50 m and to a distance of 400 m downwind.

While we observed reductions in wind speed of as much as 50% within the heliostat array, the average reduction was about 20%. Small but statistically significant differences in air temperature profiles were observed between onsite and off-site measurements, but all were less than the natural heterogeneity measured off-site. Our data show small effects on temperature (less than 0.5°C) wind speed (less than 0.4 m/sec) and evaporation (less than 1.5 ml/hr) in a limited region downwind of the Solar One heliostat field (up to 190 m from the outer fence). Because these differences are so small, relative to apparently natural heterogeneity, the effects of Solar One on rate of evaporation, air temperatures and wind speed do not appear likely to affect the downwind biological community. The picture could be different for a facility the size of the projected Solar 100 plant.

Measurements by AeroVironment, Inc. showed that maximum air flow retardation within 300 m of the field was about 15% with the heliostats up but negligible when heliostats were stowed in a horizontal position. AeroVironment, Inc. predicted the wake at the field to be detectable 1000-2000 m downstream of the plant. They believe that with the modest wind speed reduction observed, wind blown particles should be deposited within the heliostat field or immediately downstream within 60 m of the array.

Our data in themselves are not complete enough to draw positive conclusions regarding micrometeorological effects. On one hand, the data from within the heliostat field were consistent with measurements taken in a simulated heliostat array. Our downwind measurements of wind retardation (10-12%) were consistent with a shelter belt interpretation, and with measurements made by AeroVironment, Inc. The differences we measured in evaporation rates were also consistent with wind observations and other studies relating to shelter effects. On the other hand, our downwind observations may have been influenced by the agricultural fields and the evaporation pond upwind. Solar One may have been too small to effectively perturb the pattern. For example, irrigated fields in arid regions can influence downwind reaches up to the width of the field--more than 1 km under some conditions. Air temperatures can be $\geq$5°C greater at the transition from an irrigated region to a non-irrigated area.

The possible effect of Solar One on bird behavior was difficult to predict. There is an appreciable literature dealing with bird mortality around television towers. The tower at the pilot plant is not tall (100 m) when contrasted with others studied, but the tower and associated heliostats could cause some mortality of migrants and resident species. LBES observations of birds between March and June 1982 revealed that: i) fewer species were occurring on site since grading although the area was still used for feeding by some icterids (larks, blackbirds) and aerial insectivores (swallows, swifts), ii) of 15 bird casualties ascribed to the presence and/or operation of Solar One, 12 followed collisions with heliostats and 3 resulted from incineration in heliostat beams, iii) the central receiver tower did not appear to be a source of mortality. In an overlapping L.A. County Museum study between April 1982 and May 1983 60 bird mortalities were recorded, approximately half from collisions with heliostats and half believed to have been caused by predation or natural causes. The six incinerations recorded included the three incidents reported by LBES. Considering that over 100 species of birds occur in the vicinity, and that 22,000 individuals were counted in 102 days of observation during the Museum survey, the number of fatalities appears insignificant. There is no indication that Solar One has altered the avifauna of the region which is determined primarily by the presence of the evaporation pond and nearby agricultural fields.

Numbers of rodents (particularly kangaroo rats) trapped in areas downwind of the site declined steadily between 1978 and 1982 in areas both close to the field and as far east as 600 m from the fence. The most likely interpretation of these changes is a reduction in reproductivity and/or early survival caused by four consecutive years (1978-1981) of suboptimal autumn rainfall. A more normal rainfall in the winter of 1982-83 was followed by an increase in animal numbers which lends credence to the interpretation.

In April 1983 several study plots at different distances from the receiver tower were set aside for the study of natural revegetation. Vegetation analyses included both floristic inventories and quantification of plant density, diversity, and aboveground biomass. An attempt was also made to assess present and potential operational/safety problems associated with vegetation presence on the site.

The invading vegetation within the heliostat field was both floristically and structurally dissimilar from an adjacent open desert control site. The invading flora was composed of primarily introduced, weedy annuals, whereas the open desert was characterized by native perennial forbs. Quantitatively, several trends emerged: i) green biomass of ephemerals and newly germinated woody plants was highest in the control site in spring but in the heliostat field in the summer, ii) species diversity was consistently highest in the heliostat field, iii) average plant size was greater in the heliostat field, and iv) plant development and phenology was temporally shifted in the heliostat field, resulting in delayed senescence of plants into the dry season relative to the control site. Heliostat stow position and washing appeared to influence the spatial pattern of vegetation in the heliostat field. The direct effects of shading and perhaps water addition apparently influenced vegetation presence and structure to a greater degree than did previous clearing and surface disturbances.

The presence of vegetation apparently has caused operational and/or safety problems on the site, as the heliostat field was manually cleared or treated with herbicide during each year of the study. The primary problem appears to be tumbleweed, Salsola sp., which grew abundantly in the heliostat field in the summer of 1983. This dense cover of tumbleweed, which was greatest near the base of each heliostat, prevented access to control boxes and provided possible cover for poisonous snakes.

Applicability of Observations to Large Central Receiver Systems

Our observations at Solar One have relevance not only to the pilot facility, but also to future construction of larger solar thermal power plants. For example, a proposed 100 MWe plant to be sited in Johnson Valley would call for two solar collector systems, each with a central receiver atop a 200-m tower. Each heliostat field would require about one square mile and would contain from 7,500 to 8,000 heliostats. The plant would require construction of two 3-million-gallon storage tanks for molten salts, a wet cooling tower, a turbogenerating system, a control building and a 35-ha evaporating pond. The plant would use about 2,600 acre-feet of imported water annually.

In our view, the two most important features of Solar 100 are 1) the area to be graded and cleared for heliostats, and 2) the width of the heliostat fields along the azimuth of prevailing winds (west to west-northwest in Johnson Valley). Other features of possible ecological significance would be the evaporation pond and cooling tower. The size of the heliostat fields is important because cleared surfaces are a source of windblown sand unless specific steps are taken to stabilize surfaces while work is in progress. Each heliostat field of Solar 100 would be about 259 ha in area (ca. 5 times the area of Solar One). The width of a heliostat field affects the extent of downwind influences on air flow. With a heliostat field one mile (1610 m) across, one would expect the extent of the far field wake to be roughly twice that measured at Solar One--where field width is roughly 780 m. The height of the internal boundary layer would also be increased, but not doubled. These projections do not portend significant ecological effects off-site. Possible effects of drift from the cooling tower could be detected but should be small.

Prediction of bird mortality at Solar 100 is speculative because birds are--at present--much less abundant than at Solar One. We would expect an influx of some species of birds not presently occurring in Johnson Valley due to the presence of the evaporation pond, but bird kills should be low. The presence of two towers, each about twice the height of the Solar One Tower, could be a source of casualties to nocturnal migrants.

1.0 INTRODUCTION

A goal of the Solar Thermal Technology Division of the U.S. Department of Energy (DOE) has been to support and accelerate development of a self-sustaining solar thermal industry. Construction and operation of demonstration facilities to validate technical and economic feasibility, as well as to confirm environmental acceptability of the technology, has been an important element of DOE strategy. The DOE, together with the Southern California Edison Company (SCE), the California State Energy Commission, and the Los Angeles Department of Water and Power, has constructed a 10 MWe solar thermal power system near Barstow, in San Bernardino County, California. This project, Solar One, represents the first large central receiver-type solar facility for generating electricity constructed in this country and the largest such installation in the world (Frontispiece, page iii).

Solar energy is generally perceived as ecologically benign, but it is important to confirm this perception by observations made during the construction, testing and operation of a solar thermal power plant. Possible environmental impacts of solar thermal power systems have been discussed in a number of earlier reports and papers (Pritchett, 1975; Energy Research and Development Administration, 1977; Black and Veatch and Electric Power Research Institute, 1977; Davidson and Grether, 1977; Patten, 1978, 1980; Energy and Environmental Analysis, 1979; Turner, 1980; Strojan, 1980; Bhumralkar et al., 1981; Lindberg and Perrine, 1981; and Lindberg et al., 1982). Almost all these writings were based on guesses and whatever general theory could be adapted to operation of a solar thermal power system.

Environmental considerations specific to Solar One were formalized in 1977 with preparation of an Environmental Impact Statement/Environmental Impact Report by the San Bernardino Environmental Improvement Agency in compliance with the California Environmental Quality Act (CEQA). In addition, an Environmental Assessment was issued by the U.S. Department of Energy in 1978 in compliance with the National Environmental Policy Act (NEPA). These documents dealt with "environment" in its most comprehensive sense and included analysis of public and occupational health and safety, socioeconomics, institutional barriers, and ecology as well as alternative actions and mitigations. The documents differed primarily in that CEQA requires discussion of the effects of the existing environment on a proposed development and NEPA does not. While some uncertainties were identified, the conclusion to be drawn from both documents was that no environmentally disqualifying features of the Solar One development were anticipated. Nevertheless, the consortium responsible for Solar One recognized that construction of the facility presented an opportunity to validate potential environmental effects, and to obtain quantitative data that might be scaled to the environmental assessment of larger future solar thermal central receiver systems.

The Laboratory of Biomedical and Environmental Sciences (LBES), acting for DOE, was assigned responsibility in 1978 for assessing the ecological consequences of constructing, testing, and operating Solar One. In addition, SCE sponsored parallel studies which included wildlife interactions with the facility by the Los Angeles County Museum Foundation (May 1982 - May 1983); and air quality monitoring by the Statewide Air Pollution Research Center, University of California, Riverside (1979 - present). This report is a summary of observations made by LBES between July 1978 and July 1984 citing where appropriate findings of the complementary studies.

LBES undertook to answer five general questions.

1. What would be the effects of construction on the surrounding ecosystem?

2. Would the facility itself represent an attractive nuisance or hazard to indigenous wildlife?

3. Would the facility have an indirect effect on the surrounding ecosystem?

4. Would revegetation of the graded heliostat field be useful to control erosion or replace lost habitat?

5. Could the environmental observations made at Solar One be extrapolated to larger future central receiver systems?

Our efforts to answer these questions were divided into three phases: Preconstruction (1978-79), Construction (1979-81), Testing and Operation (1982-84). The study philosophy changed somewhat with each phase as a function of findings from preceding phases, new research opportunities, and impacts of development of nearby lands on interpretation of data. Detailed descriptions of monitoring protocols are presented in Section 3.0. In spite of shifting protocols we have retained our focus on the questions listed above and have been able to draw meaningful conclusions about the ecological effects of Solar One--but not without caveats. Ecological responses are often subtle and slow in expression. Our studies at Solar One were much too short to identify subtle changes, and the development of adjacent lands presented a constantly changing milieu which often precluded clear interpretations of observed changes. However, we were fortunate in having as study participants scientists familiar with ecosystems similar to that adjoining Solar One, and intimately acquainted with the species of interest through both laboratory and field research. Evaluation of data from Solar One, therefore, was examined in the perspective of many years of experience in similar environments, and, in some cases, the conclusions drawn have a higher degree of confidence than the observations at Solar One alone might justify.

2.0 GENERAL SITE DESCRIPTION

2.1 Preconstruction

The Solar One site is in the western portion of the Mojave Desert Geomorphic Province in a valley on the old flood plain of the Mojave River. The site elevation is about 590 m, with less than 1 m fall towards the Mojave River channel to the north. This site lies in the eastern portion of SCE's 946-ha Coolwater property, just east of the Coolwater Generating Station (Figs. 2.1 and 2.2A). Evaporation ponds and alfalfa fields lie west of the site; partially disturbed desert vegetation to the east. A detailed discussion of site geology and hydrology may be found in the environmental impact report (Environmental Improvement Agency 1977).

Winds are predominantly from the west-southwest, west, west-northwest, and northwest, resulting from air flows through the Mojave River channel west of the Coolwater Generating Station. About 74% of the annual wind direction frequencies are from these sectors (Environmental Improvement Agency 1977). A 2-month study showed that there were no significant differences in wind direction between the site and the Barstow airport between February-April 1972 (Hovind et al. 1972). Winds exceeding 13.5 mps (30 mph) occur about 2-3% of the time; winds exceeding 18 mps (40 mph) occur $\leq$ 1% of the time (Environmental Improvement Agency 1977).

Diurnal air temperature fluctuations are large--20° C or more. Maximum temperatures in January range from 13-18° C, in July from 35-41° C. Average January maximum is 15.6° C, July is 39.6° C. Mean monthly air temperatures range from around 9° C (December, January) to 27-31° C (June, July and August). Afternoon humidities are usually low (ca 15-25%), increasing to a maximum in early morning. Typical morning maximal humidities should be around 60-70% during the winter and 30-40% in summer (Environmental Improvement Agency 1977).

Precipitation is variable during the year and between years. The monthly mean precipitation is minimal in May and June (<2 mm), maximal in August and September (13-15 mm). The annual mean is 94 mm, with about two-thirds of it falling in winter and spring. The highest monthly rainfall recorded at the Barstow airport between 1956 and 1970 was 82 mm. Snow fell on 15 occasions between 1956 and 1970, generally as a trace (Environmental Improvement Agency 1977).

SCE has established a network of solar monitoring stations in southern California. The closest of these stations is at Barstow, from which data indicate a range of 3.0 $kW\text{-}hrs \cdot m^{-2} \cdot day^{-1}$ (December) to 8.4 $kW\text{-}hrs \cdot m^{-2} \cdot day^{-1}$ (June) of solar radiation on a horizontal surface. The annual mean is about 5.8 $kW\text{-}hrs \cdot m^{-2} \cdot day^{-1}$. The plant site should receive about 3500 hrs of sunshine annually (Environmental Improvement Agency 1977). Further climatological data are available in the environmental impact statement; the 1982 Meteorological Data Report for Solar One (McDonnell Douglas Astronautics Co. 1983); and section 4.0 of this report.

The perennial vegetation of the STPS site was composed principally of three shrubs: bur-sage (*Ambrosia dumosa*), saltbush (*Atriplex polycarpa*), and creosotebush (*Larrea tridentata*). Fifteen other kinds of shrubs and

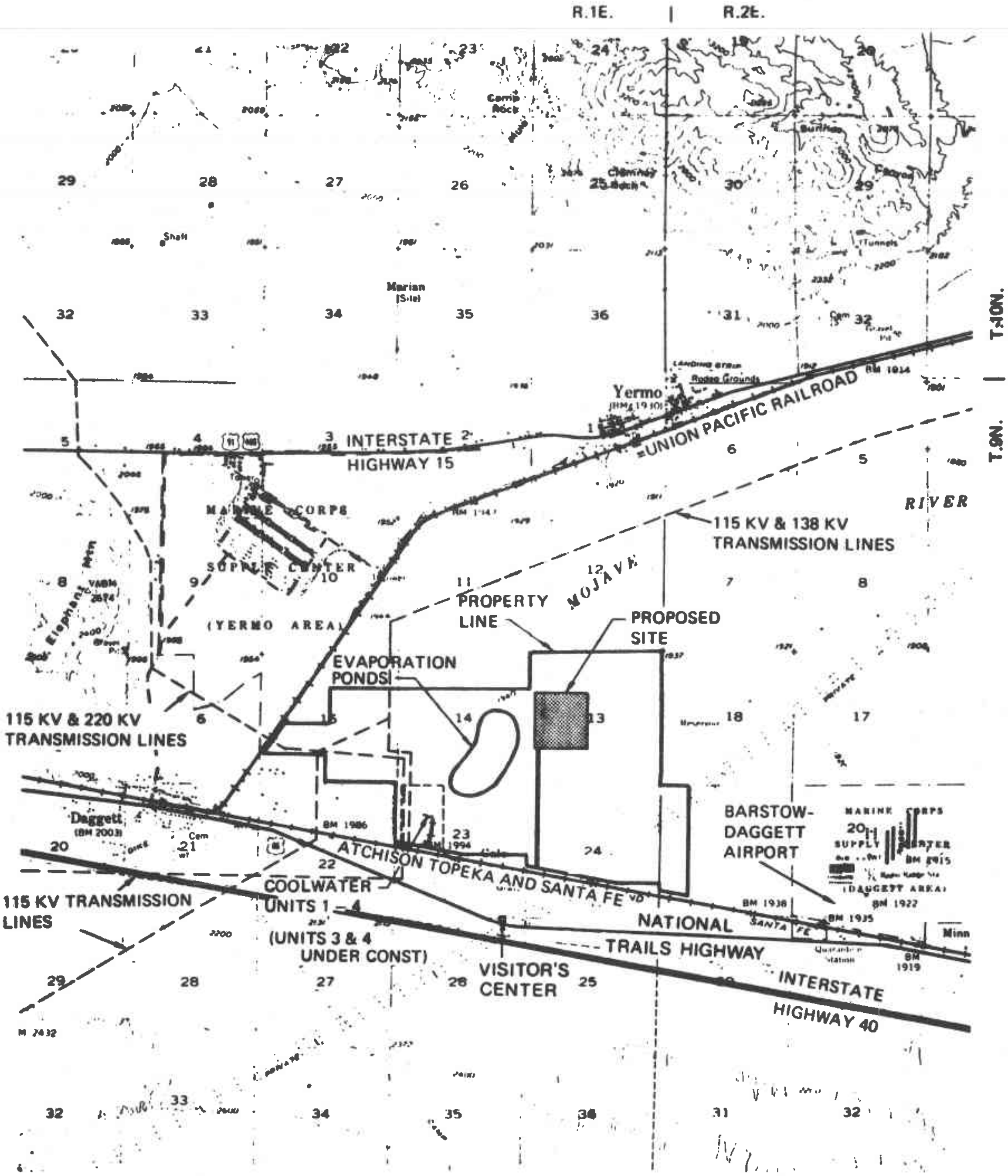

Figure 2.1. Map of Southern California Edison's Coolwater property near Barstow, California, showing site of solar thermal power plant (Environmental Improvement Agency 1977)

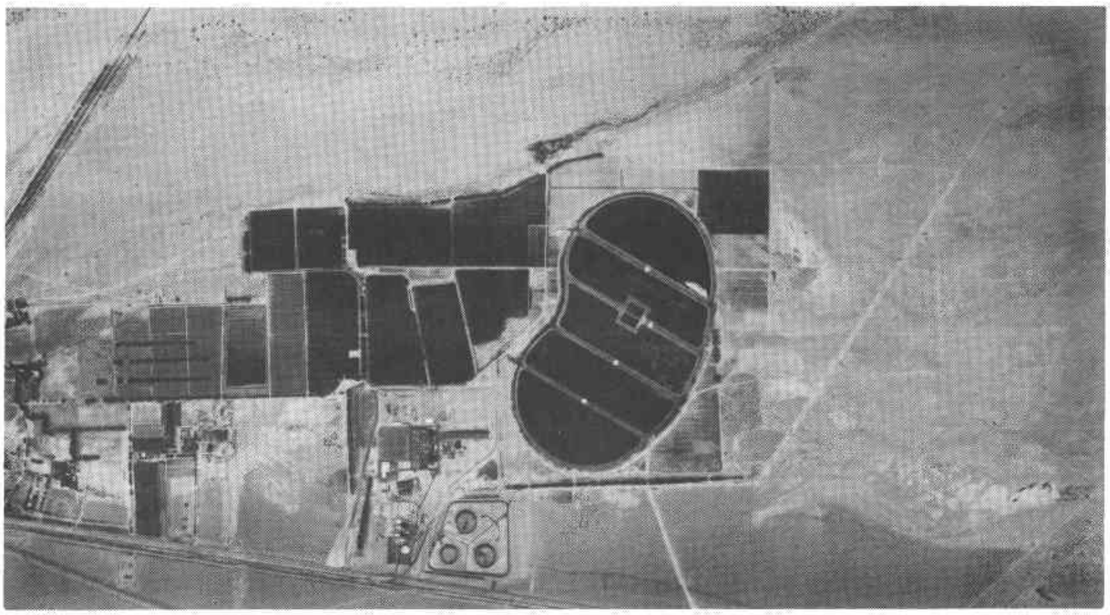

Figure 2.2A. Southern California Edison's Coolwater Generating Station (left center) in July 1979. Large kidney-shaped area is composed of evaporating ponds. Dark rectangular areas are agricultural fields. The site of the prospective solar thermal power plant is in right center.

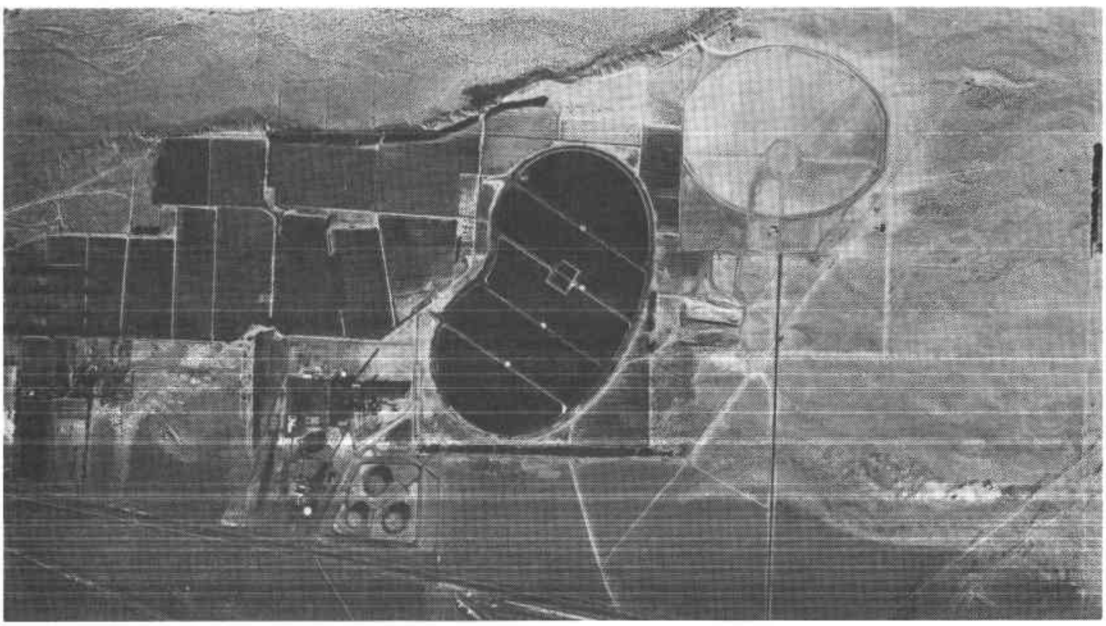

Figure 2.2B The Coolwater Generating Station in December 1979, showing the cleared heliostat field northeast of the evaporating ponds. Note the arc of sand blown to the east of the cleared field. These deposits are conspicuous to a distance of 100 m downwind of the clearing.

herbaceous perennials also occupied the site. Over 90 kinds of annual plants have been recorded on the site. The heliostat field was originally cleared of natural vegetation in 1953 and crops grown until 1956. After the field was abandoned natural processes of recovery began, and in 1979 the predominant shrub on the heliostat field was saltbush. Farther east the most common shrubs were creosotebush and bur-sage. Annual plants and animals occupying the area were typical of the Mojave Desert. Lists of species may be found in the original impact analysis and in a pre-construction site description conducted in 1978 and 1979 (Environmental Improvement Agency 1977, Turner 1979).

2.2 Construction Period (1979-81)

The specific site selected for Solar One was northeast of SCE's Coolwater Generating Station evaporating ponds and south of the dry course of the Mojave River. Construction of the power plant began in the fall of 1979 when an elliptical area of about 53 ha was cleared and graded (Fig. 2.2B). Later, drainage ditches were dug around a portion of the prospective heliostat field, a perimeter road was constructed, and the entire field fenced. Excavation for bases of 1,818 heliostats began in March 1980. Figure 2.3 shows the status of the project at about this time. After pedestals were poured and supporting pylons erected, attachment of heliostats began in mid-February 1981. This work was completed by the end of September 1981. A 100-m central receiver tower was completed in the spring of 1981 and the receiver was erected during July 1981 (Fig. 2.4). Other activities included construction of an above-ground thermal storage system (begun in July 1980), fabrication of a single 3-cell cooling tower (begun in September 1980 and completed in August 1981), the construction of a control center and installation of the turbogenerator in mid-June 1981. Basic construction of the facility was completed by the end of September 1981. Then followed a 6-month "start up" period extending to the end of February 1982. Tests of functioning of heliostats were begun in March. Steam was introduced into the receiver panels at about this time, and steam was passed into the turbine in early April. Formal plant operation began on April 12, 1982.

2.3 Testing and Operations (1982-84)

Development of vacant land on the Coolwater track and adjacent private land for purposes unrelated to Solar One continued throughout the course of the study. This included increasing the size of alfalfa fields on private land to the east of our off-site study area; construction of a coal gasification combined cycle facility to the north of Coolwater Units 3 and 4; construction of a 15-MWe solar thermal parabolic trough facility just south of our study area; and, in the winter of 1983 commitment of most vacant land at the Coolwater site to agriculture (Fig. 2.5). The progression of events is graphically evident in aerial photographs (Figs 2.3-2.5). These activities were attended by blading of access roads, cleaning of drainage ditches around Solar One, and undocumented traffic by surveyor crews and tour buses.

The purpose in citing these activities is to document our rationale for emphasizing studies within the heliostat field during 1982-84 and further explain our reluctance to interpret possible changes in the ecology as solely attributable to Solar One.

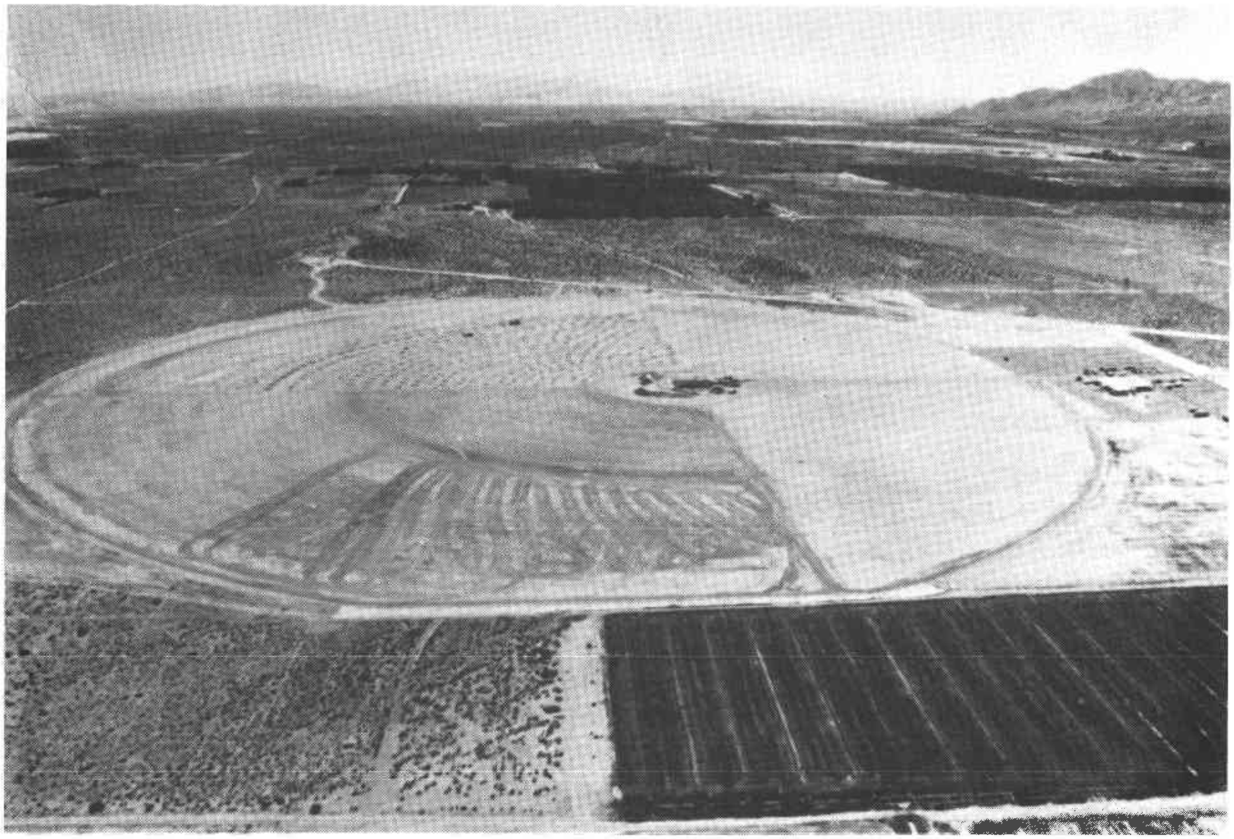

Figure 2.3. The Solar One site looking east across the heliostat field, Spring 1980. Work on heliostat pedistals has begun. Most ecological studies were conducted on the eastern sector downwind of the site between the periphery of the field and the agricultural land at top of the photo.

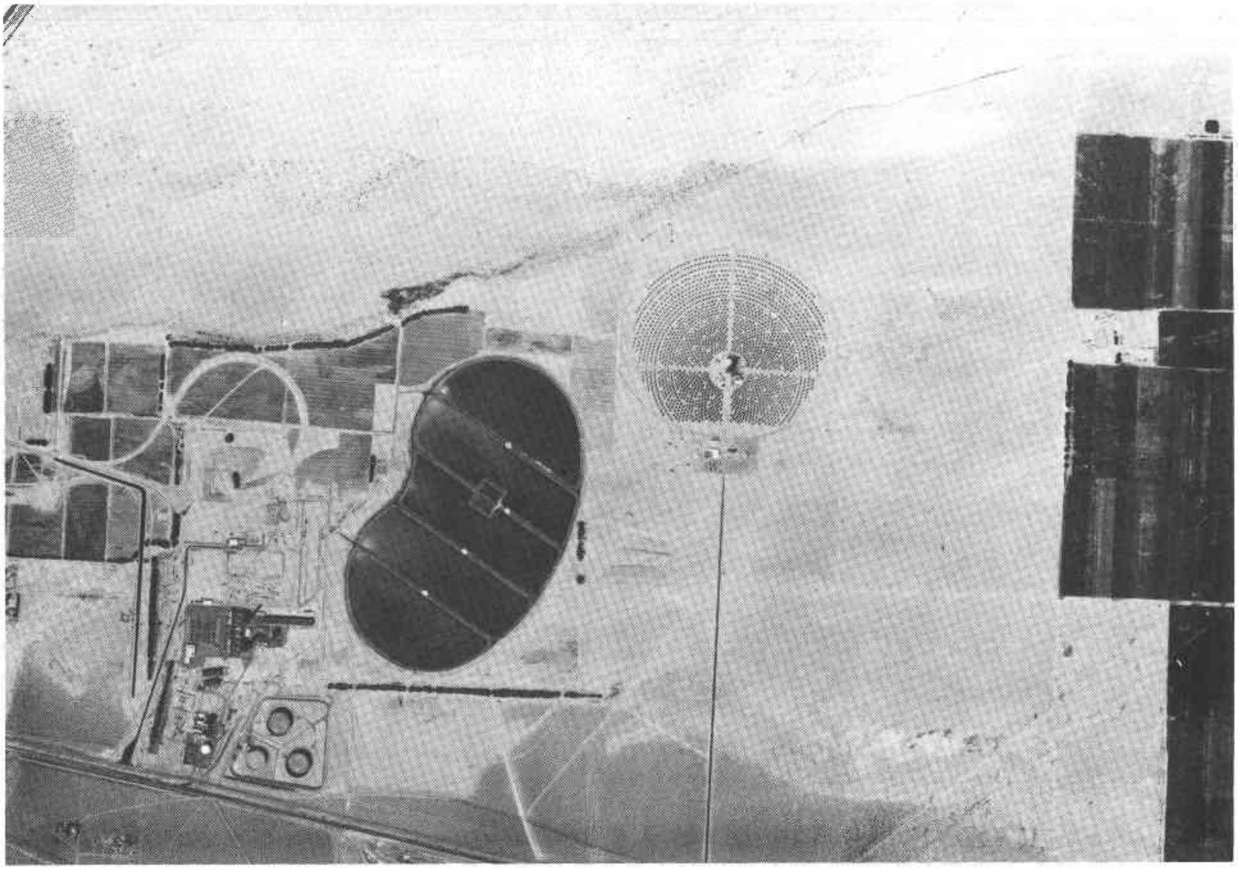

Figure 2.4. Aerial photograph of the Solar One site and vicinity on March 1982 just prior to dedication of the completed facility. The circular track left center is a coal gasification combined cycle facility under construction. Coolwater units 1, 2, 3 and 4 are lower left. Dark squares and rectangles are agricultural crop land. The dry Mojave River bed cuts diagonally across the top of the photo.

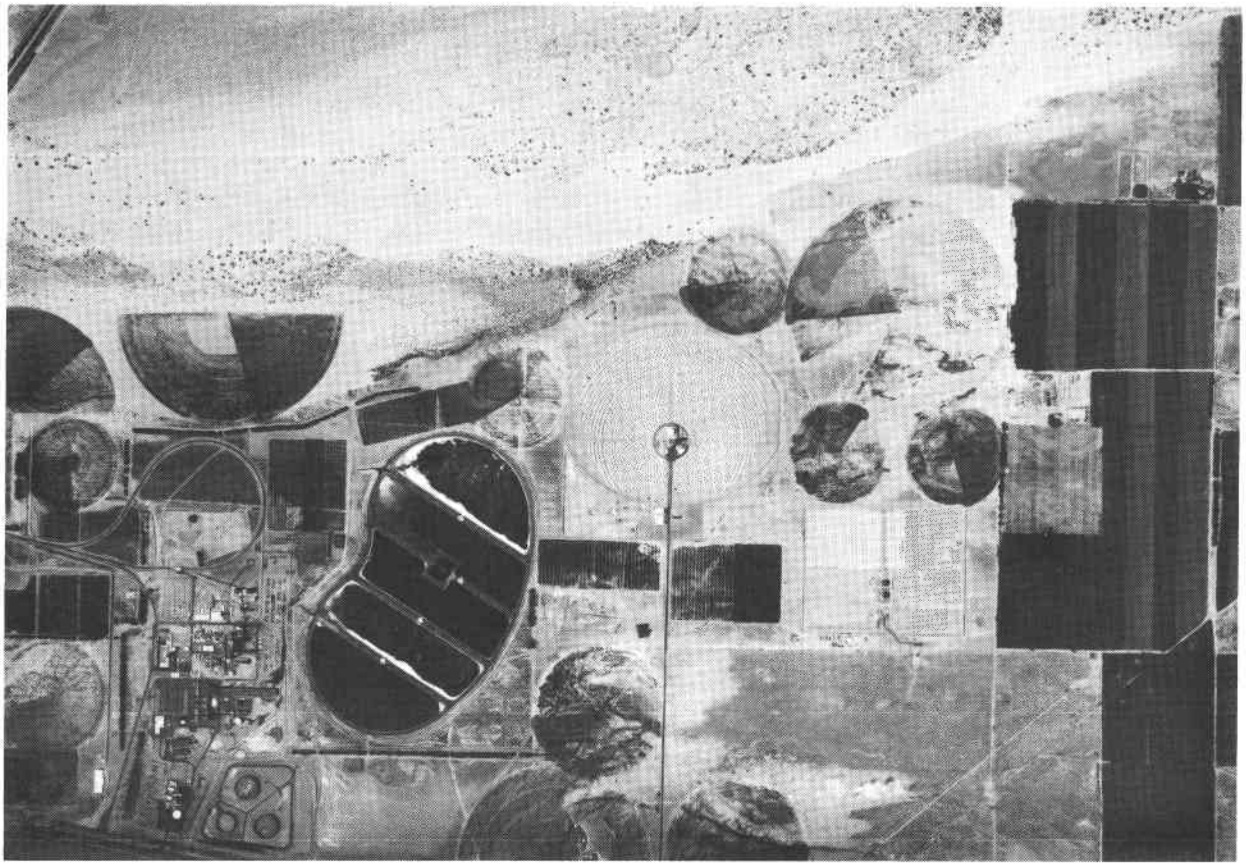

Figure 2.5. Aerial photograph of the Solar One site and vicinity in June 1984. The rectangular light area to the lower right of the heliostat field is an array of parabolic troughs. The circular and pie-shaped sectors are agricultural plots begun in the winter of 1983. The dark and light banded rectangles to the right are agricultural fields bordering the Coolwater property. The dry Mojave River bed runs across the top of the photo.

One routine procedure used in bringing Solar One on-line for testing and operation is worth special mention because of its effect on both insects (Section 6.1) and birds (Section 6.4). Typically, beams from groups of individual heliostats were brought to focus near ground level and the foci then raised to standby points near the face of the receiver (Fig. 2.6). The points of focus at the standby points then were moved onto the face of the receiver as required for testing and operation. As can be seen in Fig. 2.6 the standby points appear as luminous orbs and were at high enough temperature to incinerate insects and, on rare occasion, kill small birds. During early testing (1982-83) the heliostats were focused at the standby points frequently and for long periods. However, this phenomenon should be transitory during normal operation of Solar One. An alternative expanding ring beam control strategy is available for bringing the heliostat beams to bear on the receiver which would reduce the standby point phenomenon (Brumleve 1984). This strategy could be used at Solar One and might be adopted for future solar central receiver systems.

Figure 2.6. Receiver tower at Solar One showing luminous areas at standby focal points.

3.0 ENVIRONMENTAL MONITORING PLAN RATIONALE

Development of the monitoring plan involved reviews of pertinent literature, and preconstruction characterization of the proposed Solar One site and its environs. The objectives of the pre-construction observations were to i) establish normal attributes of the ecosystem by characterizing the existing states of soils, plants and animals in the area, identify common species, and define normal patterns of distribution and abundance, ii) evaluate seasonal variations in these attributes, and iii) identify selected species or groups of species whose status could be conveniently monitored during construction. This environmental characterization was summarized in an earlier report (Turner 1979), and was used to define a monitoring plan for the construction and operation phases. Preconstruction observations were made both in the prospective mirror field and in areas as far as 3 km east (downwind) of the mirror field. We recognized that when the prospective mirror field was cleared, graded and the soil surface stabilized, the site itself would be drastically altered. However, there was interest in cataloging the preconstruction state of the heliostat field both for historical reasons and for the ultimate purpose of restoring the field to its original state following decommissioning of the facility. We wished to understand the biological processes influencing revegetation, and to experiment with techniques capable of enhancing reestablishment and growth of native plants in this area. Limited transplantation studies with native plants were undertaken off-site but are not included in this report (Romney et al. 1979, 1981a, 1981b).

The preconstruction studies revealed that the Coolwater property contained a variety of habitats ranging from alfalfa fields to relatively undisturbed desert ecosystems, and from sand dunes bordering the typically dry Mojave River bed to a 53-ha evaporation pond near the southwest border of the site. Each habitat had its characteristic assemblage of species which overlapped with adjacent nontypical habitats. The general air flow was from west to east. We assumed that ecological effects of Solar One would be mostly manifested downwind of the site. Because the downwind area to the east consisted of a relatively undisturbed desert ecosystem, we chose to concentrate our construction phase studies in that area. However, bird populations were monitored in other habitats adjacent to the site as well as on the site itself. Biological monitoring was continued in the down-wind area during testing and operations but at a reduced level.

We were also influenced in our initial planning by the expectation that the program would continue not only through the period of construction of Solar One, but also during testing and operation of the facility. Many of the physical measurements we made downwind of the sites were more logically related to operational than construction phases of the project.

3.1 Abiotic Monitoring

The profound effects that changes in physical factors, particularly rainfall, can have on ecosystems make it imperative that the physical environment in which biological observations are made be well documented. These abiotic factors include rainfall, soil physics and chemistry, soil moisture and temperature, air temperature and quality, and--in the case of disturbed areas--saltation and sand movement. Various abiotic features of the Solar One environment are treated in later sections of this report, but a brief background discussion of some particularly important variables is presented below.

3.1.1 Micrometeorology

The importance of micrometeorological effects on ecosystems and the question of whether solar central receiver systems can affect local microclimates strongly influenced our study plan.

Some qualitative predictions of micro- to mesoclimatic changes in a heliostat field have been based on assumed alterations of albedo coupled with effects of heliostats on normal air flow (Energy Research and Development Administration 1977, Energy and Environmental Analysis 1979). Other more quantitative forecasts have been based on computer simulations (Davidson and Grether 1977, Bhumralkar et al. 1980). All of these evaluations have involved very large systems ($\geq$ 100 MWe), and not all are in agreement. One assessment expressed the view that the net albedo of the heliostat field would be about 56%, almost twice as high as the natural albedo of the environs. It was further stated that the "...increased reflectivity [of the field] could cause an appreciable cooling of air flowing over the mirror field during...daytime hours" (Energy Research and Development Administration 1977). This would imply, then, some daytime cooling of the area downwind of the field. These views were reiterated in the environmental impact statement for the Barstow project (Environmental Improvement Agency 1977), and were also among those suggested by Bhumralkar et al. (1980). None of these evaluations took into account the effects of clearing vegetation from the mirror field. Because of the removal of these plants the dissipation of heat by transpiration is eliminated. Davidson and Grether (1977) considered that the albedo of the mirror field would be reduced, and in a "global analysis" of climatological effects of one million 100 MWe plants assumed the "darkening" of 3 million km^2 of land. We undertook to analyze the off-field environment on the downwind side carefully so as to determine i) whether air temperature profiles were altered by the existence and operation of the STPS and ii) if so, to what distance such an effect was expressed.

Intensive meteorological monitoring done within the heliostat field by McDonnell Douglas Astronautics Company bore primarily on operation of the facility and analysis of its performance. The highest priority measurements were defined as direct insolation, wind speed, cloud shadow pattern, wind direction, dry bulb temperature, dew point temperature, and hail formation. Lower priority measurements include circumsolar radiation, atmospheric turbidity, barometric pressure, precipitation, and global insolation. Precipitation was a low priority variable because rainfall data are important only as they may bear on the cleansing of heliostats. These kinds of meteorological data are presented in two comprehensive volumes (McDonnell Douglas Astronautics Co. 1983, 1984).

For our purposes, however, it was important to understand how changes in the microclimate of the heliostat field might influence conditions beyond the boundaries of the plant site, and specifically as such changes might effect the ecosystem. Our micrometeorological studies might better be termed bioclimatological since we were concerned principally with the environment experienced by the biota and thus the properties of air from the soil surface to 2 m above the ground, rainfall, soil moisture relationships, and evapotranspiration (See Section 4.0).

3.1.2 Air Quality

Ambient air quality in the vicinity of the solar site has been monitored continually since 1979 by the Statewide Air Pollution Research Center under sponsorship of SCE. Environmental Applications, Inc. in their analysis of the data (1980), discussed the significant influences of pollutants from the Los Angeles Basin. More locally, the primary source of pollutants is Southern California Edison's Coolwater Generating Station. Through 1978 the station consisted of two gas-burning units. Early in 1979 a third unit went online, and a fourth unit was completed during the summer of 1979. These last two units burn a distillate resembling jet fuel. The central receiver of a solar thermal power plant becomes so hot (ca. 500° C) during operation that various chemical reactions could be catalyzed in the air next to the receiver wall. For example, nitrogen and oxygen in the air combine to form NO_x. It has been calculated that amounts of NO_x or photochemical pollutants formed at the receiver face would not be significant in terms of local air quality (Perrine et al. 1981). As a consequence we did not undertake a separate air quality monitoring program but rather depended upon the SCE-sponsored study to detect new levels of pollutants should they occur.

3.1.3 Sand Movement

We expected that large amounts of dust and sand would be blown into areas (downwind) of the heliostat field when the area was cleared and graded in the fall of 1979. This sort of unconsolidated material is important not only because of its possible effects on the off-field environment, but also because it could interfere with successful operation of the facility. Large amounts of loose sand outside the heliostat field could be remobilized by winds blowing from the east and carried back into the field . Thus we undertook to monitor movement of unconsolidated surface material (Section 4.6).

3.2 <u>Biological Monitoring</u>

In setting up a plan of monitoring we did not adopt a total ecosystems approach. As Suter (1981) has pointed out, there are often good reasons not to do this because it is so difficult to bring general ecological theory to bear on project-specific issues. More important, the evaluation of a comprehensive array of variables (e.g., many micrometeorological parameters, static and dynamic features of many different kinds of plants and animals) is not economically feasible. We simply made comparisons of a few key meteorological variables and changes in the states of a limited array of "indicator" species or assemblages of species of plants and animals. Indicator species were numerically abundant and possessed attributes amenable to convenient and reliable evaluation -- whether of growth, reproduction, or numbers. Indicator species also exhibited pre-construction similarity in areas adjoining (but not within) and at a distance from the heliostat field. The areas of interest were those i) immediately east (downwind) of the mirror field, and ii) from 300 m to 4 km east of the field -- the distance depending on what was compared and evaluated. The detection and interpretation of divergences in paired areas was the basic rationale of the off-field monitoring program.

3.2.1 Indicator Species

The biological indicator species selected for particular attention are described briefly below. Of the woody perennials, bur-sage (Ambrosia dumosa) is a small shrub, widely distributed between 100 and 1900 m altitude from southeastern California and Sonora into southern Nevada, southwestern Utah and southern Arizona and New Mexico (Benson and Darrow 1954). It is often numerically dominant in associations with creosotebush. Desert saltbush (Atriplex polycarpa) grows on alkaline soils below 1700 m from southeastern California, adjoining portions of Sonora, and southern Nevada into extreme southwest Utah and southern Arizona (Benson and Darrow 1954). It is often associated with disturbed soils. Creosotebush (Larrea tridentata) ranges from southeastern California and Sonora across southern Nevada, southwestern Utah, Arizona, New Mexico and into western Texas. It generally occurs below altitudes of 1700 m and is the dominant species of many desert communities in southwestern U.S. (Valentine and Gerard 1968, Munz 1974).

In terms of overall structure and total biomass, annual plants are of much less importance than the larger shrubs. However, these smaller plants represent a volatile and dynamic component of the desert community and may be extremely important as sources of food and water for animals. Only five species were consistently and commonly represented in our study areas: a small boraginaceous annual (Cryptantha angustifolia), a species of buckwheat (Eriogonum trichopes), a non-native but long established herb (Erodium cicutarium), desert gold (Geraea canescens), and a non-native annual grass (Schismus arabicus). We focused primarily on numbers of annual plants in the study plots, their individual dry weights, and estimates of aggregate dry weights (standing crops) of all annual species.

Species of vertebrates judged to be good indicators were Merriam's kangaroo rat (Dipodomys merriami), the roundtail ground squirrel (Spermophilus tereticaudus), the Horned Lark (Eremophila alpestris), the western whiptail lizard (Cnemidophorus tigris), and the zebra-tailed lizard (Callisaurus draconoides).

Merriam's kangaroo rat is a nocturnal granivorous, heteromyid rodent, active year-around in this part of the Mojave Desert. The species is one of the more abundant and widely distributed of the kangaroo rats, extending from northwestern Nevada through southeastern California, most of Arizona, and southwestern New Mexico well into central Mexico (Burt and Grossenheider 1952). Adult males weigh about 38 g, females slightly less. The roundtail ground squirrel is a diurnal sciurid, which is inactive most of the winter months. The species occurs only in southeastern California, western Arizona and adjoining portions of Baja California and Sonora (Burt and Grossenheider 1952). Adults weigh about 120 g.

The western whiptail lizard is a diurnal, insectivorous lizard, with a relatively brief period of aboveground activity (late April-August) by adults (Turner et al. 1969). The species is widely distributed in western U.S., ranging from southern Oregon and Idaho throughout California, Nevada and Utah, most of Arizona, and as far east as southern Colorado and western Texas and south into Mexico (Stebbins 1966). Adults weigh around 16 g. Females lay one or two clutches of eggs in the spring and hatchlings appear in late August and may be active into early October. The zebra-tail lizard is also diurnal, insectivorous, and inactive during the winter. The species occurs from northern Nevada through southeastern California and southern Arizona into Baja California and Sonora (Stebbins 1966). Adult males weigh around 17 g, females 13. Eggs are laid in the spring and the hatchlings appear in late August or September.

The Horned Lark is a bird which breeds widely in western North America. It is a resident species in the vicinity of Solar One, breeding in April-May. The nest is a grass-lined depression on the ground and two clutches of 3-5 eggs are usually laid (Peterson 1969). These larks feed on grass seeds and forbs taken at or near ground level.

We expected considerable public interest in possible effects of Solar One structures on birds. An appreciable literature dealing with bird mortaliy around man-made towers has grown up during the past 20 years (e.g., Ganier 1962, Laskey 1963, Caldwell and Wallace 1966, Stoddard and Norris 1967, Crawford 1974, Avery et al. 1978). The tower at Barstow is not tall (100 m) when contrasted with others studied, but the Barstow tower and associated heliostats were expected to cause some mortality of migrants and resident species. For example, seasonal bird mortality in the vicinity of a 366-m tower in North Dakota was estimated at over 1,000 individuals (Avery et al. 1978). At Solar One, it was also possible that birds would roost on heliostats, or even attempt to nest within the panel supports and affect system reliability.

3.3 Monitoring During Testing and Operations of Solar One

The largely negative effects of construction on the ecosystem adjacent to the heliostat field, coupled with development of the heliostat field and development of nearby land for other purposes led to a modified study plan during Solar One testing and operation which deemphasized sampling off-site biota and emphasized characterization of micrometeorological effects both within the heliostat array and the downwind study area to the east (Turner 1982). Observations of birds and small mammals were continued through the spring of 1984 and observations of natural revegetation within the heliostat array also were undertaken (Smith 1984).

4.0 ABIOTIC MEASUREMENTS

4.1 Rainfall

From a biological point of view, the single most important environmental factor at the Solar One site was rainfall. Table 4.1 summarizes rainfall between August 1978 and December 1983, and contrasts these measurements with longer-term mean values based on records between 1951 and 1974.

Precipitation in the Daggett area is controlled by two major features of atmospheric circulation. Winter storms from the Pacific bring widespread rainfall from November through April. In summer, moisture comes principally from the Gulf of Mexico and rainfall occurs in isolated showers with appreciable local variability. Note the extremely heavy rains which occurred in August 1983. Occasional tropical storms in September and early October may bring rainfall, but this did not occur during our period of observations.

Total annual rainfall exceeded long-term mean rainfall in every year except 1981. This is a deceptive point, because the seasonal distribution of rainfall is more important than the total. Relationships between germination and growth of Mojave Desert plants and amounts and seasonal distribution of rainfall have been analyzed by Beatley (1967, 1969a, 1974): "Phenological events in Mojave desert systems are triggered by heavy rains (>25 mm). The most predictable and consequential of these is a regional rain between late September and early December. This rainfall event is usually the precursor of successful vegetative and reproductive growth of plants the next spring..." (Beatley 1974).

Viewed from this perspective, winter rainfall between August 1978 and December 1981 (influencing biological events the seasons of 1979 through 1982) was less than that required to stimulate normal germination and growth of desert plants. Cummulative winter rainfall during 1982 was about normal, and that during 1983 well above average.

4.2 Soil Temperatures

A general characterization of soil temperatures was made between January and September 1979 (Table 4.2). Soil temperatures were measured with thermistors buried at depths of 10, 20, 30, 40, 50 and 100 cm at two sites on the prospective heliostat field. One site was in sandy soil, the other in silty soil. At 100 cm soil temperatures fluctuated only about 1° C per day, while at 50 cm daily changes ranged over about 5° C. At 10 cm temperatures were highly variable, with amplitudes of up to 20° C in a day.

4.3 Soil Moistures

Soil moisture was measured using themocouple psychrometers (Wescor PT-51-10) read with a Wescor HR33-T dewpoint microvoltmeter. A total of 50 psychrometers were installed between September-December 1978. The general pattern was to bury probes at 2, 5, 10, 20, 50 and 100 cm with shielded wires running to the surface. All sampling sites were from 700-900 m northeast of the center of the prospective mirror field. Two installations were placed so as to measure the effects of a wind-deposited mound: one within the mound, the other nearby. One set of psychrometers was buried beneath a road, another on

Table 4.1

Rainfall (mm) in the Daggett area between August 1978 and December 1983 and long-term mean rainfall (based on 1951-1974).

Months	1978	1979	1980	1981	1982	1983	Long-term mean
January	-	31.0	39.8	9.9	22.9	29.2	11.4
February	-	16.6	54.3	7.4	13.0	24.9	6.9
March	-	19.1	18.4	16.0	4.1	46.5	7.4
April	-	0	10.6	2.1	15.5	0	6.9
May	-	0	0	4.0	1.3	0	2.0
June	-	0	0	0	1.5	0	2.3
July	-	11.4	1.3	0	35.6	0	8.1
August	7.1	19.7	6.4	1.2	25.9	65.8	13.0
September	1.5	4.0	0	2.8	2.0	3.6	9.9
October	0.3	4.2	0	14.0	4.1	29.2	5.1
November	6.8	0	0	4.6	8.9	7.6	8.6
December	7.4	8.6	0	0.2	21.6	17.8	10.4
Totals		114.6	130.8	62.2	156.4	224.6	92.0

Table 4.2. Seasonal changes in mean soil temperatures (°C) at three depths (unshaded soil) at the Barstow STPS site in 1979. Temperatures were taken between 0900 and 1200.

Month	Number of readings	Depths (cm) 10	50	100
January	2	7.8	8.4	11.6
February	1	12.7	10.5	11.9
March	1	22.1	12.5	13.0
April	4	23.2	17.5	16.1
May	3	29.2	23.4	20.5
June	5	27.5	28.5	25.7
July	4	29.6	30.1	27.7
August	4	30.3	30.1	28.7
September	2	27.5	29.2	28.0

the adjacent shoulder. Other installations were beneath shrubs and cacti. Psychrometers were read monthly between December 1978 and March 1979; weekly thereafter.

Measurements of soil moisture between December 1978 and September 1979 were given by Turner (1979: 57). These measurements showed that soils quickly reached saturation, or near saturation, down to 20 cm following heavy rains in January. The last spring rains were in March, after which upper soil layers dried, and by May soils to 10 cm were generally too dry to measure water potentials. Changes in soil moisture below 50 cm were not synchronized with rains. Maximum soil moisture contents at 100 cm did not occur until April or May, after which water potentials changed only modestly over the next four months. Soil moistures were not significantly different beneath a wind-deposited sand mound and in an adjacent flat area.

These general trends were affected by a number of factors. Fine textured soils (but not those with high clay contents) have higher hydraulic conductivities than sandy soils in the middle range of water potentials encountered at the Solar One site. This relationship is reversed at higher soil water potentials. Comparisons of measurements beneath shrubs and in the open showed that evaporation was slowed by shrubs during the summer. Following storms in July and August of 1979 shallow soil layers (2-10 cm) beneath shrubs were slightly wetter than in the open. Roads affect soil water relations beneath them. Water is apparently concentrated in the tracks and then persists further into the dry season. A comparison of all stations showed that the greatest seasonal change in soil moisture content at 100 cm occurred beneath a road. This was partly due to concentration of water in tracks and partly to compaction of soil and associated increases in hydraulic conductivity. Water movement to a depth of 100 cm was about 0.009 $cm^3 \cdot cm^{-2}$ (soil surface)$\cdot day^{-1}$. This was about 25% of the total input of precipitation for the rainy season (0.04 $cm^3 \cdot cm^{-2} \cdot day^{-1}$).

It can be assumed that some aerosol pollutants precipitated by rain or dissolved after surface deposition would move similarly, except that somewhere below 100 cm almost all water movement would be by vapor diffusion and solutes would be precipitated in the soil. The data show that the 1978-79 winter rains were not adequate to recharge deeper ground water to a significant degree. Summer rains would be even less effective because evaporation would be greater. Hence, soil water at the Solar One--entering at rates similar to natural precipitation--is relatively immobile. Aerosol substances in rain, or dissolved by rain at the soil surface, will thus tend to collect in the root zones of local plants. Percolation to groundwater depths would only be expected following heavy rains or introduction of unusual amounts of water by operation of the facility.

4.4 Micrometeorology

Possible influences of solar thermal power plants on microclimatic variables have been considered by several authors (Davidson and Grether 1977, Patten 1978, Bhumralkar et al. 1979, 1981; Lindberg et al. 1982). Simulation studies have generally suggested that effects of altered energy exchange properties or heat ejection by solar plants would be minor or nonexistent (Davidson and Grether 1977, Bhumralkar et al. 1981) unless the facility were of enormous size (Bhumralkar 1979). Analyses of this nature involve simulations of extremely complex processes, and the following comments by Bhumralkar et al. (1979) are well worth bearing in mind: "The most important finding to date is that there are...questions and uncertainties about the capability of the two-dimensional mesocale model to simulate real atmospheric conditions realistically. In view of these, it is not possible at this stage to make a definitive and quantitative assessment of the effect of a solar power plant on...local and regional weather conditions."

Patten (1978), Patten and Smith (1980) and Lindberg et al. (1982) discussed micrometeorological parameters which could be influenced by solar thermal power plants. Some of these variables were investigated to explore the possible influence of such facilities within and downwind of heliostat fields (Patten and Smith 1980).

In keeping with the rationale that the heliostat field might have subtle micrometeorological influences outside of the immediate field environment, air temperature profile measurements, evaporation rates and wind speed profiles downwind of Solar One were made between November 1980 and September 1982 (see Turner 1981, 1982; Radkey and Zambrano 1982).

For many of these measurements, the general procedure was to select two areas for investigation and to make paired measurements at the same moment--or over the same time intervals. The idea was to select the areas to be compared so that some inferences as to possible influences of the solar thermal power plant might be drawn. Statistical comparisons were based on paired _t_-tests. We expected any possible off-field effects to be most clearly expressed in areas downwind of the heliostat field. Hence, some measurements were made directly east of the field during west wind conditions and contrasted with measurements made in areas outside the field's influence. Another technique was to compare measurements in downwind areas, but at increasing distances from the eastern edge of the field.

The positioning of sites, the equipment used, the precise time periods of measurements, and details of analytical procedures have all been set forth in previous reports (Turner 1981, 1982) and will not be reviewed here. A special study by AeroVironment Inc. (Pasadena) involving wind flow measurements was conducted in June 1982 and methods of this experiment were given by Radkey and Zambrano (1982).

4.4.1 Air Temperature Profile Measurements in 1980 and 1981

These measurements were made at two sites. One site (X-1) was established 50 m east of the fence around the heliostat field, on an east-west line with the receiver tower. We considered this the "experimental" site because, with prevailing west winds, micrometeorological patterns of this area were most likely to show effects of the field and associated structures. The control site (X-2) was about 700 m north of X-1 and about 200 m northeast of the field, where prevailing winds were unaffected by power plant structures.

Average air temperatures ranged from 10° C in December 1980 to around 35° C in June and July 1981. In general, temperature height profiles showed typical lapse conditions during the day and inversions at night at both sites (Figs. 4.1 and 4.2). Daytime temperature height profiles showed no consistent pattern of differences at the two sites. However, except during December,

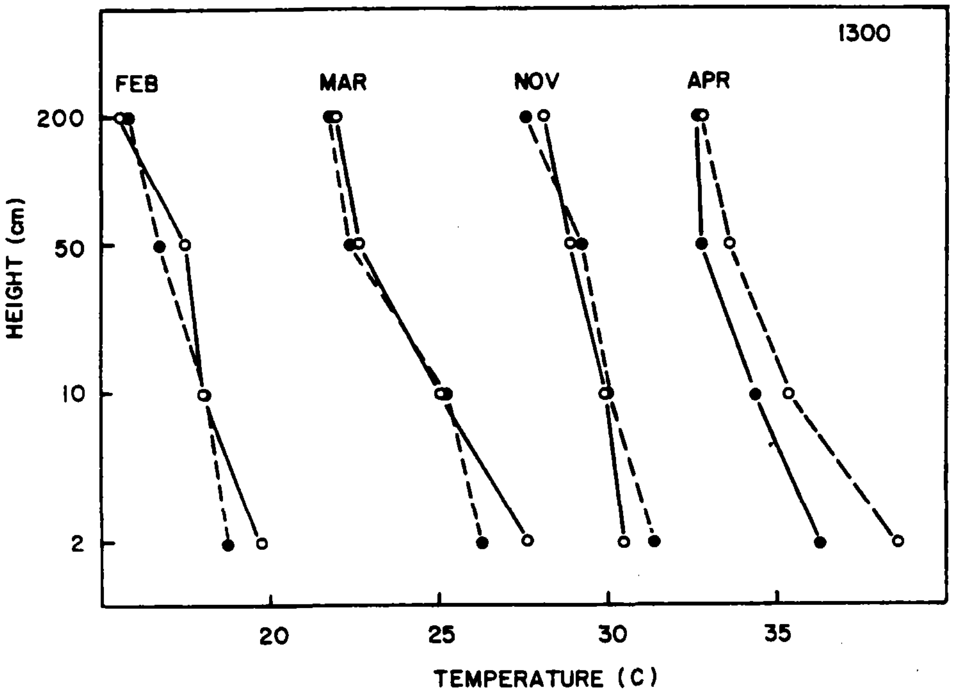

Figure 4.1 Air temperature profiles (at 1300 hours) at two sites near the heliostat field between November 1980 and April 1981. Open circles: experimental site (directly downwind of the heliostat field); solid circles: control site.

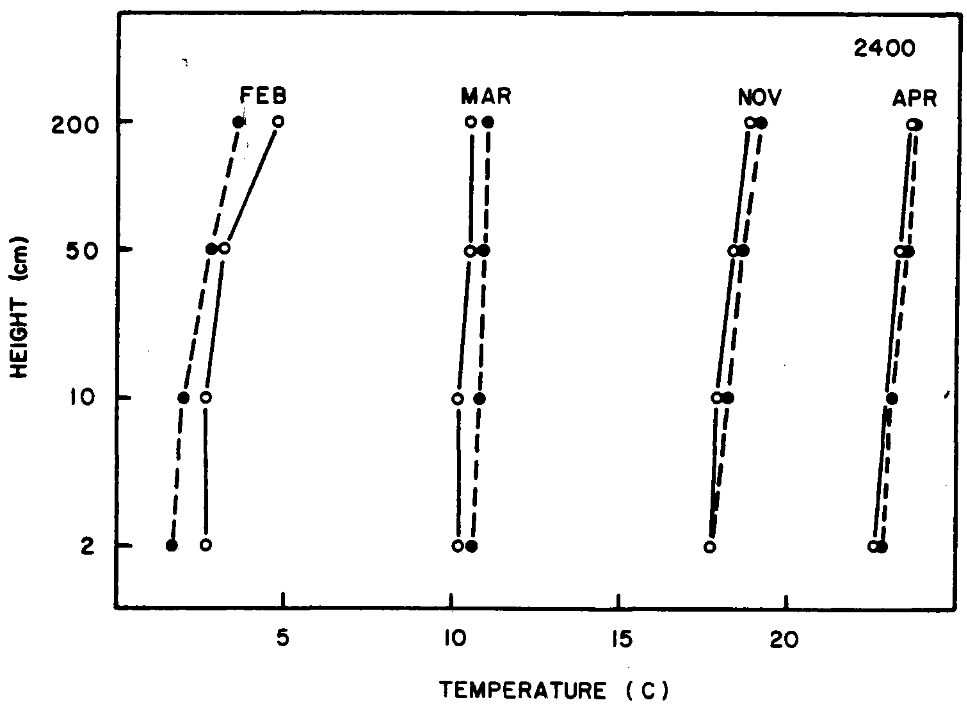

Figure 4.2 Air temperature profiles (at 2400 hours) at two sites near the heliostat field between November 1980 and April 1981. Symbols as in Figure 4.1.

night temperatures at the control site (X-2) were cooler than at the experimental site (X-1).

Daytime average temperatures and peak average temperatures at 2 m were from 1.3 to 0.2° C warmer at the control site (X-2) between November 1980 and March 1981. Conversely, between April and July 1981 these temperatures were generally from 0.2 to 0.75° C cooler at the X-2 site (Fig. 4.3). Night average and minimum temperatures at X-2 (2 m) were generally cooler by 0.8 to 0.1° C (Fig. 4.4).

Daytime average and peak average temperatues at 2 cm were consistently warmer (up to 5.8° C) at the control site (X-2) and, except during November, mean night and night minimum temperatures at this height were consistently cooler (up to 0.8° C) at the control (X-2) site (see Turner, 1981: 33). We expected temperature patterns at 2 cm to be more susceptible to influence by characteristics of energy exchange at the soil surface. On the other hand, temperatures at 2 m are certainly more affected by advected energy. This, in turn reflects the influence of upwind energy exchange conditions (Oke, 1978). It is possible that the shift in daytime temperature differences between March and April 1981 at 2 m resulted from construction activities in the heliostat field. The sometimes dramatic differences between the control (X-2) and experimental (X-1) sites at 2 cm may have resulted from changes in the soil surface composition. The experimental site (X-1) is in the area where new sand was deposited and where a high proportion of the surface is covered with fine sand. The control site, however, has a more typical ground surface consisting of desert pavement interspersed with open areas.

The data from which the temperature differences at the two sites were derived (Figs. 4.3, 4.4) were not all significantly different (based on paired t-tests). Daytime average temperatures at 2 m were not significantly different from one another in December 1980, April 1981 and May 1981. Day peak average temperatures at 2 m were not significantly different from one another in March and May 1981. Night average and night peak average temperatures were not significantly different from one another in May and July 1981. At 2 cm, day average temperatures (February 1981), day peak average temperatures (November 1980 and February 1981), and night peak average temperatures (May 1981) were not significantly different. In spite of the foregoing we believe the general site relationships described are supported by the overall body of our data.

The magnitude of temperature differences between control (X-2) and experimental (X-1) sites at 2 m (up to 1.3° C but usually 0.5° C) is modest, and is not likely to augur important biological or ecological problems. However, ecosystems can be affected by very small temperature differences when expressed over extensive areas and for long periods of time (e.g., Nobel, 1980). The temperature differences between control (X-2) and experimental (X-1) sites at 2 cm (up to 5.8° C) are of greater ecological interest--if indeed these differences represent effects of construction. The soil surface, and the zone just above it, are an important region for small animals and plant germination and growth. Temperature differences of 5-6° C could influence these biological processes, although the intensity of the effect would be modified by the timing of various biological events.

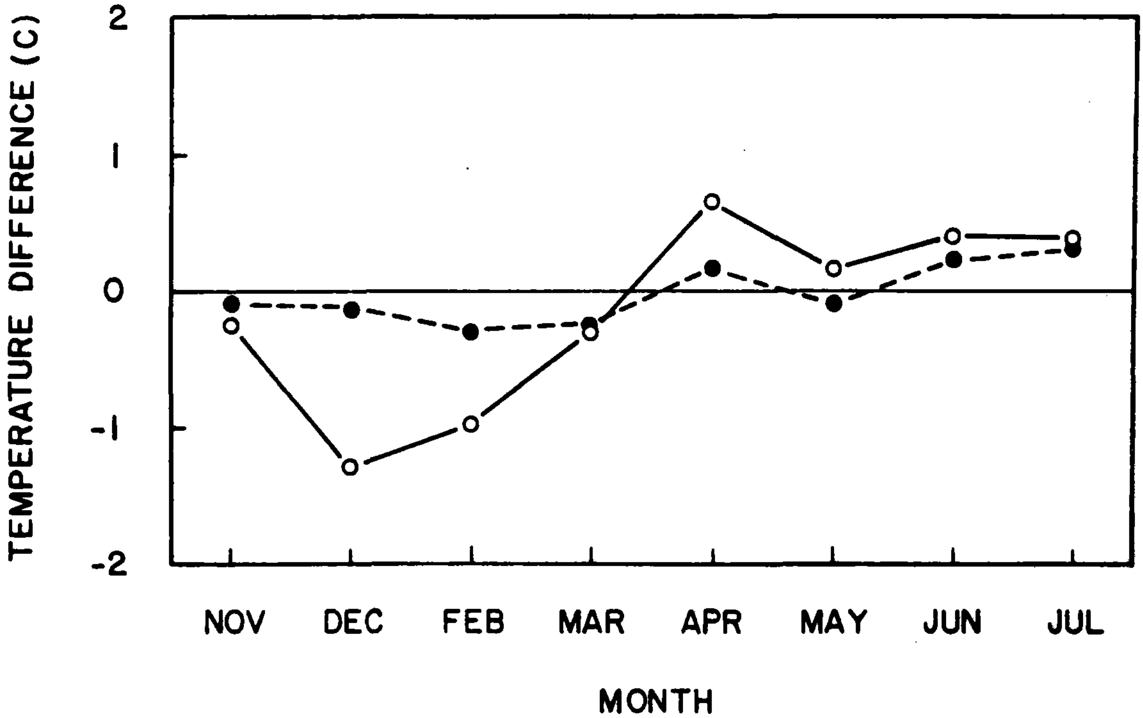

Figure 4.3 Differences between mean temperatures (at 2 m) at two sites near the heliostat field between November 1980 and July 1981. Open circles: mean daytime peak temperature differences; solid circles: mean daytime temperature differences.

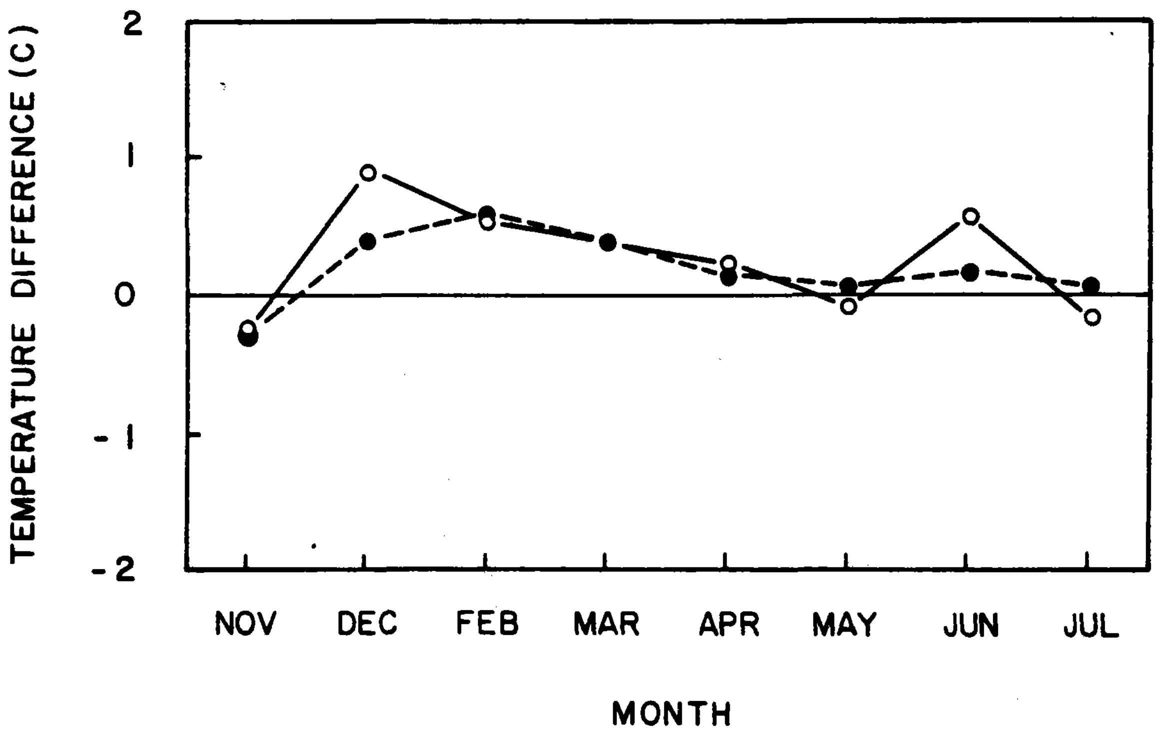

Figure 4.4 Differences between mean temperatures (at 2 m) at two sites near the heliostat field between November 1980 and July 1981. Open circles: mean nighttime minimum temperature differences; solid circles: mean nighttime temperature differences.

4.4.2 Air Temperature Profile Measurements in 1982

Maximum daily air temperatures near Solar One increased from about 20° C in March 1982 (day 90) to about 40° C in late July and August (days 200-240). During the same period minimum daily air temperatures increased from about 10° C to roughly 27° C and dew point temperatures rose from -15° C in late April (day 112) to 18° C after summer rains. These observations were similar to 30-year patterns established at nearby Barstow-Daggett Airport (Turner 1979, McDonnell Douglas Astronautics Co. 1983).

Table 4.3 contrasts differences in air temperatures at 50 cm and 2 m measured at points about 25 m east of the perimeter fence and at points 100 and 150 m east of the fence. Samples include measurements made at all times between March and September 1982 (except those during August). These measurements were made during west wind conditions. The table shows that air temperature differences at 2 m were greater during the day (0601-1800) than at night. Temperature differences 150 m downwind were generally greater than at 100 m downwind. Measurements in Table 4.3 show that locations near the field were cooler than sites up to 100 m downwind, except between 1201-1800 h when sites closest to the field were warmer than ones 100 m downwind. Between 1201-1800 h temperatures 150 m downwind were also cooler than those closer to the field.

Between August 27 and 29, 1982, we made air temperature profile measurements (0 to 2 m) at a point 125 m into the eastern part of the heliostat field. At the same time we made corresponding measurements at a point about 25 m east of the last row of heliostats, but still within the perimeter fence. Differences between temperatures recorded at these two points simultaneously were computed by subtracting temperatures measured outside of the heliostat array from those within (Fig. 4.5).

Surface temperatures within the heliostat field were much lower than those outside during the morning (0800-1200 h), but warmer between 1500 and 1900 h. Similar patterns, though of less amplitude, were exhibited at 2, 10 and 50 cm. At 2 m the pattern was reversed on August 28, but was similar to the other profiles on August 29.

Figures 4.6 and 4.7 illustrate air temperature profiles within (Fig. 4.6) and outside of (Fig. 4.7) the heliostat array for a 41-h period between 1900 h on August 27 and 1200 hr on August 29, 1982. These figures illustrate two points of note. First, between 0800 and 1000 h on both mornings lapse conditions outside the heliostat array were strongly developed. At the same time this condition was more weakly expressed within the heliostat field. (The lapse condition occurs when temperatures decrease with height above ground). Shapes of lapse curves within and outside of the heliostat array were also different throughout the day. Second, almost no inversion occurred--either inside or outside of the heliostat area.

4.4.3 Measurements of Evaporation Rates in 1982

Pan evaporation rates at 3 control sites about 900 m northeast of the heliostat field increased, on average, from about 8 ml/h in April (day 110) to about 22 ml/h in early July (day 195)--with subsequent decreases in late July and August (see Turner 1982: 34). These evaporation rates were typical of

Table 4.3. Mean air temperature (^{o}C) differences ± standard errors of means measured at points 25 m (P) and 100-150 m (D) downwind of the east perimeter fence at Solar One. Paired differences were computed as D-P.

Hours	n	Distance of more remote sampling point (m)	Height of sampling points	
			50 cm	2 m
0001-0600	60	100	0.01 ± 0.004	0.05 ± 0.003**
0601-1200	75	100	0.31 ± 0.017*	0.24 ± 0.013*
1201-1800	60	100	0.01 ± 0.014	-0.15 ± 0.009*
1801-2400	80	100	0.09 ± 0.002	0.11 ± 0.002*
1201-1800	120	150	0.21 ± 0.009*	0.59 ± 0.009*

*Difference significant at 5% level.

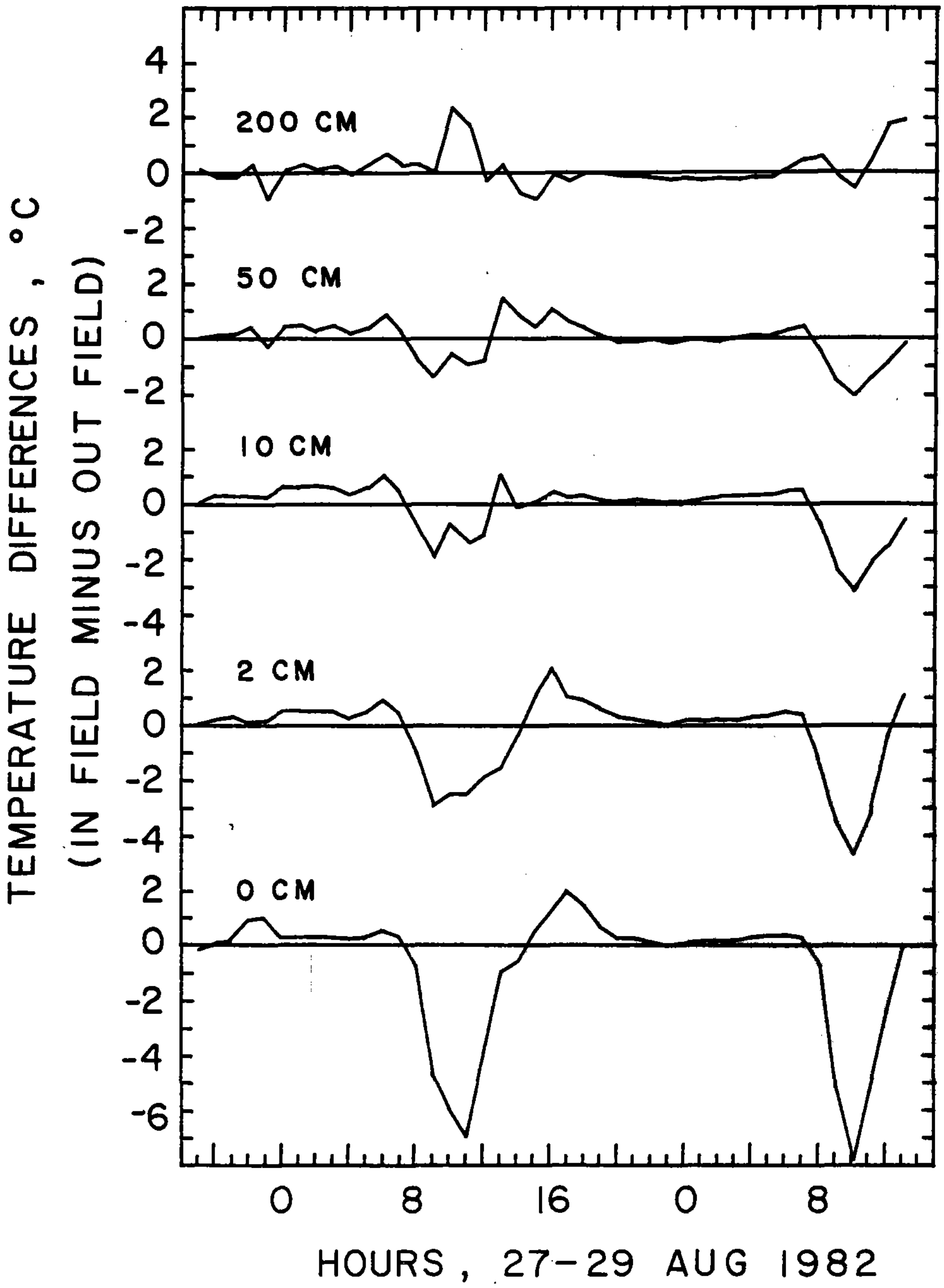

Figure 4.5 Differences in air temperatures measured within the Solar One heliostat field and 25 m outside of the heliostat array in August 1982.

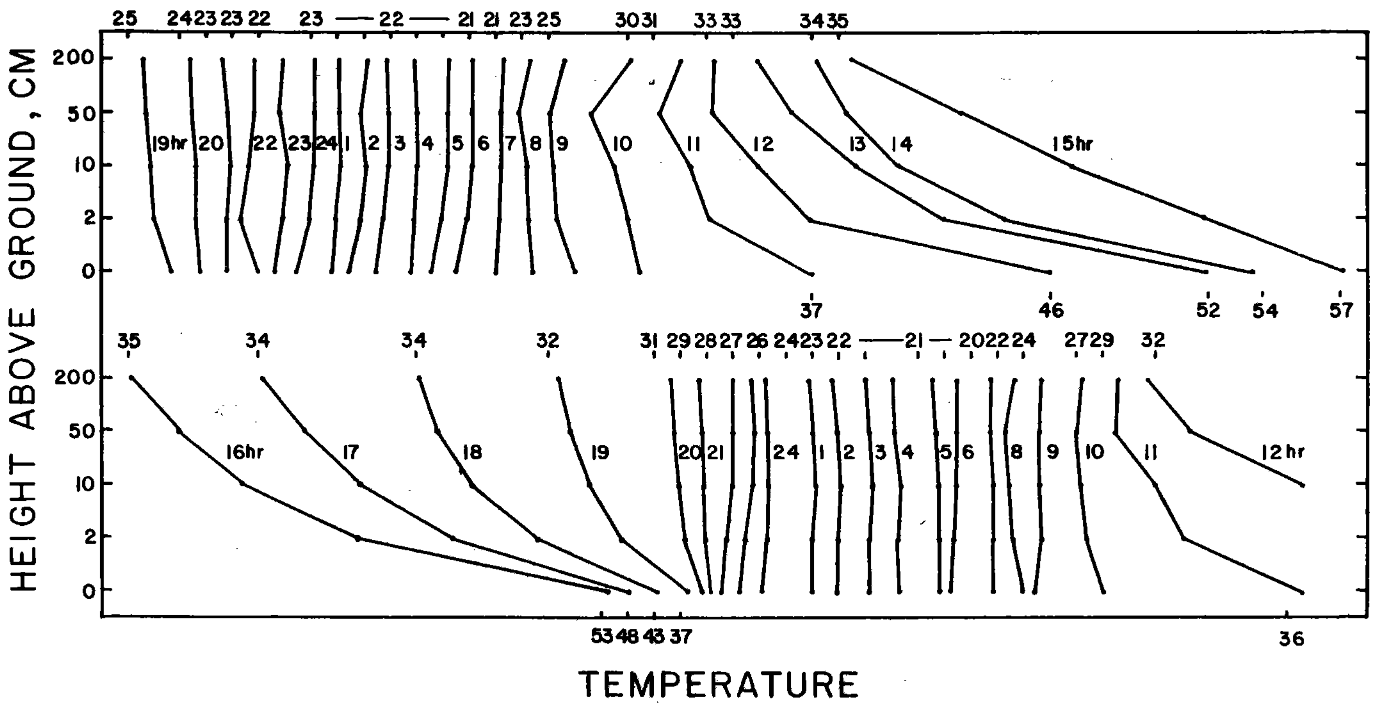

Figure 4.6 Air temperature profiles measured within the Solar One heliostat field over a 41-h period between 1900 h August 27 and 1200 h August 29, 1982.

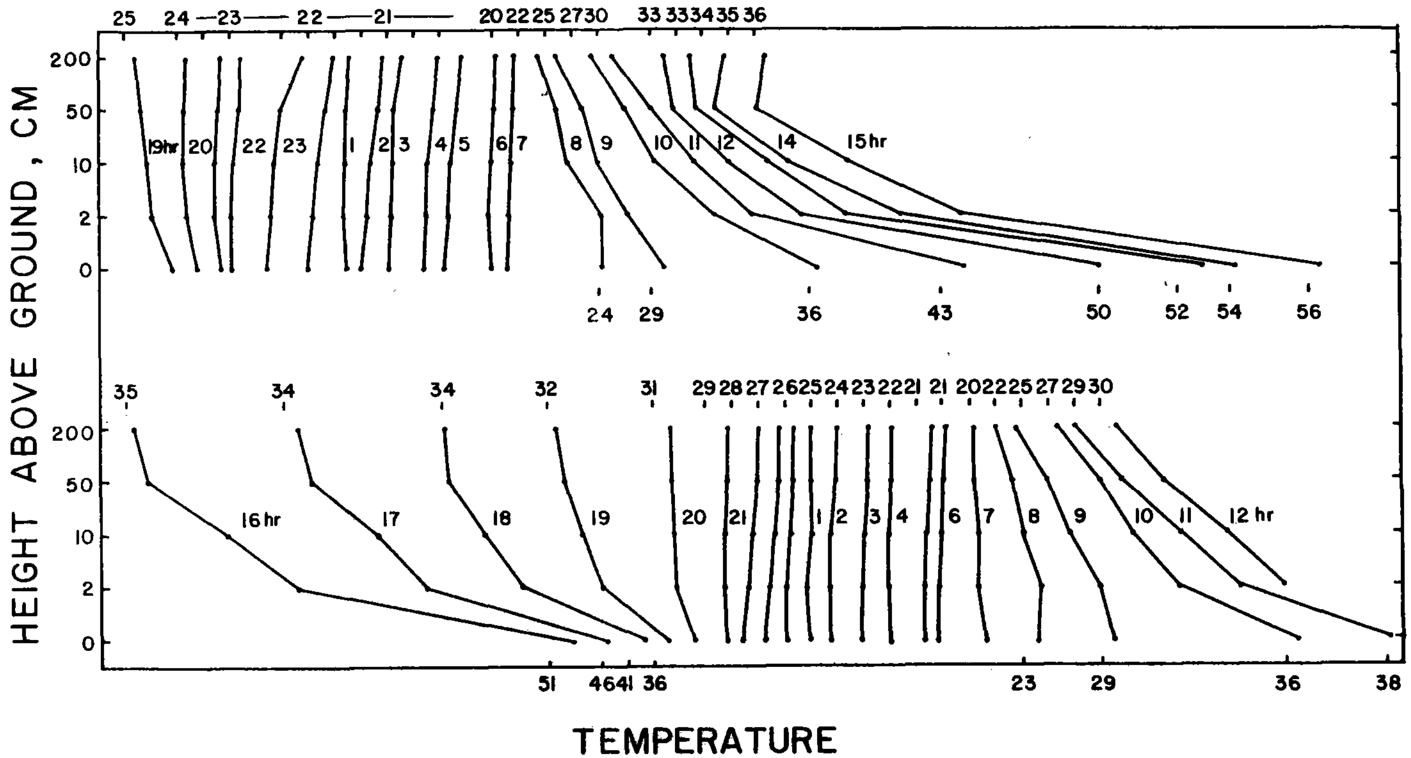

Figure 4.7 Air temperature profiles measured outside of the Solar One heliostat field over a 41-h period between 1900 h August 27 and 1200 h August 29, 1982.

arid and semi-arid environments (Rosenberg 1974). The pattern of increasing evaporation rate through day 195 was driven by increasing air temperatures over this interval, while the decrease in evaporation after that point was probably due more to high dew point temperatures (high atmospheric water content). An evaporation rate peak on day 112 in a cool part of the year was due to a cool, very dry air mass which moved through the area. Sharp evaporation rate decreases later in the year (days 182, 210, 225 and 237) were typically related to precipitation events with their high dew point and relatively low air temperature.

In order to compare evaporation rates at experimental and control sites we examined differences in observed rates (control minus experimental) between days 110 and 240 (Fig. 4.8). The experimental sites lay 50 and 200 m directly east of the field. Evaporation averaged about 1.2 ml/hr greater at the control site over this interval of time. These differences were compared by paired _t_-tests and results indicated that statistically significant differences occurred more often later in the period of observation.

We expected the heliostat field to affect the downwind environment only during periods of west winds (i.e., winds blowing across the field from the west). We compared relationships between evaporation rates at control and experimental sites under west wind conditions and at times when west winds were not blowing by regressing control site rates on experimental site rates (Fig. 4.9). The two regression lines in Fig. 4.9 had the same slopes, but differed significantly in their intercepts. That is, evaporation rates under west wind conditions at the experimental site were slightly (but significantly) lower than those measured at the control site.

The decrease in evaporation rate from pans downwind of the site during westerly wind flow conditions was almost certainly owing to a shelter effect caused by the heliostat field. Shelter belts commonly influence downwind regions for distances 10 to 25 times the height of the barrier, depending on barrier physical parameters (Oke 1978, Rosenberg 1974). The influence of belts depends on height, length and porosity. Increasing porosity permits wind penetration of a barrier and prevents the turbulent return of air which has overtopped the barrier. Longer barriers exert more constant influence, but gaps may cause jetting--thus increasing rather than decreasing air movement behind the barrier. Shelter belts generally are thought of as altering wind conditions (speed, turbulence) behind it, but conditions in the lee of a barrier are complex and not well understood (Rosenberg 1974). Evaporation is reduced in the lee of shelter belts (Hanson and Ranzi 1977; Rosenberg 1974). A mid-northern states study indicated that a 50% reduction in wind resulted in a 14% reduction in evaporation (Hanson and Ranzi 1977). It is reasonable to view the heliostat field as a variable highly porpous shelter belt with a height of up to 7 m. The influenced region (10-25 times height for a porous barrier) would then be up to from 140-175 m downwind with a maximum influence about 42 m downwind of the field perimeter (Rosenberg 1974).

4.4.4 Wind Speed Measurements in 1982

Wind speeds were compared at points 25 m and 100-150 m downwind of the heliostat field and also at points inside of and outside of the heliostat array.

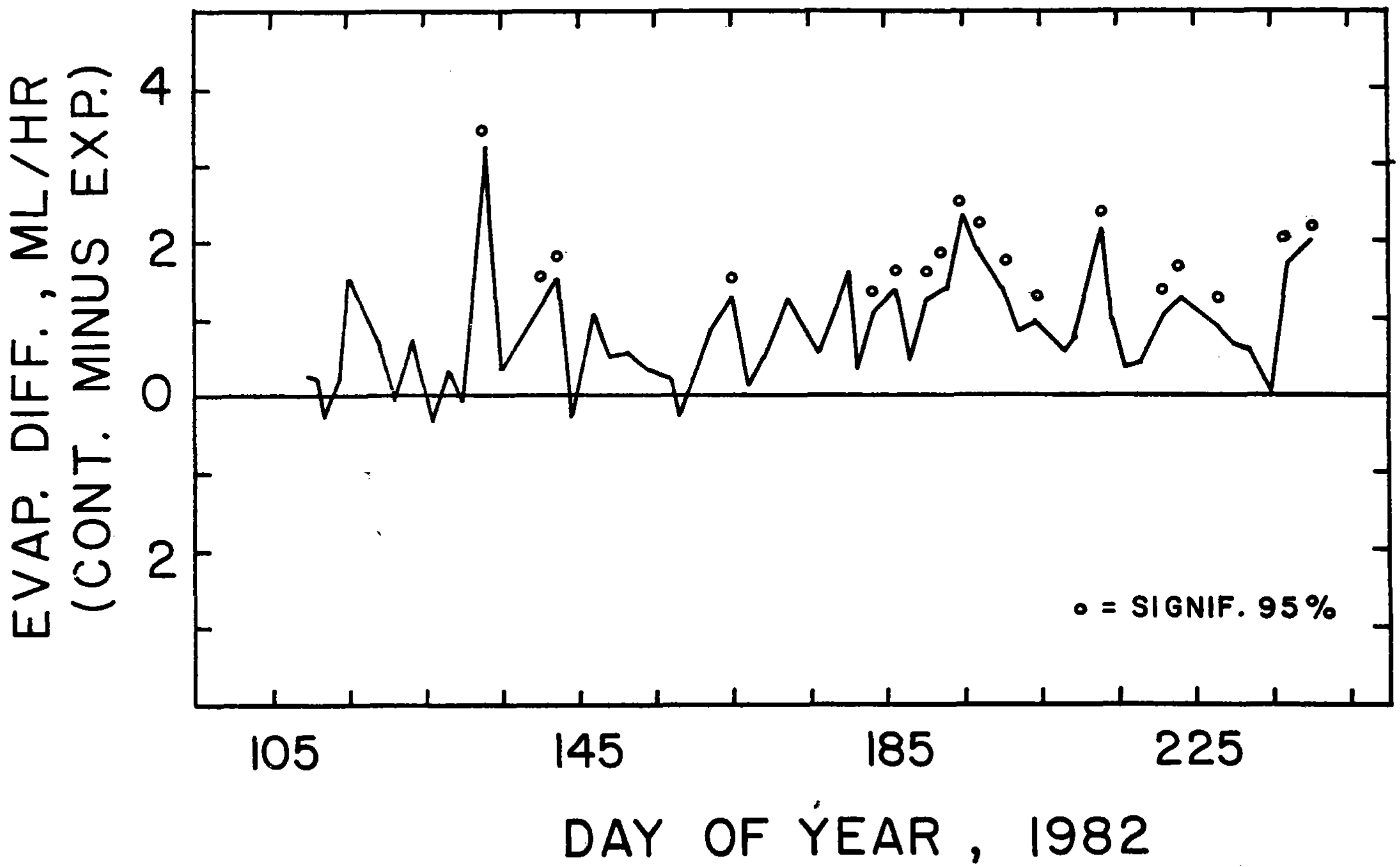

Figure 4.8 Differences in evaporation rates measured at a control site and at a point 25 m downwind of the Solar One heliostat field in 1982.

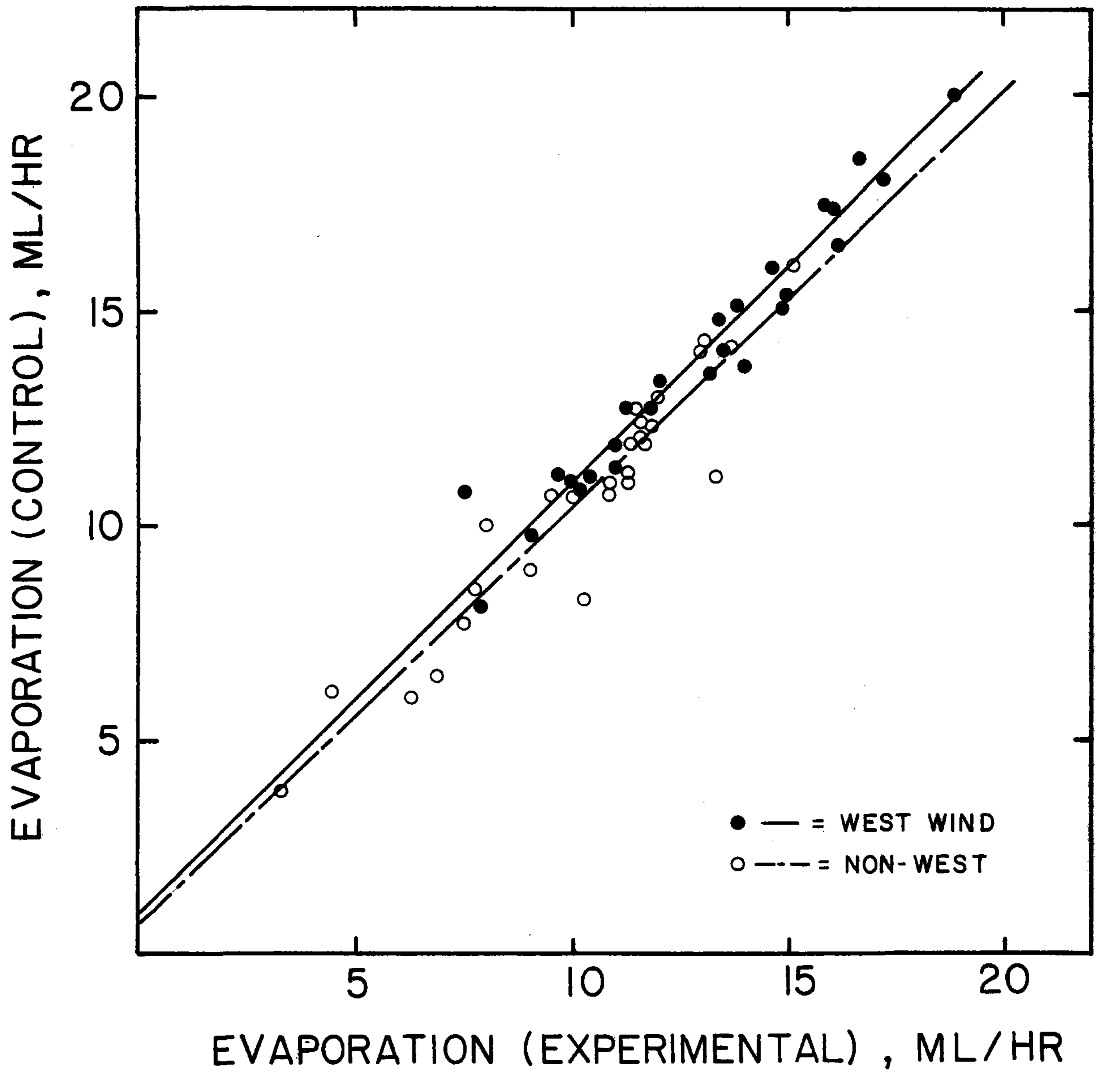

Figure 4.9 Evaporation rates measured at a control site plotted against those measured simultaneously downwind of the Solar One heliostat field.

Table 4.4 gives mean differences in wind speed measured at points close (ca. 25 m downwind) to the perimeter fence and 100 and 150 m downwind. Differences between stations were greater at 2 m, and wind speeds near the field were less than those farther downwind. At 1 m above the ground only differences between 0001 and 1200 h were significantly different.

Figure 4.10 illustrates differences in wind speeds (m/sec) measured inside of and outside of the heliostat array, as well as actual wind speeds measured outside the heliostat array. Wind speeds inside were clearly less than those measured outside the heliostats.

In June 1982 AeroVironment Inc. conducted a 5-day measurement program at Solar One using TALA kite anemometers. Data were obtained at strategic points to a distance of about 400 m downwind of the heliostat field and at a reference location about 300 m north of the heliostat field. At each of 8 downwind sites (100-400 m east of the field), kite measurements were taken for 10-min periods (one sample every 10 sec) at consecutive heights above ground of 10 m, 20 m, 30 m and 50 m. These data defined the wind shear profile. Mean turbulence intensities were also computed for all sampling points (Radkey and Zambrano 1982).

According to these authors wind speed was reduced downwind by about 15% relative to the reference point when heliostats were up. Radkey and Zambrano judged that this wake deficit was detectable from 1000 to 2000 m downwind of Solar One. Conversely, no wake deficit was measured when heliostats were stowed. It was also judged that windblown particulates would accumulate within the heliostat field itself or within 60 m of the downwind boundary of the field.

Radkey and Zambrano postulated that if a 100 MWe array of heliostats like those at Solar One were to be constructed, the wake deficit would extend over a height and downsteam extent in direct proportion of the linear diameter of the larger facility. These authors also observed that, "The magnitude of the wake deficit for a plant of infinite diameter should not exceed twice the deficit observed for the 10 MWe plant. Thus, the wind related environmental effects should be essentially of the same magnitude for a 100 MWe plant as for the existing 10 MWe plant."

4.5 Air Quality

4.5.1 Airborne Particulates

Beginning in August 1979, airborne particulates were measured every 6 days by personnel of the Statewide Air Pollution Research Center at the University of California, Riverside, at a site about 1 km southeast of the solar site. UCR used a Sierra Instruments Hi-Vol Air Sampler mounted about 3.8 m above the ground. Although the UCR station was not directly downwind of the solar site, we used their air sampling data for the period August 1979 to May 1980 because no other measurements were available for this period.

In July 1980 we installed a Sierra Instruments Model UV-1 High Volume Sampling System 100 m east (downwind) of the solar site. The instrument was positioned 1.2 m above the ground. Measurements were made every 6 days through August 1981. Net weights of material on filters were converted to estimates of $g \cdot m^{-3}$ of air flow.

Table 4.4 Mean wind speed (m/s) differences ± standard errors of means measured at points 25 m (P) and 100-150 m (D) downwind of the east perimeter fence at Solar One in 1982. Paired differences were computed as D-P.

Hours	n	Distance of more remote sampling point (m)	Height of sampling points	
			1 m	2 m
0001-0600	60	100	0.07 ± 0.003*	0.24 ± 0.004*
0601-1200	75	100	0.19 ± 0.005*	0.22 ± 0.004*
1201-1800	40	100	0.12 ± 0.010	0.37 ± 0.010*
1801-2400	100	100	0.04 ± 0.005	0.01 ± 0.005
1201-1800	78	150	0.13 ± 0.008	0.28 ± 0.008*

*Difference significant at 5% level.

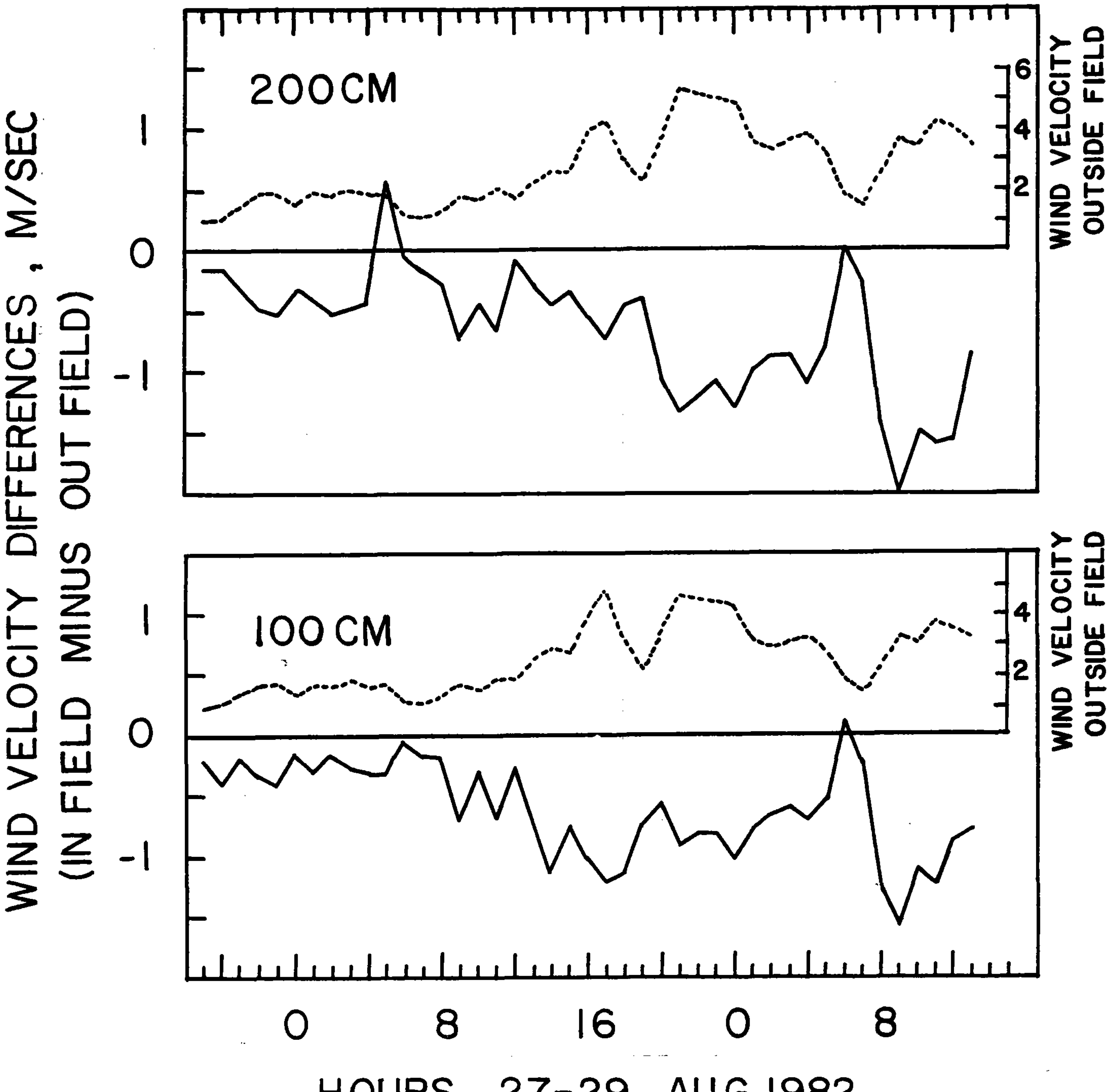

Figure 4.10 Wind speeds measured outside the Solar One heliostat field (above) and differences between wind speeds measured within and outside the heliostat array (below).

Table 4.5 gives estimated mean masses of airborne particulates ($g \cdot m^{-3}$) measured between August 1979 and August 1981. Monthly means were generally between around 20 to 80 $g \cdot m^{-3}$, and only during November 1980 and May and June 1981 was this range exceeded. These higher means were owing to unusual winds, often (as in November 1980) resulting from a single very high sample. Measurements taken at the UCR station during clearing and grading of the heliostat field (September-October 1979) were not unusual, but we emphasize that this station was not directly downwind of the solar site. As indicated above, unusually high monthly means observed subsequent to grading and clearing were associated with windstorms and not to any construction operations.

4.5.2 Atmospheric Pollutants

During 1979 and 1980 C.R. Thompson, of the Statewide Air Pollution Research Center at the University of California, Riverside, measured amounts of ozone, nitric oxide and nitrogen dioxide in air downwind of the solar site. The UCR station was about 1 km southeast of the heliostat field. For a one-year period beginning in the fall of 1979, Southern California Edison made similar measurements about 2 km south of the solar site, south of the highway between Needles and Barstow (see Fig. 2.1). The SCE data were taken to establish baseline conditions in support of an application to site a coal gasification facility at Cool Water, and have been summarized by Environmental Applications, Inc. (1980).

Table 4.6 presents, on a quarterly basis, observations between November 1979 and October 1980. December, January and February are winter months, March-May are spring months, June-August are summer months, and September-November represent autumn. Measurements of ozone at the two sites were in good agreement, with highest values in spring and summer. Measurements at both the SCE and UCR sites showed that times of maximal concentrations of ozone were always in the afternoon, ranging from around 1300-1400 in the winter to as late as 1700 during the summer. Seasonal changes closely followed total insolation. Both California (10 pphm) and federal (12 pphm) ozone standards were violated at times during the spring and summer and were attributed to contributions from the Los Angeles Basin. Mean quarterly concentrations of NO_2 were consistently higher at the SCE sampling site (Table 4.6), but amounts of oxides of nitrogen were low at both stations. The maximum NO_2 concentration reported for the SCE site was 9.5 pphm during the fall. The California standard is 25 pphm. The average annual NO_2 concentration at the SCE site was 1.4 pphm, while the federal standard is 5 pphm. Times of highest concentration of NO_x were almost always early in the morning, ordinarily from 0300 to 0700.

Can high temperatures and high solar intensity adjacent to the receiver of an operating solar thermal power plant catalyze the production of significant amounts of air pollutants (e.g., NO_x)? This issue has been explored by Perrine et al. (1981), assuming a facility rated at 430 MWe with 61,000 heliostats. Their worst case analyses--based on chemical and kinetics, mass emission rates, transport and dispersion--indicated "that some air pollutants may be produced...in quantities sufficient to be of regulatory concern. However, these authors continued: "In all likelihood the quantities produced will be small, and fully merit for solar its general recognition as a benign energy technology." On the basis of this study, we do not consider this problem an environmental issue with Solar One.

Table 4.5. Airborne particulates measured east (UCLA) and southeast (UCR) of the solar site between August 1979 and August 1981. Measurements until May 1980 were made by UCR; thereafter by UCLA.

Month and year	Numbers of samples taken	Mean mass of particulates ($\mu g \cdot m^{-3}$)	Standard error of the mean	Range
Aug 1979	6	66.1	4.9	49.3-76.8
Sept	5	77.9	1.4	74.9-83.0
Oct	5	83.7	14.2	46.6-108.2
Nov	5	56.1	3.8	44.3-63.7
Dec	3	72.6	16.0	44.8-100.0
Jan 1980	5	28.3	4.2	18.3-43.9
Feb	5	27.8	4.3	15.2-38.2
March	5	65.6	22.3	22.2-141.0
Apr	5	76.8	11.6	57.4-120.8
May	5	73.9	11.2	49.5-110.9
Aug	2	37.7	13.8	23.9-51.5
Oct	2	62.2	25.4	36.8-87.7
Nov	4	250.9	164.7	46.0-741.3
Dec	5	83.5	17.2	41.7-142.2
Jan 1981	4	38.7	6.4	30.7-60.7
Feb	4	20.2	1.4	16.6-22.7
March	5	28.4	10.0	5.5-65.2
Apr	5	42.4	10.4	16.8-67.5
May	4	100.1	45.7	31.1-233.5
June	4	96.0	47.7	13.5-233.0
July	4	69.1	7.0	52.5-80.0
Aug	5	67.6	10.9	41.7-105.9

Table 4.6 Mean concentrations (pphm) of gases measured south and east of Solar One between November 1979 and October 1980.

Time of year	Ozone		NO_2		NO	
	SCE	UCR	SCE	UCR	SCE	UCR
Fall	3.4	2.6	1.7	1.2	0.9	2.6
Winter	2.4	2.4	1.4	0.05	1.1	1.9
Spring	4.4	3.6	1.2	0.01	0.4	0.7
Summer	5.9	5.3	1.4	0.07	0.3	0.4

4.6 Surface Soil Movement

4.6.1 Soil Characteristics

Surface soils of the site are predominantly well to poorly graded sands. Below 1.5 m soils are mostly sandy; below 3 m soils are generally well graded sand with some silt and gravel (EIA, 1977). Bare lenses of silt and clay loams occur here and there on the surface. The sandy soils are low in salt content, but the heavier soils are often quite saline--sometimes precluding plant growth.

Chemical and physical attributes of eight soil samples taken from depths of 10-30 cm in the prospective mirror field and from northeast of the mirror field were analyzed. Concentrations of boron, calcium, magnesium and sodium, and electrical conductivities were determined in soil saturation extracts. Concentrations of chloride, nitrate-nitrogen and sulfate-sulfur were determined with 1:5 water extracts. Concentrations of Ca, Mg, K and Na were determined with ammonium acetate extracts and results converted to a dry soil basis. Phosphate-phosphorus was determined with sodium bicarbonate extracts. Concentrations of Fe, Zn, Cu and Mn were determined with DTPA extracts. Values for Site 5 (near the center of the prospective mirror field) and Site 16 (northeast of the field) are given in Table 4.7. Values for the other six sites were summarized by Turner (1979: 56).

4.6.2 Saltation and Sand Movements

Surface movements of sand were measured in areas downwind (east) of the prospective heliostat field between June and August 1979--before the field was cleared and graded. The sampling devices used were designed by Lawrence-Livermore Laboratory and measured both saltation and creep. An illustration of the design of the sampler was given by Turner (1979: 18). Measurements during the summer of 1979 showed about 76% of all soil particles collected were moving along the surface at < 1 cm above the ground. Essentially all surface soil movement occurred during a single thunderstorm on August 16, 1979 (see Turner, 1979: 17-19).

During the first week of September 1979, four more samplers were positioned downwind of the prospective field. Stations 1 and 2 were, respectively, 100 m and 60 m east of the eastern edge of the heliostat field. Station 3 was about 200 m north of Station 2. Stations 4-6 were about 600 m east of the field, in a north-south line. These devices measured fluxes of windblown sand at five levels above the ground (from 1 to 36 cm). The width of the device was 0.95 cm, so mean daily sand flows across a 1-cm path could be computed by calculating the mean daily weight of sand collected (total weight divided by days) and dividing by 0.95. Weights of material collected by the six meters between 16 June 1979 and 10 May 1980 were summarized by Turner (1981: 88). Table 4.8 abstracts estimated fluxes for a 77-day period prior to clearing and grading the heliostat field and for three periods after construction operations began in September 1979.

Fluxes were low at Stations 1 and 3 during the summer of 1979, then increased dramatically at Stations 1 and 2 after clearing and grading began. These two stations were just east of the field. Station 3 was apparently too far north to be so conspicuously affected. Stations 4, 5 and 6 were so far

Table 4.7. Chemical and physical attributes of soil samples taken near the center of the prospective mirror field (5) and northeast of the field (16). Samples were taken at depths of 10-20 cm.

Attribute	Site 5	Site 16
pH	8.4	8.3
Soil type	sandy	loamy sand
Cation exchange capacity (meq/100 g)	18.0	45.0
Particle size (%)		
> 2 mm	0	21.0
fine gravel	1.7	4.9
coarse sand	12.6	27.0
medium sand	16.6	12.4
fine - very fine sand	31.9	20.5
silt	27.2	11.1
clay	27.5	3.2
Loss on ignition (%)	1.8	1.3
Boron (ppm)	0.4	0.6
Ca (ppm)	2800	1900
Mg (ppm)	64	32
K (ppm)	115	83
Na (ppm)	220	40
Fe (ppm)	5.4	4.4
Zn (ppm)	0.6	2.4
Cu (ppm)	0.8	1.1
Mn (ppm)	2.8	2.7
Chloride (ppm)	35	27
Nitrate nitrogen (ppm)	6	8
Sulfate sulfur (ppm)	75	50
Phosphate phosphorus (ppm)	7	7
Electrical conductivity (mmho cm^{-1})	1.1	0.6
Ca + Mg (meq l^{-1}) saturation extract	3.0	4.4
Na (meq l^{-1}), saturation extract	7.7	1.8

Table 4.8 Fluxes of sand ($g \cdot cm^{-1} \cdot day^{-1}$) along 1-cm paths at stations downwind of the solar field between June 1979 and May 1981. Weights of sand (g) collected in meters are given in parentheses. No observations (n.o.) were made at Stations 2, 4, 5 and 6 before September 2, 1979.

Dates	Stations 1	2	3	4	5	6
June 16-Sept 1, 1979 (77 days)	0.048* (3.5)	n.o. -	0.025* (1.9)	n.o. -	n.o. -	n.o. -
Oct 22, 1979-Feb 29, 1980 (131 days)	10.8 (1344.1)	>20.2 (2513.9)	0.14 (17.4)	0.001 (0.12)	0.02 (2.49)	0.05 (6.22)
Mar 1-June 15, 1980 (106 days)	0.25 (25.4)	0.75 (75.4)	0.07 (6.6)	0.24 (24.5)	0.04 (3.7)	0.08 (8.2)
Mar 29-May 10, 1981 (43 days)	0 (0)	1.54 (63.1)	0 (0)	0 (0)	0 (0)	0 (0)

* These data were erroneously transposed in the report of baseline studies (Turner 1979: p. 19).

east of the site that high fluxes were never measured there (except at Station 4 during the spring of 1980). Analysis of the vertical distribution of sand fluxes showed that most of the sand moved near the ground--within 1 cm of the surface.

Movement of sand off the newly cleared heliostat field was substantial during the late fall of 1979. In fact, so much sand moved across Station 2 during this time that the meter overflowed on several occasions. Later the surface of the field stabilized somewhat and fluxes between March 1 and June 15, 1980, were much lower (at Stations 1 and 2) than measured during the previous 4-1/2 months. After June 1980 there were barely detectable collections of material in saltation meters until the spring of 1981, when sand was again collected at Station 2. This period of collection coincided with a period of higher than usual winds, suggesting that some material on the surface of the heliostat field was still susceptible to mobilization 18 months after clearing.

Richard Hunter estimated the amount of sand blown off the heliostat field between October 1979 and the end of February 1980. He assumed the diameter of the heliostat field to be 800 m, and loss rates based on measurements at Stations 1 and 2. Hunter estimated that roughly 160 metric tons of sand were removed during this time. If all of this had been evenly deposited in a sector extending to 100 m from the field's eastern edge, new deposition would have been about 11 metric $tons \cdot ha^{-1}$. However, sand deposited downwind of the field was not uniformly dispersed, but formed mounds in wind shadows of shrubs (Fig 4-11). Most of the observed increases in sand depth took place immediately following the clearing and grading of the heliostat field (as reflected in the 1980 measurements), (Fig. 2.3B) but sand continued to accumulate between January 1980 and May 1981.

In February 1982 we laid out four lines, 40, 80, 130 and 200 m east (downwind) of the east perimeter fence around the heliostat field. Lines were 240 m long and ran in a north-south direction, with south ends along a line running due east from the receiver tower. Calibrated aluminum stakes were placed 10 m apart along each of these lines (100 in all), and the initial level of soil surface recorded at each stake on 23 February. Measurements were made again on 23 April, 16 June, and 7 October, 1982.

Table 4.9 gives mean changes in soil surface levels based on inspections of calibrated stakes in 1982. Along the two lines closest to the heliostat field there was a net reduction of surface levels owing to movements of sand to areas farther downwind. Between 130 and 200 m of the field we measured small increases in surface levels. Note, however, that this pattern was not consistently expressed over shorter intervals between February and October. Between 17 June 7 and October we measured inputs of new sand at all distances.

Heights of selected sand mounds were measured downwind of the prospective heliostat field in October 1978, and remeasured in January 1980, May 1981 and October 1982. Table 4.10 summarizes mean changes in heights of mounds east of Solar One.

In summary, direct measurements of sand depths showed that sand was deposited downwind of the heliostat field during clearing and grading, and intermittently during construction. Sand mound heights behind shrubs

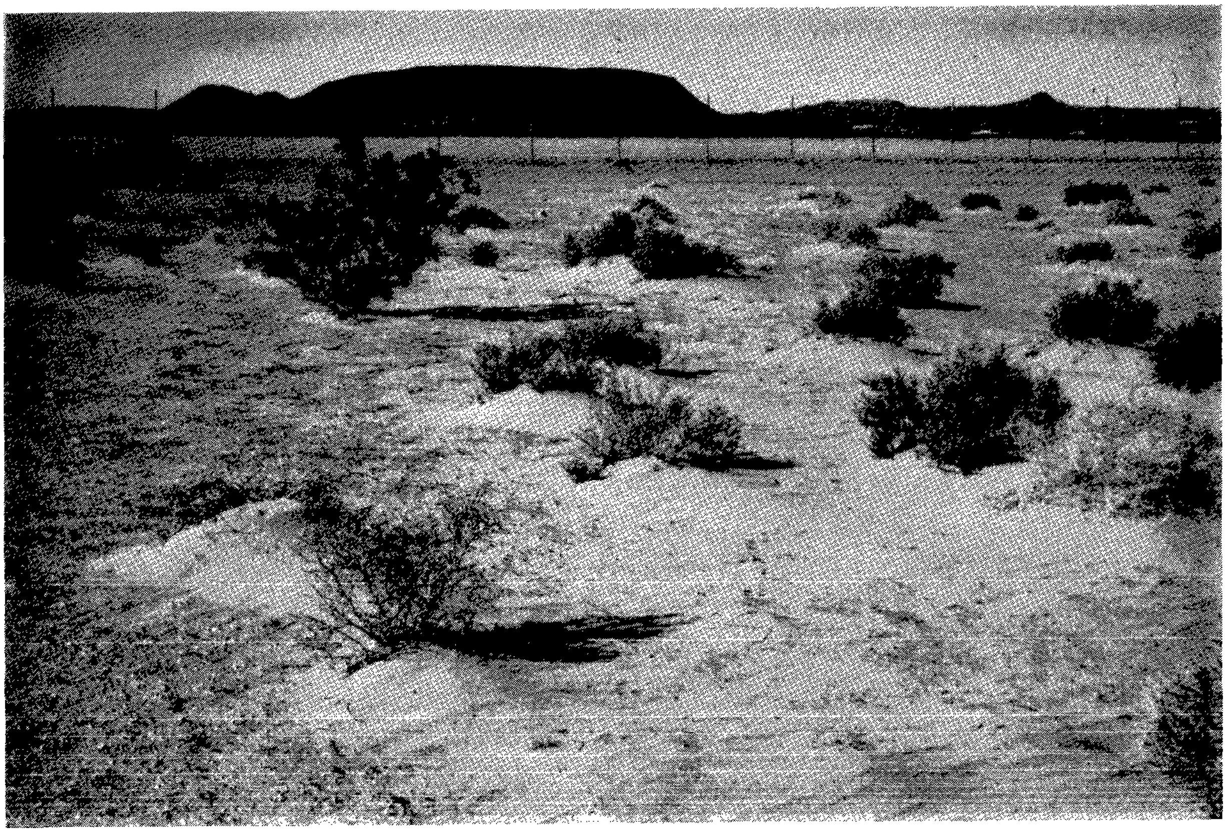

Figure 4.11 Newly deposited sand just east of the cleared heliostat field in the spring of 1980. Largest fence posts indicate location of East Gate.

Table 4.9 Mean changes in soil surface levels (mm) ± one standard error at four distances downwind of the Solar One heliostat field in 1982.

Distance from field (m)	Feb 23 - Apr 23	Apr 24 - June 16	June 17 - October 7	Net change, Feb - Oct[1]
40	-4.1 ± 1.4	-1.2 ± 1.7	2.0 ± 0.6	-2.9 ± 1.4
80	-3.4 ± 1.3	1.3 ± 0.7	1.6 ± 0.5	-0.3 ± 0.5
130	0.0 ± 0.5	-1.6 ± 0.4	2.7 ± 0.6	1.9 ± 0.7
200	-0.2 ± 0.6	-0.8 ± 0.4	1.3 ± 0.5	0.3 ± 0.7

[1]Net values may differ slightly from sums because of rounding and loss of stakes owing to traffic and accidents.

Table 4.10 Changes in peak heights of sand mounds deposited downwind of shrubs east of the Solar One heliostat field in 1982. Sample sizes are given in parentheses.

Distance from field (m)	Mean changes (cm) in mound heights ± one standard error		
	Oct 1978-Jan 1980	Jan 1980-May 1981	May 1981-Oct 1982
26-37	18 ± 7 (3)	10 ± 2 (4)	-7 ± 2 (7)
40-49	14 ± 2 (5)	1 ± 1 (4)	0 ± 2 (9)
51-58	7 ± 2 (3)	6 ± 2 (3)	2 ± 2 (7)
60-79	-	-	3 ± 1 (12)
87-98	0.4 ± 0.2 (10)	1.1 ± 0.4 (11)	0.2 ± 0.2 (12)

increased conspicuously through 1981 within 100 m of the fence. Measurements of mound heights and aluminum stakes in 1982, however, showed that after heliostats were installed sand mounds ablated as fine material was moved farther east. Slight ablation occurred at locations within 40 m of the fence, slight deposition at 130 m, and no significant changes were observed at 80 and 200 m. It appears that fine material is continuing to move to the east, but this was not measured. Observations during 1982 were complicated by loose surface soil bladed from access roads and removed from drainage channels. Some fine materials may have deposited because of development of the coal gasification plant.

5.0 VEGETATION STUDIES

5.1 Background Studies of Vegetation

5.1.1 History of Disturbances of the Site

Our discussion of the vegetation of the STPS site and areas lying east of the site can best be appreciated in the light of recent history of these areas. The prospective mirror field was cleared of vegetation in the fall of 1953. Clearing was accomplished by dragging, and resulting brush was burned. The land was apparently disked. Crops were grown until 1956, probably alfalfa and some barley--the latter as a cover crop. After the field was abandoned natural processes of recovery began. For several years the bared sand blew off to the east, resulting in distinct mounds beneath shrubs in the less disturbed areas to the east. In 1979, the principal shrub growing in the prospective heliostat field was saltbush (*Atriplex polycarpa*). Some areas (particularly in the northwestern portion of the field) sustained higher densities of this shrub than others, possibly because of irrigation of alfalfa fields to the west. These shrubs were of varying ages, but the oldest were on the order of 23 years old. Based on this past experience, it is reasonable to expect natural restoration of some shrub cover within decades after the termination of the Solar One project--unless the soils in the heliostat field are physically or chemically altered by construction and operation of the facility.

The status of vegetation on the prospective heliostat field and in areas east of the field was assessed by sampling during 1978 and 1979, before construction of Solar One began, and all procedures and findings were set forth by Turner (1979: pp. 19 et seq.). Our analyses included estimates of densities and biomass of species registered in sampling quadrats or along belt transects. Shrub volumes (V) were estimated from three linear dimensions--height (h), diameter$_1$ (d_1) and diameter$_2$ (d_2), with the two diameters measured at right angles:

$$V(m^3) = hd_1d_2/4$$

Relationships between shrub volumes and weights were estimated by dimension analysis of *Atriplex polycarpa* collected at the site; for *Larrea tridentata* and *Ambrosia dumosa* we used equations based on dimensions analyses at other Mojave Desert sites. Estimating equations were linear regressions forced through the origins.

Shrubs were counted and measured along three lines in the prospective heliostat field in 1978. These lines ran north (1), northeast (2), and slightly north of east (3) outward from the center of the field and extended several hundred meters beyond the expected margin of the field. Shrubs were also counted and measured in six 1-ha plots lying east of the prospective field. Three of these plots lay just east of the eastern margin of the field, the other three were about 700 m further east. Shrubs were also counted in four east-west belt transects lying within and beyond the field, or outside the field. These belts were 4 m wide and from 500 m to 1200 m long. Shrubs were measured in alternate 25 m sections along each transect.

Annual plants were counted in quadrats within the field in 1978, and in near and far plots in 1978 and 1979. Permanent marks were placed so that annual quadrats could be located in the same places each year. Previous studies at the Nevada Test Site have shown high variability among annual populations of annual plants, and repeated sampling does not work well in patchy environments. In addition to counting annuals, we harvested individuals of common species and determined mean dry weights of entire plants. These dry weights were combined with estimates of densities to estimate dry weight standing crops.

Over 130 kinds of plants were identified on the site, 18 of which were non-native species (see Appendix 5, Turner 1979). Many of these species were of low abundance and sporadic occurrence. Only 66 species were listed in the original environmental impact statement (EIA, 1977: Appendix E). Our list was more complete because we spent more time in the area and because a number of usually uncommon species were recording during the favorable spring of 1978. The three principal shrubs were creosotebush (Larrea tridentata), desert saltbush (Atriplex polycarpa), and bur-sage (Ambrosia dumosa). Saltbush was much more abundant in disturbed areas, while the other two shrubs assumed dominance in less disturbed areas east of the prospective power plant. Aggregate densities of perennials (including herbaceous species) ranged from as low as 0.2 to $4.4 \cdot m^{-2}$. Cover by shrubs was low in the areas cleared in 1953 (<6%) but increased to as high as 18% in areas to the east. Estimated aggregate densities of annual plants ranged from around 600 to $9{,}000 \cdot m^{-2}$, depending on sampling locale. Three introduced annuals--the grass (Schismus arabicus), Russian Thistle or tumbleweed (Salsola sp.) and filaree (Erodium cicutarium)--were all common and made up a large proportion of the standing crops of annuals on the site.

About 25 species of annual plants were recorded at the site in 1978-79. An aggregate annual plant density of from 3000 to 8900·plants m^{-2} (peak density) was observed, with an aggregate dry weight standing crop of from 670 to 930 $kg \cdot ha^{-1}$.

5.2 Observations of Shrubs During Construction

After construction began we concentrated on comparisons of growth of shrubs in areas east of the heliostat field. This work was conducted during the growing seasons of 1980 and 1981, and involved measurements of vegetative growth and development of flowers and fruits by bur-sage (Ambrosia dumosa), creosotebush (Larrea tridentata) and saltbush (Atriplex polycarpa). Six plots were located 100, 400 and 800 m east of the field, with two plots at each distance.

The performance of shrubs was assessed with techniques used in earlier studies in southern Nevada (Turner and Edney 1977, Turner and Vollmer 1980). Measurements were made twice yearly--before and after the growing season. Production of flowers and fruits depends on numbers of nodes or shoot tips, so counts of the latter were an indispensable common denominator for comparisons between shrubs. Counts of reproductive structures were made at times of peak flowering and fruiting, as determined by observations of phenology.

Flowers of creosotebush are produced at young nodes near shoot tips. Any shoot bearing leaves was considered a viable shoot tip, and flowering and fruiting success was evaluated in terms of numbers of potential sites. The inflorescences of bur-sage are extensions of shoot tips. Counts of shoot tips give a good indication of reproductive potential of a given branch. Flowering stalks grow indeterminately so we estimated numbers of heads on stalks. We simply measured lengths of inflorescences from first to last flower heads. Fruit production was estimated similarly. Saltbushes are dioecious (i.e., shrubs are either male or female). Monitoring of this species was restricted to mature (15+ years) female plants. Flowers are produced on inflorescences growing from stem tips, but we restricted our work to counts of the conspicuous winged fruits.

Ten shrubs of each species were selected in each plot. On each subject shrub five branches were tagged, and the vegetative growth and reproduction associated with these branches were the bases for comparisons. At the beginning of each growing season we measured "growth potential" variables to determine whether shrubs selected for study in different plots had comparable potential for growth and reproduction: i) numbers of tips or nodes per branch, ii) number of tips or nodes per shoot, and iii) lengths of shoots. As the growing seasons progressed we made further counts or measurements relating to shoot elongation, growth of new shoots, and production of fruits and flowers. Experience in Nevada has shown that most of these variables are not normally distributed. Typical distributions are positvely skewed, with a concentration of values at the low end of the scale. We made inter-plot comparisons using Friedman's non-parametric test, which is based on rankings of observations in various plots (Sokal and Rohlf 1969). None of various statistical comparisons of pre-season states showed significant differences between plots (Turner 1981: Appendix G).

Tables 5.1 and 5.2 show results of measurements of growth and reproduction during the 1980 and 1981 seasons. The 1981 season was so poor that we were not able to make measurements of some reproductive parameters. Values of p with asterisks are statistically significant (* = 5% level, ** = <1% level). In four cases in Tables 5-1 and 5-2 X^2 values are statistically significant, indicating a difference between plots. In all four cases, the difference lay in the plots 400 m downwind of the site. Means for plots close to (100 m) and remote from (800 m) the site were almost identical. It is highly unlikely that the differences observed at an intermediate distance were in any way related to construction activities.

5.3 Post Construction Observations of Vegetation

5.3.1 Influence of Climate

Rainfall averaged 92 mm annually at the Daggett FAA airport 2 km S of the site, based on records from 1951 to 1974. During that period, rainfall was divided about evenly between winter storms and summer thunder-showers. Average temperatures during the spring growing season were about 8°C (minimum) and 24°C (maximum). Summers were very hot, with maximum air temperatures of 45°C or more not uncommon. Winter annuals germinated between December and March, depending on timing of rainfall, and died in late April or early May between 1978 and 1984. Summer ephemerals tended to occur sparsely, mainly in response to heavy thundershowers, and occurred primarily in disturbed habitats.

Table 5.1. Measurements of vegetative growth and reproduction by three kinds of shrubs in areas downwind of the solar site in 1980.

Species	Variable	Distances (m)				
		100	400	800	X^2	p
Ambrosia dumosa	Inflorescences per shoot	1.3	1.1	1.0	0.64	0.73
	Lengths of shoot inflorescences (mm)	14.2	23.9	10.5	8.44	0.01**
	New shoots per branch	5.0	4.9	5.0	0.46	0.80
	Lengths of new shoots (mm)	56.1	49.9	49.4	0.59	0.75
Larrea tridentata	Nodes per shoot tip	4.7	4.8	4.5	0.10	0.95
	Shoot lengths (mm)	218	189	193	4.94	0.08
	Flowers per branch	32.3	26.3	31.6	11.11	0.004**
	Fruits per branch	21.2	18.0	21.9	5.99	0.05*
Atriplex polycarpa	New shoots per branch	2.8	2.7	2.8	0.74	0.72
	Lengths of new shoots (mm)	176	113	138	0.31	0.86
	Reproductive indexes (per branch)	1.5	0.7	1.4	5.66	0.06

Table 5.2. Measurements of vegetative growth and reproduction by three kinds of shrubs in areas downwind of the solar site in 1981.

Species	Variable	Distances (m)			X^2	*p*
		100	400	800		
Ambrosia dumosa	Inflorescences per shoot	none	none	none	-	-
	New shoots per branch	1.3	1.5	1.7	2.94	0.23
	Lengths of new shoots (mm)	15.5	24.5	20.7	4.25	0.12
Larrea tridentata	Nodes per shoot tip	4.1	3.7	4.2	0.95	0.62
	Shoot lengths (mm)	67.9	58.8	67.2	6.32	0.04*
	Flowers per branch	9.8	9.2	10.2	3.35	0.19
	Fruits per branch	4.4	4.5	5.7	1.69	0.43
Atriplex polycarpa	New shoots per branch	4.6	4.3	3.4	3.19	0.20
	Lengths of new shoots (mm)	70.4	68.9	50.5	3.61	0.16
	Reproductive indexes	not measured			-	-

Because spring-active annuals can germinate in response to rainfall at any time between December and March, total rainfall between October and March is a useful indicator of the development and productivity of Mojave Desert annuals during the spring (Beatley 1974). The long-term mean rainfall at Daggett during this period is 50 mm, whereas the mean winter rainfall from 1978 to 1984 was 81 mm. October to March rainfall was highest prior to the spring growing seasons of 1980 and 1983, with 125 and 135 mm of rain occurring, respectively. Not surprisingly, an abundant crop of annuals occurred in the site vicinity in each of these years. In contrast, only 33 mm of rain was recorded prior to the 1981 spring growing season, and a depauperate spring flora ensued. Normal rainfall occurred prior to the 1979, 1982, and 1984 spring growing seasons, resulting in moderate numbers of annual plants in those years.

Summer rainfall was highest in 1982 and 1983, and these years were characterized by locally abundant populations of weedy summer annuals, particularly in the heliostat field. Summer ephemerals were sparse in the desert adjacent to the heliostat field in all years of the study, but particularly in the dry summers of 1978-1981.

5.3.2 Responses of Annual Plants Following Grading of the Heliostat Field

In April 1980, about six months after the heliostat field had been cleared and graded, a sparse flora germinated and became established on the field area (Turner 1981). Density of plants was low, but 25 species of plants were observed, 21 annuals and 4 perennial forbs, (Table 5.3). Approximately half of these species were introduced, indicating that a "disturbance" type flora was revegetating the site. In June 1981 six species were observed on the heliostat field, with half of the species again being introduced (Table 5.3).

In April 1983, annual vegetation in the heliostat field in areas not influenced by individual heliostats was compared to vegetation in undisturbed desert east of the heliostat field (Smith 1984). Results of this analysis showed that annual plant density within the heliostat field was reduced by 98% and total aboveground biomass by 95% relative to the open, undisturbed desert. These reductions were directly attributable to soil surface disturbance, soil compaction, and probably also to continued surface disturbances such as vehicular traffic, human trampling, etc.

Effects of sand deposition on annual plants were measured at specific distances downwind from the perimeter fence of the heliostat field. In 1980, during the time of peak sand deposition, new sand mounds had fewer, larger _Schismus arabicus_ than adjacent areas with little or no deposition (Figure 5.1). Density and size (individual plant biomass) of _Schismus_, the dominant annual on the site, and of _Erodium cicutarium_, the dominant forb, are given in Table 5.4 for the 1981-83 growing seasons. In 1981 low winter rainfall resulted in low germination and early senescence of annual plants. Both density and size of _Erodium_ were reduced within 100 m of the eastern border of the heliostat field, but this was not true of _Schismus_.

In 1982 _Schismus_ density was considerably reduced and _Erodium_ was absent near the field. Individual biomass of _Schismus_ was reduced at 80 m, but _Erodium_ size was similar at 80 and 200 m. In 1983 density of _Schismus_ had

Table 5.3. Ephemeral plants growing in heliostat field in April 1980 and June 1981.

Introduced species	Native species
	April 1980
Bromus tectorum	Astragalus didymocarpus
B. wildenovii	Cryptantha angustifolia
Capsella bursa-pastoris	Descurainia pinnata
Chenopodium album	Eremalche exilis
Cynodon dactylon*	Eriogonum trichopes
Erodium cicutarium	Euphorbia sp.
Hordeum glaucum	Geraea canescens
H. vulgare	Hesperocallis undulata*
Plantago major	Lupinus shockleyi
Salsola sp.	Oenothera sp.
Schismus arabicus	Palafoxia linearis*
Sisymbrium irio	Plantago insularis
	Stephanomeria pauciflora*
	June 1981
Salsola sp.	Cryptantha angustifolia
Schismus arabicus	Stephanomeria pauciflora
Sisymbrium irio	Tiquilia plicata*

*denotes herbaceous perennial

Figure 5.1 Area of deposition of new sand downwind of the solar site in the spring of 1980. Notice the lower density (but larger size) of grasses (Schismus arabicus) growing in newly deposited sand.

Table 5.4 Density and average biomass of *Schismus arabicus* and *Erodium cicutarium* with respect to distance from the heliostat field. Error estimates are ± 1 S.E.

Distance m	Year	Schismus		Erodium	
		n/m^2	mg/plant	n/m^2	mg/plant
0-100	1981	280 ± 73	2 ± 0.5	8 ± 4	9 ± 4
100-200		218 ± 70	9 ± 4	166 ± 4	77 ± 20
40		400 ± 50	30 ± 4	0	-
80	1982	1600 ± 250	14 ± 2	10 ± 4	112 ± 41
200		2100 ± 250	25 ± 3	24 ± 6	97 ± 24
40	1983	4800 ± 1800	25 ± 5	0	-
200		3100 ± 640	38 ± 11	80 ± 33	464 ± 202

fully recovered 40 m from the heliostat field and plant size was constant at various distances. Erodium was again absent. Available photographic evidence indicates that sand deposition on the periphery of the heliostat field reduced densities of these annuals soon after clearing, but individual plants were larger. However, numerical analyses suggest that if vegetation was affected the effect disappeared within three years after the heliostat field was cleared.

5.3.3 Plant Invasion into Heliostat Field After Placement of the Mirrors.

An analysis of invading vegetation within the heliostat field was conducted during 1983 and 1984 (Smith 1984). Vegetation analyses included both floristic inventories and quantification of plant density, diversity, and aboveground biomass. Methodologies used in the study were described by Smith (1984).

A list of plant species occuring in the heliostat field the spring and summer of 1983 is given in Table 5.5. As in 1980-81, approximately half of the species were introduced types, most of which are considered pests. In contrast with the 1980-81 surveys, perennial forbs and shrubs were relatively more abundant in the 1983 surveys. Furthermore, several shrubs had become established in the heliostat field by 1983. The dominant shrub in the field was Atriplex polycarpa (saltbush), which was also true prior to clearing. Seven other species were found only in the heliostat field in April 1983, and twelve were found only in the field in July 1983. However, most of these species were introduced, weedy annuals. In contrast, four species were found only in the open desert and not in the heliostat field in 1983. Each of these species (Datura meteloides, Eriogonum inflatum, Psathyrotes ramosissima, and Tiquilia plicata) is a native perennial forb. Thus, the flora of the heliostat field can be broadly characterized as introduced and weedy, whereas the open desert had a greater representation of native perennial forbs.

Quantitative estimates of plant density and biomass in April 1983 are given in Table 5.6. As a result of dense germination by the introduced grass, Schismus arabicus, the open desert control site had much higher overall plant density and biomass than did the heliostat field. Data from March 1984 show a similar trend. Total plant density was $1650 \cdot m^{-2}$ in the control and $81 \cdot m^{-2}$ in the heliostat field, and corresponding estimates of aboveground standing crops were 34 and 4.5 $g \cdot m^{-2}$. The results indicate that previous surface clearing and disturbance was the primary factor limiting vegetation presence in the heliostat field. However, increased species diversity in the two heliostat field sites relative to the control site suggests that the vegetation was already showing a response to the less stressful microclimate beneath the heliostats. This is further illustrated by a comparison of the inner and outer heliostat fields more. Herbaceous dicots (with a higher species diversity) occurred in the inner field, where heliostat packing is higher and shading more complete.

Quantitative estimates of overall density and aboveground standing crops of vegetation on each site in July 1983 are given in Table 5.7. By July, essentially all annual plants had died in the open desert. In contrast, green vegetation was quite abundant in the heliostat field. Furthermore, this green vegetation steadily increased in numbers, cover, and standing crop into the inner field.

Table 5.5 Plant species growing in heliostat field in April and July, 1983.

Introduced species	Native Species
April 1983	
Brassica nigra	Allium sp.*
Bromus rubens	Amsinckia tesselata
Descurainia sophia	Atriplex hymenelytra**
Erodium cicutarium	A. polycarpa**
Hordeum leporinum	Chenopodium atrovirens
Salsola sp.	Cryptantha angustifolia
Schismus arabicus	Eriogonum trichopes
S. barbatus	Eremalche exilis
Sisymbrium irio	Hesperocallis undulata*
Sonchus asper	Malacothrix glabrata
S. oleraceus	Pectocarya recurvata
	Phacelia crenulata
July 1983	
Conyza canadensis	Ambrosia acanthicarpa*
Lactuca serriola	Atriplex hymenelytra**
Plantago lanceolata*	A. polycarpa**
Salsola sp.	Bebbia juncea**
Schismus arabicus	Chenopodium incanum
S. barbatus	Cryptantha sp.*
Sonchus oleraceus	Eremalche plumatella*
	E. trichopes
	Eremalche exile
	Oryzopsis hymenoides*
	Palafoxia linearis

*Denotes perennial forb.
**Shrub

Table 5.6. April 1983 vegetation analysis at Solar One. Site abbreviations are: OH = outside heliostat field; IH = interior heliostat field.

Parameter	Control	OH	IH
Total plant density ($n \cdot m^{-2}$)	2,116	26*	20*
Grass density ($n \cdot m^{-2}$)	2,109	25*	18*
Forb density ($n \cdot m^{-2}$)	6.9	0.9*	2.4*
Total plant biomass ($g \cdot m^{-2}$)	46	2.6*	3.4*
Grass biomass ($g \cdot m^{-2}$)	45	2.4*	2.6*
Forb biomass ($g \cdot m^{-2}$)	1.1	0.2*	0.75
Species diversity (H^1)	0.01	0.44*	0.76*

*Significantly different from control site ($p=0.05$)

Table 5.7 July 1983 vegetation analysis at Solar One. All parameters in the heliostat field were significantly different from the control site ($p = 0.01$). See Table 5.6 for site abbreviations

Parameter	Control	OH	IH
Total plant density ($n \cdot m^{-2}$)	0.05	2.18	10.9
Annual plant density ($n \cdot m^{-2}$)	0.05	2.01	10.7
Perennial plant density ($n \cdot m^{-2}$)*	0.004	0.17	0.18
Total plant biomass ($g \cdot m^{-2}$)	0.36	27.2	82.9
Annual plant biomass ($g \cdot m^{-2}$)	0.34	26.6	82.0
Perennial plant biomass ($g \cdot m^{-2}$)	0.02	0.62	0.92
Species diversity (H^1)	0.039	0.381	0.303
Salsola sp. cover (%)	0.09	4.5	14.4

*Does not include mature shrubs in control site.

A comparison of spring (Table 5.6) and summer (Table 5.7) vegetation analyses in 1983 shows that plant standing crop in the heliostat field was roughly 20-fold greater in the summer than in the spring, and was roughly equivalent in the summer to the Schismus dominated vegetation in the control site in the spring. This difference in biomass between spring and summer floras is illustrated in Figure 5.2. However, species diversity was highest in the heliostat field in the spring because of the dominance of Salsola in the summer vegetation. The shift in relative magnitudes of spring and summer standing crops at two kinds of sites clearly showed the importance of micro-climate in determining potential plant productivity at each site. In the cool winter-spring period, germination and standing crop was highest in the open desert, where full sunlight would not be detrimental due to moist soils and cool temperatures. In the dry, hot summer maximum plant development occurred in the most heavily shaded sites, and progressively decreased as the amount of sunlit ground surface area increased. Observations in July--showing most green, viable plants clustered around heliostat bases--further illustrates this point (see Smith 1984).

Heliostat stow position (i.e., at night and during inclement weather) and washing schedules may influence the small-scale distribution of plants beneath heliostats. Heliostats are generally stowed horizontally with reflective surfaces facing down, or vertically with mirror surface parallel to the prevailing wind source. When vertically stowed, a "drip line" can be created along the length of the heliostat during rains. This is also the position used to wash heliostats. Concentrated sources of water, particularly from washing, can result in a dense band of vegetation along the "drip line". Although not specifically observed in the summer of 1983, this zone could become dominated by large Salsola and possibly Atriplex bushes during the summer months. Because the apparently preferred stow position is vertical, this band of vegetation could become a distinct feature of the heliostat field vegetation if left unaltered.

5.3.4 Operational and Safety Aspects of Vegetation Within the Heliostat Field

Because the heliostat field at Solar One has been cleared of vegetation in each year of operation, we conclude that the presence of vegetation on site has posed operational/safety problems or hazards. Observations in 1983 and discussions with site personnel indicated that dense vegetation cover can affect normal heliostat operation and may be potentially deleterious to worker safety. The main problem has been the presence of dense stands of tumbleweed (Salsola sp.) during the summer. Tumbleweeds were most abundant on the side of the heliostat pedestal facing the central receiver and toward which the mirror surface usually faces. This is also the side of the pedestal where the control box is located, so that access to the control box for routine maintenance or testing activities may be difficult beneath many heliostats.

There has been no indication that plants actually interfere with the normal tracking motion of the heliostats, although spring and summer weeds were observed to have grown to a meter in height. The largest plants in the spring flora were Brassica nigra and Sonchus oleraceus, neither of which occurred in dense enough stands to pose a major problem. In July, however, several large tumbleweeds (each larger than 50 x 50 cm) occurred beneath almost every heliostat in the inner area of the heliostat field, and Salsola

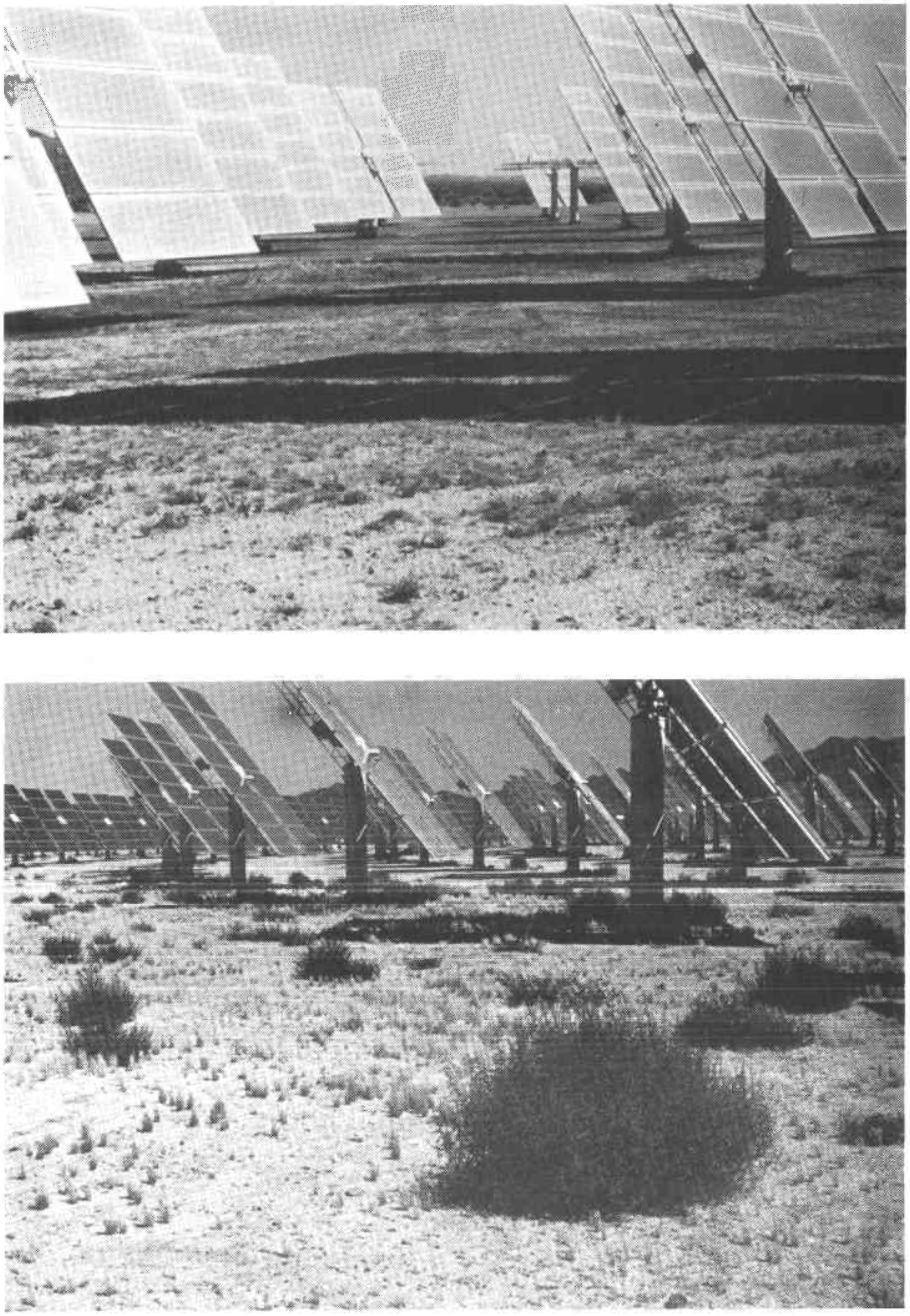

Figure 5.2 Plant invasion into Solar One heliostat field in April (left) and July (right) 1983. Vegetation in April is predominantly Schismus arabicus, while the large plants in July are Salsola sp.

cover appeared to be almost complete beneath some heliostats. A particular problem with tumbleweeds is their tendency to become uprooted after dying. Dead plants then blow across the site during windstorms, and often accumulate in large "drifts" aginst fences or other structures. Prevention of this dispersal of dead tumbleweeds was a possible reason for clearing them from the site while they were sill young and green.

Worker safety aspects of vegetation in the field has been primarily related to the shelter provided for animals, particularly poisonous snakes. Rattlesnakes (usually sidewinders) have often been observed in the Solar One heliostat field, even in the central area near the tower. No one has been bitten, but the presence of dense vegetation around the heliostats and particularly around control boxes increases the risk. Most snakes have been seen at night or near sunrise and sunset, so the snakes undoubtedly have access to shelter in the form of burrows or protected areas independent of vegetation cover. Thus, removal of vegetation alone will not solve the potential problem. Nevertheless, removal will reduce cover available for snakes and possibly for the rodents they feed on, and thus possibly reduce the abundance of snakes in the heliostat field.

With the exception of the dense tumbleweed population, plants have not yet posed serious problems in normal operations of Solar One. Vegetation may be somewhat beneficial because once it has developed sufficiently, plants act as surface stabilizers. Sand blasting of paint on the west side of many heliostat pedestals is evident, but no damage or pitting to glass has been observed. Dust was not a problem until cultivation of crops in adjoining field began. We recommend clearing only problem plant species (e.g., tumbleweed and large weedy spring annuals like black mustard and sow thistle). Obvious perennial (i.e. woody) plant species such as saltbush and other desert shrubs should be left undisturbed. Because all clearing efforts have been by mechanical means, this strategy would not be difficult to implement.

5.4 Summary

Effects of construction and operation of a 10 MWe solar thermal power plant (STPS) were studied from 1978 through 1978. Two major effects on vegetation were noted: (i) construction of the facility, which involved clearing and leveling 53 ha of desert land, and (ii) operation of the facility, which indirectly influenced vegetation because the heliostats deflected incident radiation from the ground surface.

Construction of the facility began in the fall of 1979. Following the clearing and leveling of the heliostat field, an estimated 160 metric tons of aeolian sand were blown off the cleared site and deposited downwind (east) of the site. Most of this sand loss and resulting deposition occurred during the spring windy season of 1980. Deposition east of the heliostat field occurred in distinct mounds of sand on leeward sides of shrubs, and was primarily confined to within 100 m of the edge of the cleared area. Analyses in 1981 and later indicated that sand movement from the heliostat field decreased substantially after the first year, and that sand accumulated near the field in 1980 was gradually transported farther downwind in subsequent years.

Annual plant populations within 100 m of the edge of the cleared area exhibited reduced densities in 1980, apparently due to burial of seeds by the sand deposits and perhaps owing to reduced seed production in the cleared area. However, plant populations appeared to recover fully within four years, indicating that no long-term effect of clearing is expected downwind of the site.

A number of conclusions can be drawn from the floristic inventories and quantitative vegetation analyses conducted in the heliostat field in 1983-84 at Solar One. Aggregate plant population density and standing crop were higher in the open desert than in the heliostat field in the spring, but were substantially higher in the heliostat field in the summer. Non-native species dominated the vegetation of both sites at both times of the year--the grass Schismus arabicus in the spring and tumbleweed in the summer. Species diversity was higher in the heliostat field in both spring and summer, and average plant sizes of individual species were also greater in the heliostat field in both seasons. If the dominant species is excluded from consideration in both the spring and summer floristic inventories, a distinct dissimilarity of the flora and vegetation structure can be seen between the two sites. In general, the heliostat field was characterized by introduced weedy annuals which were not well represented in the open desert. Several species of native perennial forbs occurred in the open desert flora, but were conspicuously absent from the heliostat field.

Analysis of an area within the fenced heliostat field which had been cleared and compacted but did not have overlying heliostats in April 1983 pointed to two conclusions regarding plant invasion into the site: i) the low plant density and diversity there showed that disturbance alone did not enhance vegetation establishment in the heliostat field, and ii) the lack of similarity in floristic composition between the compacted control area and actual heliostat field sites indicated that the higher diversity and common occurrence of weedy annuals, many of them quite mesophytic in character, must be attributed to the presence of the overlying structures in the heliostat field and possibly to added moisture from heliostat washing. Although quantitative data were not collected from the compacted control area in the summer, it was again more similar in species composition to the open desert rather than to the heliostat field.

The results obtained in this study clearly show that plant development has been greatly enhanced in the more moderate microenvironments created beneath heliostats, as would have been predicted by earlier experiments (Patten and Smith, 1980). Three factors may account for this: i) reduced surface temperature extremes due to shading by the heliostats, ii) reduced evaporation from the soil surface, and thus conservation of soil moisture, due to shading and wind deflection by the heliostats and iii) addition of water to the soil beneath each heliostat due to regular washing of the mirror surfaces. Because it was not possible to obtain accompanying microclimatic and soil moisture data in this study, the relative importance of these factors cannot be evaluated. Probably all three played a role in stimulating larger plant size, greater overall plant cover and enhanced survival into the dry season, as was observed beneath heliostats in this study.

6.0 ANIMAL STUDIES

6.1 Arthropods

Arthropods were sampled in two plots within the prospective heliostat field and nine plots east of the field during 1979. In each plot two sets of pitfall traps were installed: one a square grid of 25 traps, each 5 m apart; the other consisting of 17 traps forming a cross with arms 8 m in length. Drift fences were used to enhance effectiveness of traps. Arthropods on plants were sampled with a sweep net. The net was swept 50 times along two transects in each plot.

This work showed that the arthropod fauna of the Solar One site was similar to that of other areas of the northern Mojave Desert (e.g., see Thomas and Sleeper 1977, Mispagel 1978, Franco et al. 1979, Stave and Shiff 1981, Mispagel and Sleeper 1983). Creosotebush supports a varied assemblage of sap-feeding and defoliating insects, principally hompterans and orthopterans. Other shrubs are populated with various hemipterans, mealybugs, thrips, phytophagous beetles, and larvae of as many as half-a-dozen familes of small moths. Some 300 different kinds of arthropods were distinguished in samples from the Solar One site. A list of various taxa and identified species was given by Turner (1979: Appendix 15).

Ants were among the more conspicuous diurnal surface-dwelling species, particularly harvester ants. The greatest numbers of all species of ants were recovered from the prospective heliostat field and plots just each of the field. Solenopsis maniosa was the predominant species, apparently because this ant exploits disturbed soil environments (Snelling and George 1979) and the area in question had a history of disturbance (see p. 5-1). Since this species is known to develop nest systems to a depth of 2 m it is not surprising that it was one of the first of the native fauna to reestablish itself on the graded heliostat field: possibly from remnant populations. It is doubtful that the presence of harvester ants in the heliostat field compromise Solar One operations. They do, however, represent a food source for birds and lizards which have been observed feeding on them in the heliostat field.

One exploratory study was undertaken of host-specific leaf hoppers occurring on creosotebush adjacent to the heliostat field (Schiff 1982). The premise was that if the plants were placed under stress by construction activities they would be unable to support normal populations of this insect. However, no changes in leafhopper population were detected.

After testing and operation of Solar One began in the Spring of 1982 it was observed that insects were being incinerated in the heliostat beams - most conspicuously when the heliostats were focused on the standby points.

This phenomenon was investigated by personnel of the Los Angeles County Natural History Museum between (McCrary et al. 1984, Flanagan, unpubl. report). Whereas only six birds were known to have died in heliostat beams between 1982 and 1984, untold numbers of insects were incinerated during this time. During 71 observation periods between September 1982 and May 1983, heliostats were at standby points 19 times. Insect deaths were recorded during 10 of these periods. Heavy periods of incineration occurred on 8 October 1982 (7,059 insects/hr) and 4 May 1983 (632/hr). No incinerations were recorded in December, February, and March. Only occasional to moderate numbers of incinerations occurred at other times--from 8 to 234 insects/hr (McCrary et al. 1984).

In only a few instances were the particular species of insects killed identified. The insect parts that were identified included wasps, bees, dragonflies and butterfies. On one occasion, about 75 dragonflies were found around the base of the control tower, none of which showed any sign of incineration (McCrary et al. 1984). Between October 1983 and January 1984, Flanagan found three dead insects in the heliostat field: a monarch butterfly, a queen butterfly and a noctuid moth. Both butterfies were singed.

The attraction of insects to the beam standby points--and possibly the face of the receiver--is an intriguing question with important ecological implications. Insects are a significant component of desert ecosystems and the consequences of their mass destruction are not easily predictable. The phenomenon could threaten local apiaries and crops dependent upon insect pollination.

A meaningful investigation of this problem would be inordinately difficult. One would have to determine which species are being killed and in what numbers, and then determine whether the observed deaths have significant effects on local populations or merely substitutes for other natural sources of mortality.

6.2 Reptiles

The following kinds of reptiles were observed in the vicinity of the solar site: zebra-tail lizards, western whiptail lizards, leopard lizards, desert iguanas, horned lizards, long-tailed brush lizards, glossy snakes, sidewinders, coachwhips, bullsnakes, long-nosed snakes, and the desert tortoise.

Lizards were counted along two lines across the prospective mirror field and three 800-m north-south lines downwind of the field in the spring and summer of 1979 before construction began (Turner 1979: p. 47 et seq.). Line 20 was 50 m east, Line 31 was 360 m east, and Line 32 was 610 m east of the edge of the prospective heliostat field. This work showed that the whiptail lizard (*Cnemidophorus tigris*) and the horned lizard (*Phrynosoma platyrhinos*) were more abundant in undisturbed areas east of the prospective field, while the zebra-tail lizard (*Callisaurus draconoides*) was more abundant in the disturbed and open areas within the field. The desert iguana (*Dipsosaurus dorsalis*) showed no trends in numbers (Table 6.1).

During the spring and early summer of 1980 and 1981 we again made counts along Lines 20, 31 and 32. Lines were walked in the morning, usually between 0700 and 1200--the normal period of peak activity of lizards in the area.

The two most abundant species were zebra-tail lizards and whiptail lizards, and we report observations of these species. Turner (1979: p. 48) showed that the apparent incidence of *Callisaurus* was about the same between early May and late July, with no evidence of a seasonal effect on counts. Counts of *Cnemidophorus*, however, were highest early in the season and diminished significantly towards the end of July.

Table 6.1. Mean numbers of lizards counted (per walk) along lines at the Barstow STPS site in 1979.

Species	Lines					
	In prospective mirror field		East of prospective mirror field			All
	12 (42)	13 (39)	20 (75)	31 (77)	32 (77)	(310)
Zebra-tail lizard (*Callisaurus draconoides*)	1.62 (68)	1.04[1] (28)	1.40 (105)	1.25 (96)	0.94 (72)	1.19 (369)
Whiptail lizard (*Cnemidophorus tigris*)	0.88 (37)	1.12[1] (30)	1.35 (101)	1.79 (138)	1.79 (138)	1.43 (444)
Desert Iguana (*Dipsosaurus dorsalis*)	0.48 (20)	0.22[1] (6)	0.65 (49)	0.47 (36)	0.39 (30)	0.45 (141)
Horned lizard (*Phrynosoma platyrhinos*)	0.26 (11)	0.37[1] (10)	0.23 (17)	0.49 (38)	0.69 (53)	0.42 (129)

[1] adjusted for line length

Table 6.2 gives mean numbers of these two species counted on three lines in 1979 (prior to construction activities) and again in 1980 and 1981. The general points to emphasize here are i) the decline in apparent abundance of Callisaurus on all lines between 1979 and 1981, and ii) the conspicuously greater abundance of Cnemidophorus along Line 20 in the spring of 1980. Turner (1981: p. 71 et seq.) analyzed the counts of Callisaurus and Cnemidophorus in detail, and a recapitulation of the sampling data may be found in that report. There was no question as to the reality of the decline in apparently abundance of zebra-tail lizards between 1979 and 1981, for this was observed in other parts of the Barstow region as well (Leon Hunter, pers. comm.). For monitoring purposes, the important thing to consider was possible differences between lines. In 1979, counts of zebra-tail lizards did not differ as a function of distance from the prospective heliostat field, and the data from 1980 and 1981 were in general accord. The 1981 observations were hard to judge because counts were so low along all lines, but the virtual absence of these lizards along Line 20 was notable.

Counts of whiptail lizards along Line 20 were distinctly greater than those along Lines 31 and 32 in 1980, but this was not true in 1981 (see Turner 1981: 72 et seq.). We concluded that construction activities in some way influenced numbers of whiptailed lizards counted on Line 20 during the spring and summer of 1980. We can eliminate the possibility of an increase in numbers owing to improved reproduction and/or survival of lizards--the response was simply too rapid. There are several other possible explanations: i) lizards moved into the area as a result of clearing and grading the heliostat field, ii) lizards moved into the area from areas farther east, and iii) deposition of new sand along Line 20 made whiptail lizards more conspicuous and readily counted. The last explanation is doubtful because, as we showed previously, new sand entered close-in areas during the spring of 1981 as well as 1980.

The idea of animals moving out of the disturbed heliostat field into adjoining areas is superficially attractive, but not strongly supported by counts of other kinds of lizards. Counts of desert iguanas in 1980 were conspicuously higher along Line 20 than in 1979, but so were counts along Lines 31 and 32. On the other hand, counts of zebra-tail lizards and horned lizards declined along all lines between 1979 and 1981. Rodent trapping during the spring of 1980 gave no evidence of increased numbers in the plot closest to the heliostat field, but we must recall that this plot was about 300 m east of the field, while Line 20 was only 50 m downwind. It is also important to bear in mind that when clearing and grading began in the fall of 1979, adult whiptail lizards were dormant and underground. There is no way of knowing how well these animals survived early construction operations in the heliostat field. It is possible that some of these lizards survived, emerged in the spring of 1980, and quickly moved off the open surface of the field into less disturbed environments. We can neither prove nor refute this premise. We consider it very unlikely that whiptail lizards moved into areas along Line 20 from locales farther east (downwide) of the heliostat field, but again we cannot disprove this possibility.

6.3 Rodents

Rodents were trapped within the prospective heliostat field and at various distances east of the field between September 1978 and July 1979 (Turner

Table 6.2. Mean Numbers of lizards counted (per walk) along 800-m lines downwind of the solar site, 1979-1981. Total lizards counted are given in parentheses.

Species	Year	Line 20	Line 31	Line 32
Zebra-tail lizard (*Callisaurus draconoides*)	1979	1.40 (105)	1.25 (96)	0.94 (72)
	1980	0.34 (26)	0.18 (14)	0.40 (31)
	1981	0.02 (1)	0.05 (3)	0.28 (18)
Whiptail lizard (*Cnemidophorus tigris*)	1979	1.35 (101)	1.79 (138)	1.79 (138)
	1980	2.74 (211)	1.40 (108)	1.16 (89)
	1981	0.97 (62)	0.78 (50)	0.47 (30)

1979) and east of the field between October 1979 and July 1981 (Turner 1981). The most abundant species in the area was the kangaroo rat, Dipodomys merriami, which occurred at densities of around 75 to 82 per hectare in the fall of 1978. Between 1978 and the summer of 1981 apparent densities of D. merriami declined fairly steadily in areas 150 m east of the solar field and 600 m east of the field. By July 1981, estimated densities were only about 6% of those recorded in September 1978 (Turner 1981: 65). Analyses of densities and dates showed that the negative slopes of regression lines for the two areas were the same, although the area closest to the solar field almost always sustained greater numbers of kangaroo rats (Turner 1981: 66). These analyses were judged to provide "...no evidence that numbers of kangaroo rats...in the proximal plot were adversely affected by construction activities," and that the "...decline in numbers of kangaroo rats in both plots was apparently owing to a sequence of conditions unfavorable for reproduction and/or survival of young" (Turner 1981: 67).

Trapping was continued, on a reduced scale, during 1982, 1983 and 1984, during construction, testing and operation of Solar One. Two areas were used, one between 55 and 95 m east of the heliostat field perimeter fence and another between 155 and 195 m east of the fence. The former was in an area where substantial amounts of windblown sand were deposited during 1980 and 1981. The latter was beyond the areas of obvious sand deposition. Live-trapping was conducted along two 300-m north-south lines in each area. Each line had 20 stations and two traps at each station.

By 1984 areas east of the heliostat field were extensively disturbed by development of agricultural fields. The trapline closest to the field was still intact, but about half the extent of each of the other three lines had been destroyed. The results of trapping in 1984 will be discussed separately.

Trapping along all four lines was carried out between 19-21 April and 19-21 July 1982, and 11-13 April and 13-15 July 1983. Earlier trapping efforts were designed to afford estimates of density (Turner 1981), but in 1982 and 1983 we trapped only to provide comparisons between sandy and non-sandy areas.

Table 6.3 shows animals trapped in 1982 and 1983. The 1983 trapping was clearly more productive than that of 1982--both in terms of numbers of individuals and species. During these two years 15 pocket mice (Perognathus longimembris) were trapped along lines 155-195 m east of the heliostat field, only three along the lines closer in. This was probably owing to differences in substrates and ground cover in the two areas. The more distant traplines had less sand, and more continuous cover by annual grasses and filaree (Erodium cicutarium). Whether the increased numbers of ground squirrels (Citellus tereticaudus) taken in 1983 reflect real changes in numbers of squirrels or changes in behavior cannot be ascertained.

On 28 April 1984, 112 traps were set out-- 40 along the intact line and 32 along what was left of the other three lines. The small remaining area of undisturbed habitat was overrun with two kinds of rodents: 51 kangaroo rats (D. merriami) and 7 pocket mice (P. longimembris). This sort of trapping success had never been experienced in any earlier effort in this area.

Dipodomys merriami is a seed-eater, and its well-being is directly tied to production by plants affording these foods. Germination, growth and

Table 6.3. Numbers of rodents trapped along two lines in each of two areas east of Solar One during the spring and summer of 1982, 1983.

Dates	Lines 55-95 m from east edge of field	Lines 155-195 m from east edge of field
April 1982	4 Kangaroo Rats[1]	4 Kangaroo Rats 3 Pocket Mice[2]
July 1982	2 Kangaroo Rats	2 Kangaroo Rats 1 Ground Squirrel[3]
April 1983	13 Kangaroo Rats 1 Pocket Mouse 1 Grasshopper Mouse[4]	8 Kangaroo Rats 9 Pocket Mice 1 Wood Rat[5]
July 1983	8 Kangaroo Rats 6 Ground Squirrels 2 Pocket Mice 1 Grasshopper Mouse	5 Kangaroo Rats 3 Ground Squirrels 3 Pocket Mice 1 House Mouse[6]

1. Dipodomys merriami
2. Perognathus longimembris
3. Citellus tereticaudus
4. Onychomys torridus
5. Neotoma lepida
6. Mus musculus

reproduction by plants are, in turn, influenced by rainfall. We have already discussed (p.4-1) Beatley's analyses of winter rainfall and plant germination and growth, and this line of thinking has been extended to the dependence of desert rodents on winter annuals and rain (Beatley 1969b).

In Figure 6.1 we set forth trapping experience relating to D. merriami between the fall of 1978 and the summer of 1984, as well as autumn rainfall totals for 1977 to 1983. The periods of low trapping success corresponded to seasons following low winter rainfall. With one exception (1983), trapping success was high following seasons with September-December rainfall exceeding 25 mm. The relative abundance of D. merriami in areas east of the heliostat field declined markedly between 1978 and the summer of 1982 (see Turner 1981: 65). One possible explanation for these changes--which occurred in areas close to and relatively remote from the field--is that the decline was associated with four years of distinctly suboptimal rainfall, and not to construction and operation of Solar One. This was the view expressed by Turner (1981). An alternative explanation is that the activities attending construction and operation of Solar One were so pervasive that all the areas examined, including those 600 m east of the fence, were affected. In view of the 1983 and 1984 data--showing apparent increases of D. merriami following two years of favorable winter rainfall-- we favor the interpretation originally tendered by Turner (1981).

6.4 Birds

Bird studies in the vicinity of Solar One began with pre-construction counts of birds in the prospective heliostat field and areas east of field between September 1978 and May 1979 (Turner 1979), further work in these areas during construction in 1980 and 1981 (Turner 1981), seven 3-day censuses within the heliostat field between March 4 and June 10, 1982 (Turner 1982), and work by employees of the Los Angeles County Natural History Museum between the spring of 1982 and April of 1984 (McCrary et al. 1984; Flanagan, unpubl. report). During this time about 140 species of birds were observed in the vincinity of the solar facility. Of these, 107 were listed by McCrary et al. (1984) and the others were reported by Turner (1979, 1981) or in Flanagan's report. Flanagan listed 13 resident species: Mourning Dove, Roadrunner, Great Horned Owl, Northern Flicker, Common Raven, Loggerhead Shrike, European Starling, Red-winged Blackbird, House Finch, and House Sparrow.

Pre-construction observations in 1978-79 used the Emlen (1971, 1977) transect method to make density estimates within the prospective heliostat field and areas downwind of the field. Transects ranged from 800 to 1600 m in length. The observer walked these lines during the 2 1/2-3 hours after sunrise at about 1 km/hr, recording all visual and auditory detections along each side of a line. Converting these counts to estimates of density was based on estimates of the widths of strips in which detections of various species could be made. Some species were detected over greater distances than others. Estimated strip widths were 60 m for most species, but were as high as 120 m for some types (e.g., Say's Phoebe, Yellow-rumped Warbler, Savannah Sparrow), and even 500 m for the Western Kingbird. For some species, strip widths varied with season and amount of vegetative cover. No strip widths were estimated for wide-ranging species (e.g., falconiforms, ravens), and densities of these species were not estimated. Other habitats in the vicinity of the solar site were inspected and simple lists of birds observed were

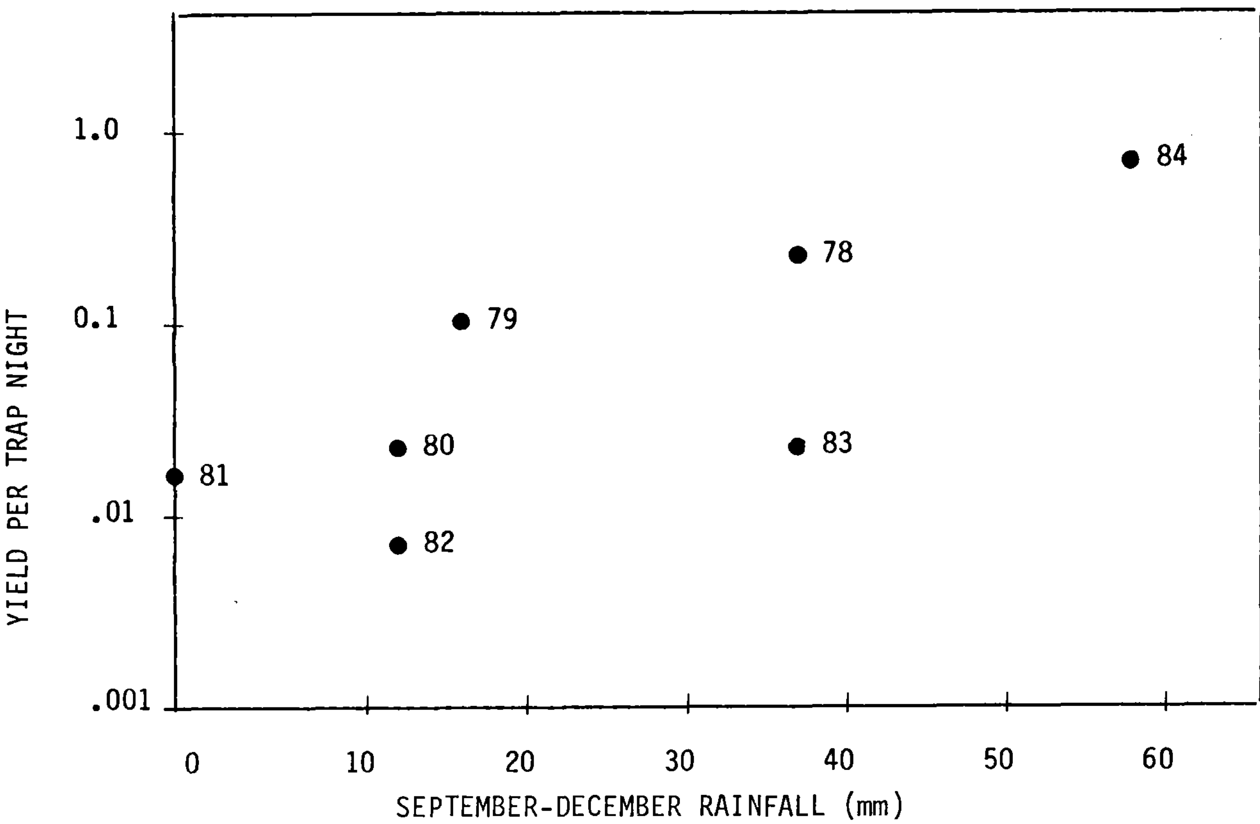

Figure 6.1. Trapping success for the Kangaroo Rat (*Dipodomys merriami*) as a function of fall rain between 1978 and 1984. Numbers by data points indicate year of measurement.

maintained. Such observations were made in adjoining alfalfa fields, along tamarisk windbreaks, and in the vicinity of evaporation ponds. In January 1981, with construction underway, a new program of observations within the heliostat field was begun. This included one transect 450 m long, which completely encircled the innermost ring of heliostats, four 150 m transects (one in each quadrant of the field) around the outermost ring of heliostats, and four 100 m transects (one in each quadrant) midway between the innermost and outermost ring of heliostats. Observations and counts were made in these areas in January, April, May and July of 1981. Arrangements were also made for the collection and preservation of birds found dead in the construction area by SCE and/or DOE employees.

Table 6-4 summarizes pre-construction observations of birds within the prospective heliostat field and also gives counts of birds seen there during the first half of 1981--after most of the heliostat pedestals and some of the heliostats were in place. The post-construction fauna was obviously diminished--both in terms of species richness and diversity. Most of the Horned Larks were observed on the ground, and in the northwest quadrant of the field. This was apparently owing to the proximity of an alfalfa field. All species except the Horned Lark, the American Kestrel and the Mountain Bluebird were observed above pedestal height. Swallows and Ravens fed or hunted over the field, whereas blackbirds were seen flying between feeding and roosting areas. No birds were observed on pedestals, heliostats, or around the periphery of the core area. Birds within the heliostat field displayed normal behavior and only one dead bird was found. A Say's Phoebe (Sayornis saya) was found dead at the base of a building in late March 1981.

Between September 1978 and May 1981 densities of birds were estimated from transect data in an area 300-600 m downwind of the eastern edge of the heliostat field (See Turner 1981: Appendix 7). The purpose of these observations was to see if construction activities affected the behavior and density of birds in areas outside of the heliostat field. Table 6.5 summarizes estimates of densities of Horned Larks in the plot 300-600 m east of the field and in three other areas in which transect counts were made.

We initially established a control area between 1.9 and 2.2 km east of the field, but later moved to another area (4.1 - 4.5 km east of the field) because it was more comparable to the close-in site. Given the mobility of birds, about all that can be said of the sampling data between January 1980 and May 1981 is that there were no obvious indications of effects of construction on larks 300-600 m east of the edge of the field. Estimated densities in this area were generally higher than those observed farther east (except in April 1980). Larks were present in the easternmost area in January 1981, but were only seen in flight over the plot. The higher density in the 300-600 m area in May 1981 was due to the proximity of a recently mowed alfalfa field.

Herbert Hill carried out seven 3-day censuses within the heliostat field between March 4-6, March 22-25, April 14-16, April 27-30, May 12-14, May 26-28 and June 8-10, 1982. This work was carried out along 9 transects: one 450-m transect completely encircling the innermost ring of heliostats, four 150-m transects (one in each quadrant of the field) following the outermost ring of heliostats, and four 100-m transects (one in each quadrant) midway between the innermost and outermost rings of heliostats. Observations were made twice each day--in the early morning and again in late afternoon. Table 6.6 summarizes counts of living birds within the field.

Table 6.4. Birds observed in prospective heliostat field (September 1978, January, March and May 1979) and after installation of some heliostats in 1981. Pre-construction data record presence of species (+) or a range of estimated densities ($n \cdot km^{-2}$) if species was observed at different times. Post-construction data give numbers of birds seen during six (January), four (April), ten (May) and five (July) counting periods. Dashes indicate that species were not observed.

Species	September 1978-May 1979	1981 Jan	Apr	May	July
Turkey Vulture	+	-	-	-	-
Marsh Hawk	+	-	-	-	-
American Kestrel	-	2	-	-	-
Prairie Falcon	+	-	-	-	-
Killdeer	+	11	-	-	-
Burrowing Owl	+	-	-	-	-
Western Kingbird	0.1	-	-	-	-
Say's Phoebe	1.0	-	-	-	-
Horned Lark	50 - 540	0	1	73	53
Rough-winged Swallow	-	-	-	-	1
Barn Swallow	+	-	-	3	-
Cliff Swallow	-	-	-	2	-
Common Raven	+	1	-	3	-
Loggerhead Shrike	1.0 - 2.1	-	-	-	-
Yellow-rumped Warbler	2.1	-	-	-	-
Mountain Bluebird	-	2	-	-	-
Western Meadowlark	4.2 - 7.3	-	-	-	-
Starling	+	-	-	-	-
Red-winged Blackbird	0.4	-	-	4	-
Brewer's Blackbird	+	-	-	15	-
Savannah Sparrow	3.1	-	-	-	-
Lark Sparrow	4.2	-	-	-	-
White-crowned Sparrow	9.1	-	-	-	-
Song Sparrow	10.4	-	-	-	-

Table 6.5. Estimates of densities ($n \cdot km^{-2}$) of Horned Larks downwind of the solar site between September 1978 and May 1981. Dashes indicate that no observations were made in areas.

Dates	Distances downwind (m) from eastern edge of field			
	50	300 - 600	1900 - 2200	4100 - 4450
Sept 1978	92	100	-	-
Jan 1979	4.2	4.2	-	-
March	63	37	-	-
May	108	44	-	-
Sept	-	20.8	-	-
Jan 1980	-	4.5	3.0	-
Apr	-	20.8	-	41.7
May	-	34.2	-	30.7
Sept	-	14.6	-	18.8
Jan 1981	-	16.4	-	0
Apr	-	15.6	-	10.4
May	-	39.6	-	17.7

Table 6.6. Counts of birds within the heliostat field at Solar One in 1982.

Species	Mar 4-6	Mar 22-25	Apr 14-16	Apr 27-30	May 12-14	May 26-28	June 8-10
White-faced ibis		1					
Ring-billed gull		1	2				7
Killdeer							1
Avocet				2	2		
Red-tailed hawk	1						
Mourning dove				2	5		
Say's phoebe						1	
Horned lark	1				3	17	4
Barn swallow	1		1		3		
Raven	1				2		
Starling		30	4	1	12	40	36
Brewer's blackbird			2		5	8	4
Yellow-headed blackbird			6				
Red-winged blackbird			3				
Brown-headed cowbird						1	
House finch							1
Totals	4	32	18	4	32	67	53

Almost all of the birds observed by Hill were flying over the field at heights ranging from just above the heliostats to above the top of the receiver tower. Of the 210 sightings listed in Table 6.6, only one was of a bird perched on a heliostat--a House Finch during June 1982. Birds seen feeding on insects in the air were various swallows and swifts and a few tyrannids (e.g., Say's Phoebe, Kingbird). The other birds feeding in the field were Horned Larks and Starlings, often seen in substantial numbers feeding on seeds. In one instance (May 13), Hill reported a Horned Lark feeding on ants among the heliostats.

Pat Flanagan made other observations in and around the heliostat field between 1982 and 1984. Table 6.7 summarizes some statistical features of her data. The large numbers of birds observed in 1983-84 were owing to the presence of huge numbers of aquatic birds.

The greatest interest in birds at Solar One has to do with mortality following collisions with structures or inflicted by heliostat beams. During the early phases of testing, heliostats were brought to standby positions--creating luminous orbs about 100 m from the receiver panels (Fig. 2.6). Hill found dead birds in the heliostat field during 1982 (Turner 1982), as did Flanagan between 1982 and 1984 (McCrary et al. 1984; Flanagan, unpubl. report). Birds were most commonly killed by collisions with heliostats, but at least six birds were incinerated in heliostat beams. Table 6.8 summarizes overall experience between 1982 and 1984. This table does not include old remains of birds apparently killed by predators. Both Hill and Flanagan found old carcasses, wing fragments, tufts of feathers, etc., which were ascribed to actions by predators. It must be recognized that such remains could have been owing to heliostat collisions followed by partial consumption by predators. Instances of this nature were enumerated by Turner (1982: Table 4) and in Flanagan's report.

It appears unlikely that birds mortally burned in heliostat beams are entirely incinerated. According to Flanagan, the death of the Vaux's Swift was witnessed by several people. Although there was a large puff of smoke, the body of the bird was subsequently recovered. Even the hummingbird was not entirely burned. Hence, we judge that the reported incidence of birds killed by collisions and burning is a reasonable measure of the relative frequency of such events. Birds apparently often survived entry into heliostat beams. Flanagan reported several instances when workers observed the passage of a bird into a beam. In both cases smoke was observed, followed by erratic flight, but both birds recovered and survived their exposure. Some birds apparently perceive and evade the beams. Hill reported that avocets "...flew near the receiving tower and...suddently swerved to avoid the beam." Flanagan described a group of Canadian geese which flew east from the evaporating ponds towards Solar One and then turned in a manner suggesting deliberate avoidance of heliostat beams.

The general environmental setting at Solar One is not representative of the western Mojave Desert because of the evaporation ponds and agricultural activities adjoining the facility. McCrary et al. (1984) described research in a typical creosotebush scrub area in California where only 30 species of birds were observed in the course of a year. At Solar One about 140 species were recorded between 1978 and 1984. The diversity of habitats has undoubtedly enriched all elements of the local avifauna. McCrary et al. (1984)

Table 6.7. Bird census data at Solar One between 1982 and 1984.

	Spring 1982	Fall 1982	Winter 1982	Spring 1983	Fall 1983	Winter 1983	Spring 1984
Total spp. per census	60	82	40	68	39	34	36
Mean spp. per census	23.6	16.8	13.7	16.2	18.7	21.4	18.6
Peak numbers, all species, per census	1040	474	884	532	1812	1044	1284
Number of resident spp.	12	13	10	13	9	7	1

Source: P. Flanagan

Table 6.8. Deaths of birds in the Solar One heliostat field owing to collisions and incinerations (1982-1984).

Time	Incinerations	Collisions
Spring 1982	1 Vaux's Swift (*Chaetura vauxi*) 1 White-throated Swift (*Aeronautes saxatilis*) 1 hummingbird 1 Barn Swallow (*Hirundo rustica*)	1 American Kestrel (*Falco sparverius*) 5 Mourning Doves (*Zenaida macroura*) 2 European Starlings (*Sturnus vulgaris*) 1 Horned Lark (*Eremophila alpestris*) 1 Yellow Warbler (*Dendroica petechia*) 1 Brown-headed Cowbird (*Molothrus ater*) 1 House Finch (*Carpodacus mexicanus*)
Fall 1982	1 Yellow-rumped Warbler (*Dendroica coronata*) 1 sparrow	1 Blue-winged Teal (*Anas discors*) 1 Red-necked Phalarope (*Phalaropus lobatus*) 1 hummingbird 3 Savannah Sparrow (*Passerculus sandwichensis*) 1 White-crowned Sparrow (*Zonotrichia leucophrys*) 1 Dark-eyed Junco (*Junco hyemalis*) 1 Yellow-headed Blackbird (*Xanthocephalus xanthocephalus*) 1 blackbird
Winter 1982-3	none observed	1 Western Meadowlark (*Sturnella neglecta*) 1 White-crowned sparrow
Spring 1983	none observed	1 Eared Grebe (*Podiceps nigricollis*) 1 Yellow-rumped Warbler 1 MacGillivray's Warbler (*Oporornis tolmiei*) 1 Red-winged Blackbird (*Agelaius phoeniceus*) 1 Tricolored Blackbird (*A. tricolor*) 1 Yellow-headed Blackbird
Fall-Winter 1983	none observed	3 Mourning Doves 1 House Finch? 1 White-crowned Sparrow? 1 Eared Grebe? 1 Starling?
Spring 1984	none observed	2 Horned Larks?

suggested that "To insure a minimized impact, future solar receiver power plants in the Mojave desert should not be sited in close proximity to open water or agricultural fields." This is a useful idea, but it is important to recognize that interactions between aquatic birds and Solar One were limited. Tables 6.6 and 6.8 show that use of the heliostat field by birds and associated impacts of the facility principally involved passerines. Icterids and fringillids were the dominant interacting families.

The conclusions to be drawn from observations of birds at Solar One are that i) the natural avifauna of the heliostat field was altered, but the area was still used for feeding by some icterids and aerial insectivores, ii) birds were killed because of collisions with heliostats and, less commonly, by incineration in heliostat beams, iii) the incidence of facility-imposed mortality was not great considering the large number of birds in the area, iv) the central receiver tower was not an important source of mortality, and v) siting solar facilities in areas with limited open water and no agriculture would reduce effects on local birds.

6.5 Sensitive Species

The general area of the Barstow STPS was surveyed in 1972 in connection with the permitting process for the Coolwater Combined Cycle Project, and the site of Solar One was examined in April 1977 (Environmental Improvement Agency 1977). These surveys reported no rare or endangered species of plants or animals on the site. A fuller and more recent discussion of this aspect of the general area of the solar site was developed for the SCE Coal Gasification Demonstration Project to be constructed south of Solar One. Several sensitive species of plants and animals were listed as possible inhabitants of the area. The California Native Plant Society has proposed a classification of "rare" for *Dalea arborescens* (indigo bush), *Linanthus arenicola* and *Astragalus jaegerianus* (milkvetch), and a status of "endangered" for *Eriophyllum mohavense*. The U.S. Department of Interior has proposed *Chorizanthe spinosa* and *Salvia columbariae ziegleri* (chia) as "rare." Of these plants, we observed only *Linanthus arenicola* in study plots east of the solar site. The Solar One site was not judged a critical habitat for this species (Turner 1979:22). *Muilla coronata* (muilla) was identified in the vicinity of Solar One. This species is classified as "rare" by the California Native Plant Society, but is not listed federally (Turner 1981, 74).

According to McCrary et al. (1984), "...no species of insects known to be under state or federal protection are anticipated or known to occur in the immediate vicinity of Solar One..." These authors also stated that "None of the bird species recorded in the area of Solar One are listed as threatened or endangered by either the U.S. Fish and Wildlife Service or California Department of Fish Game." The Prairie Flacon (*Falco mexicanus*) and the Golden Eagle (*Aquila chrysaetos*) are viewed as "sensitive" species by the California Department of Fish and Game, and both species "...are known to nest within eight miles of the [Solar One] area," according to the Gasification Demonstration Project Environmental Impact Report. The desert tortoise (*Gopherus agassizii*) is "protected" in California and is under consideration for federal listing as Threatened in California. Tortoises were observed by both DOE and SCE employees in the vicinity of Solar One, and we observed one about 800 m east of the site.

The most interesting problem involving sensitive species is that of the status of ground squirrels (Spermophilus) occupying the area downwind of the solar site. Two closely related species (S. tereticaudus and S mojavensis) occur in the northwestern corner of the Mojave Desert. The latter species, the Mojave ground squirrel, is classified as "Rare" by the California Department of Fish and Game (Hoyt 1972, Wessman 1977). The ground squirrels in the vicinity of Solar One have, at various times in the past, been identified as both species. In the course of our work we trapped ground squirrels which could not be definitely identified. We supported a special study by David Hafner during the summer of 1981 to resolve this issue (Hafner and Yates 1982). The general conclusions were as follows: i) on the basis of conventional morphological criteria morphs of both species of ground squirrels occupy the area downwind of the solar site, ii) the S. tereticaudus morphs were trapped in more sandy areas--a distinction which has been typical of past experience, iii) all ground squirrels downwind of the solar site had chromosome numbers of 36, and chromosome morphologies were identical, iv) on the basis of karyotypic data (i.e., chromosome counts and morphology) the squirrels at Solar One should be considered S. tereticaudus.

7.0 DISCUSSION

A convenient format for summarizing the findings of this study is to attempt to answer the five questions posed in the Introduction.

i) What would be the effects of construction of Solar One on the surrounding ecosystem?

Following several years of work during and prior to the construction of Solar One we wrote: "Our observations...are reassuring in that off-field environmental effects were apparently highly localized. Wind removal of loose sand from the cleared heliostat field and ensuing indirect effects on some species of plants and animals occupying close-in areas were the only impacts identified" (Turner 1981: 77). Subsequent observations through spring 1984 have reinforced this conclusion. Heavy deposits of sand within 50 m of the heliostat field effected the numbers and species diversity of annual plants but no effects were evident on the perennial vegetation, and no effects were detected at greater distances from the facility.

Measurements of sand depths at various distances downfield suggested that sand is moving gradually east, and that present rates of removal from the heliostat field are too low to replace losses of sand from those areas heavily impacted in 1980. Unless the surface of the field is further disturbed, we predict that the sand blown off the field in late 1979 and early 1980 will eventually be redistributed progressively farther east.

Since the primary source of this windblown material was clearly the heliostat field during grading, it follows that any procedure which will better control this material during grading of future facilities will reduce offsite impacts proportionately.

ii) Would Solar One represent an attractive nuisance or hazard to indigenous wildlife?

Three kinds of potential hazards were identified at Solar One: the central receiver and tower, the reflective surfaces of heliostats, and the standby points near the receiver surface at which heliostats were brought to focus. Insect incinerations were heavy but bird casualties were insignificant in proportion to the great numbers of birds in the area.

While insect remnants were recovered near the central receiver tower, and on the platforms and walkways servicing it, there was no direct evidence of insect incinerations at the face of the receiver. The nearness of the standby points, the light weight of insect parts, and the obvious incinerations occuring in the standby points, led to the assumption that the insects had been killed in the standby points and that the remnants had drifted into the tower area. The assumption could not be verified. If true, it is not clear why insects were attracted to standby points but not a similarly glowing receiver. Possibly air turbulence across the face of the receiver prevented contact. No bird fatalities were attributed to interaction with either the receiver or the tower structure.

The standby points represented a significant hazard to insects which were attracted and incinerated in large numbers. Only six bird fatalities were attributable to incineration. All but one of these birds were insect-feeding species, possibly lured into the standby point in pursuit of prey. The significance of the large insect kill on the local ecology is not known. If this phenomenon were to occur near crops dependent upon insect pollination or near apiaries it might be perceived unfavorably. Since an alternate procedure is available to bring the heliostats to bear on the receiver, we recommend its adoption. A procedure which removed or reduced the standby phenomenon would effectively mitigate the uncertainty of the significance of insect kills.

Depending upon the angle of attack, the reflective surfaces of heliostats can present an optical illusion of open sky. Of the 45 bird fatalities ascribed to the presence and/or operation of Solar One, 39 apparently resulted from collisions with heliostats. Clearly, more intensive searching would have revealed more casualties, but we have no reason to believe that proportions killed by collisions and incineration would have changed. Any further studies of bird mortality could be sharpened by attempting to relate numbers of fatalities to total exposure, i.e., by attempting to estimate deaths per bird-hour within the solar facility. Such a program would require a substantial observational effort. No sensitive or endangered species were reported killed, and again total fatalities were an insignificant proportion of the resident population.

The heliostat structures _per se_ represent something of an attractive nuisance to birds. Large flocks of Horned Larks regularly rest in the heliostat field in the shade of the structures and have been observed feeding on ants. Birds have been observed occasionally using the heliostats as perches and one or two cases of birds fouling the mirror surface with excrement have been reported by Solar One operations personnel. There has been no evidence of nest building within the structures. We would expect that with the increased agricultural activity immediately adjacent to Solar One, use of the heliostat field by birds will increase. However, we have no evidence to date that Solar One represents a significant hazard to birds or that the presence of birds compromise any aspect of Solar One operations.

Small animals such as kangaroo rats, lizards and snakes can easily penetrate the perimeter fence and forage within the heliostat field. To date, however, there is no evidence of new burrow systems or permanent colonization by rodents. Harvester ants are well established and represent a food source for birds and lizards. A few sidewinder rattlesnakes have been observed and killed by Solar One operations personnel. To date there is no evidence that use of the field by indigenous species has compromised any aspect of Solar One operations. The occasional discovery of a poisonous snake must, of course, be considered a potential personnel hazard. Our personal judgement is that the hazard is more perceived than real.

One caveat is worth mention. There is clear evidence that given the opportunity local species of plants and animals would recolonize the field. In an ecological perspective, Solar One has been in place for a very short time. If Solar One were to be operated for the nominal 30 year life of a power plant one could expect a continuing battle to keep the field in the relatively barren condition it is now. While the cost of so doing may be acceptable for Solar One, it may not be acceptable for a future facility ten times larger.

iii) Would Solar One have an indirect effect on the surrounding ecosystem?

The general lack of observed effects on the downwind ecosystem resulting from construction of Solar One, reinforced our belief that if the surrounding ecosystem were to be affected it would be through a change in microclimate brought about by the presence and operation of Solar One. Thus, in 1982 we undertook micrometeorological studies both witnin the heliostat field and in areas downwind. We found that the presence of Solar One did indeed affect certain micrometeorological states in downwind areas. We also showed that air temperature profiles among an array of heliostats differed from those measured concurrently outside. Morning surface temperatures were much lower inside the field (although this difference disappeared by late afternoon). The differences were small but statistically significant.

In Section 4.0 we presented evidence for small effects on temperature (less than 0.5 °C) wind speed (less than 0.4 m/sec) and evaporation (less than 1.5 ml/hr) in a limited region downwind of the Solar One heliostat field (up to 190 m from the outer fence). Because these differences were so small, relative to apparently natural heterogeneity, the effects of Solar One on rates of evaporation, air temperatures and wind speed will not affect the downwind biological community. The picture could be different for a facility the size of the projected Solar 100 plant.

A good case may be made that the extension of irrigated agriculture into California desert areas will have a much greater effect on climatic and micrometeorological variables than 10 MWe solar thermal power plants. Irrigated fields in arid regions can influence downwind reaches up to the width of the field--more than 1 km under some conditions (de Vries 1959). Air temperatures can be $\geq$5°C greater at the transition from an irrigated region to a non-irrigated area (Rider et al. 1963).

iv) Would revegetation of the graded heliostat field be useful to control erosion or replace lost habitat?

Unfortunately the study period was too short to address this question. The fine surface material in the heliostat field remaining after grading and construction has blown away leaving a coarse hard surface resistant to erosion if left undisturbed. Vehicular traffic associated with maintenance activities and washing of heliostats could alter this condition. While some evidence of erosion is present it is not clear at this time that surface erosion is a problem at Solar One.

If revegetation were to be undertaken it could replace lost habitat, but the issue is not relevant to a small scale installation such as Solar One. Stabilization of surface soil and replacement of lost habitat may be important considerations for larger installations in different ecological settings.

v) Can the environmental observations made at Solar One be extrapolated to larger future central receiver systems?

Our observations at Solar One have relevance not only to the pilot facility, but also to future construction of larger solar thermal power plants. For example, Southern California Edison is already looking ahead to the possible design of the plant in Johnson Valley which calls for two solar collector systems, each with a central receiver atop a 200-m tower. Each heliostat field will require about one square mile and will contain from 7,500 to 8,000 heliostats (Southern California Edison 1982). The plant will require construction of two 3-million-gallon storage tanks for molten salts, a wet cooling tower, a turbogenerating system, a control building and two evaporation ponds totalling 43 ha. The plant will use about 2,600 acre-feet of water annually.

In our view, the two most important features of Solar 100 are i) the area to be graded and cleared for heliostats, and ii) the width of the heliostat fields along the azimuth of prevailing winds (west to west-northwest in Johnson Valley). The size of the heliostat fields is important because cleared surfaces are a source of windblown sand unless specific steps are taken to stabilize surfaces <u>while work is in progress</u>. We have pointed out that an estimated 160 metric tons of sand were blown off the area cleared for Solar One (ca. 53 ha). Each heliostat field of Solar 100 would be about 259 ha in area. The width of a heliostat field affects the extent of downwind influences on air flow. At Solar One the far field wake was estimated to be "...detectable 1000 to 2000 m...downstream with the amount of retardation a maximum within 300 m...of the array" (Radkey and Zambrano 1982). With a heliostat field one mile (1610 m) across, one would expect the extent of the far field wake to be roughly twice that measured at Solar One--where field width is roughly 780 m (Radkey, pers. comm.). The height of the internal boundary layer would also be increased, but not doubled (Radkey, pers. comm.).

Increases in bird mortality at Solar 100 are more difficult to foresee because birds are--at present--much less abundant than at Solar One. The long-term influences of a 35-acre evaporating pond are difficult to forecast, although one would expect an influx of some species of birds not presently occurring in Johnson Valley. The presence of two towers, each about twice the height of the one at Solar One, could be an added source of casualties.

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