SOLAR ENERGY CONVERSION : AN
ANALYSIS OF IMPACTS ON DESERT
ECOSYSTEMS

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SOLAR ENERGY CONVERSION: AN
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ARIZONA STATE UNIVERSITY

DEPARTMENT OF ENERGY
CONTRACT NO. EC-77-S-02-4339

FINAL REPORT

EXECUTIVE SUMMARY

1. The desert region of North America is considered a prime area for the development of solar energy conversion facilities. Development of these facilities will both create disturbances and alter the environment of the construction area. The desert ecosystems are under stress and can be expected to respond dramatically to any major environmental change caused by solar energy conversion system construction and operation.
2. There are solar energy conversion systems in the Southwest that are functional while others are in the testing or planning stages. Two solar powered irrigation pumping systems are functional using parabolic mirror solar concentrators. The solar thermal power system concept ("power tower") is being tested at a 5 MW thermal test facility near Albuquerque, New Mexico prior to actual construction of a 10 MW_e solar thermal power system near Barstow, California. A 100 MW_e solar thermal system (central receiver system) is being planned as a follow up project to the 10 MW_e facility. Photovoltaic solar dispersed power systems are also planned for construction in the next decade.
3. Impacts resulting from construction and operation of solar conversion facilities have the potential of altering the complex desert ecological systems. These ecosystems are composed of two parts, the biotic or organism component and the abiotic or chemical and physical components. Within the biotic component energy is transferred through the food chain and organisms interact in the process of growth and survival. The abiotic

factors such as temperature, precipitation, soil, etc. establish the environment within which the organisms function. Interrelationships between organisms and abiotic factors generate flows of nutrients and other ecosystem constituents through biogeochemical cycles. It is these interacting processes and cycles that may be altered by solar conversion facilities.

Based on the ecosystem concept, theoretical ecological impacts of solar conversion systems have been developed. These are discussed under the impact categories of shading, wind deflection and physical disturbance.

Ecosystem factors that are considered to have significant changes resulting from shading are solar radiation, soil and air temperatures and soil moisture. These factors greatly influence the functional processes of plants and animals and these changes are expected to cause changes in growth diversity and density of plants and animals and behavioral patterns of animals.

Wind deflection by solar conversion facilities is expected to cause changes in air velocity and turbulence, air temperature profiles, heat flux patterns, soil moisture and evaporation and humidity. Organism response will relate directly to development of stress or optimal conditions as these factors change.

Construction and maintenance of solar conversion facilities will cause physical disturbances which may change soil structure, runoff and soil erosion patterns, moisture holding capabilities of the soil and energy flux patterns due to surface albedo changes. Plant and animal changes in density diversity, growth, reproduction and behavior can be expected as a result of disturbance alterations within the solar collector array.

4. Research needs to study the impacts of solar energy conversion systems are based on the research required to test hypotheses developed from an analysis of the theoretical ecological impacts of solar collector systems.

Hypotheses on biotic changes in solar collector arrays are based primarily on the concept that abiotic changes are the driving variables governing biotic changes. General biotic changes will be in plant productivity, plant species diversity and animal species composition.

Plant and animal density and diversity should increase with time while plant productivity is increasing. Density of soil organisms should also increase over time. Diurnal animal behavior should be altered. Plant and animal responses will vary depending on whether the desert community was preserved or the site was cleared.

Abiotic hypotheses are based on the premise that solar radiation or energy input will be altered and air movement will be changed. It is hypothesized that more of the radiation available to organisms will be diffuse, soil will be compacted changing soil moisture availability, and air temperatures should be cooler on the average within the collector array. Other hypotheses are related to these.

The research needed to test these hypotheses is designed around sampling changes in plant and animal processes and monitoring the abiotic changes within and outside of a solar collector array. There are established techniques for measuring the suggested biotic and abiotic changes and these should be used.

5. The short and long range research program to establish the impacts of solar energy conversion is based on background studies and the hypotheses on potential impacts. The research program is considered in two parts, the first a chronological sequence of events that should lead to an adequate understanding of the environmental problems resulting from various solar conversion systems and the second, a presentation of specific types of research manipulation and monitoring to be done at various solar conversion facilities and/or collector simulation sites.

The chronological research program is a six step sequence. The first step is to develop a theoretical base of ecosystem parameters that might be altered due to construction and maintenance of solar collectors. This theoretical base is presented in the body of this report and should be used as a background when considering any further research or monitoring program.

The second step is validating the theoretical responses proposed in step one. This could be done, in part, as actual solar energy conversion systems are constructed but it would be better to be able to project potential environmental changes prior to establishing a monitoring system

or research program at any actual site. This pretesting or prior validation can be done by simulating a solar collector facility and then studying those ecosystem parameters that are expected to change under this form of altered environment. Step three is directly related to step two. Once expected ecosystem changes are validated, alternative methods of monitoring should be tested to establish the level of detail desired from future monitoring programs. This can be developed at a simulation site prior to establishing a monitoring program for an actual solar collection facility that is planned or under construction.

Step four is the establishment of a baseline study and monitoring program for the first functional solar thermal power system (STPS) to be constructed near Barstow, California. This program should be based on all the background material developed in the theoretical impact review as well as at a solar collector simulation facility. Data from the monitoring program at the 10 MW_e STPS at Barstow will be used as a guide to develop construction and operation procedures at future solar conversion facilities. For this reason step five should include various forms of manipulation of site characteristics at the Barstow facility. These should include such modifications in procedures as changing the soil surface and using different heliostat washing techniques. Monitoring these manipulations then becomes an integral part of the overall monitoring program.

Step six is the establishment of monitoring programs for future STPS and photovoltaic facilities. These programs may be limited based on the data obtained from the ecosystem parameter validation tests (Step 2) and the monitoring and manipulation program at the Barstow STPS.

Specific monitoring and manipulative programs are the second part of the research program as presented and should be developed for each solar conversion or simulation facility to be studied. The ecosystem parameters to be studied at each facility are defined and the specific length of time of measurement to enable adequate determination of parameter response is presented.

Three solar conversion or simulation facilities are discussed in this section. These include a solar powered irrigation pump system at Willard, New Mexico, a solar collector simulator facility such as one being studied

near Phoenix, Arizona, and the 10 MW_e STPS to be constructed near Barstow, California in the next few years.

The specific data collection research needs at the Willard irrigation facility should be limited to only plant density and diversity and a few abiotic variables such as solar radiation, heat flux, temperatures, wind, precipitation and soil water. These factors should be measured only periodically over the next three years to compare with data taken from other solar collector facilities. The selection of these parameters and those described for the simulation site and 10 MW_e STPS facility are based on the background theoretical impact data and are only a few of the large number of biotic and abiotic variables that could be measured.

Research at the solar collector simulation site is more intensive because the data are to be used as guides for future monitoring programs and possible modifications in construction or maintenance procedures. The period of study should last at least three years, if not longer, because of the response time lag of the biotic components of the ecosystem. Plant and animal density and diversity as well as plant productivity and animal behavioral patterns should be closely monitored within the collector simulation array and in an adjacent control site. Soil organisms should also closely be measured for possible changes resulting from abiotic parameter modification. The abiotic factors that should be measured include those that are involved in energy flux, the water cycle and soil characteristics. After getting baseline data on changes resulting from collector influences in all of these factors for two years, site manipulation should be done to determine the impacts of altering construction or maintenance activities on ecosystem parameter responses. These manipulations should include altering vehicular traffic density and patterns, modifying the ground surface through use of different surface materials and use of alternative heliostat washing techniques. Study of the impacts of these alterations in procedures should continue for at least two years.

The monitoring program at the 10 MW_e STPS at Barstow should be established in two steps. The first step is to determine the baseline characteristics of the ecosystem parameters to be monitored. This baseline study should occur prior to site preparation and should last for at least

six months and preferably a year. The monitoring of these parameters should begin following construction except for soil characteristics that should be monitored throughout the construction phase.

The factors to be monitored should be essentially the same as those measured at the simulation site, although the intensity of measurement might not be as great. When the monitoring begins, manipulative studies should also be started at the 10 MW_e STPS site. The manipulations would include those used at the simulation site, i.e., vehicular use variations, soil surface changes, and washing procedure changes, as well as altering the stow position of the heliostats and monitoring ecosystem variables in areas with different heliostat packing factors (densities). The ecosystem parameters that are expected to respond to these changes in operation procedures are indicated in the text.

The monitoring program at Barstow should continue for the life of the facility (i.e., to 1984 or 1985). The large amount of data obtained from this monitoring effort will give guidance to the type and intensity of any monitoring program at a future solar energy conversion system.

SOLAR ENERGY CONVERSION: AN ANALYSIS OF IMPACTS ON DESERT ECOSYSTEMS

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SOLAR ENERGY CONVERSION: AN ANALYSIS OF IMPACTS ON DESERT ECOSYSTEMS

I. INTRODUCTION

The deserts of North America are considered to be prime areas for the development of solar energy conversion. The northern or cold deserts have limited potential; however, the deserts of the Southwest have an environment with most of the characteristics necessary for construction of economically feasible solar energy conversion facilities. The deserts of the Southwest, including southern California, Arizona, New Mexico and western Texas, have extensive periods of sunshine, little cloudiness and precipitation and very few days with any appreciable amount of snow.

These typical characteristics of the Southwest deserts create an environment that is marginal for sustaining a high level of species density and productivity. Because of this marginal level of productivity, the desert ecosystem is extremely fragile to any types of disturbance. Disruption of the plant community will cause a shift in species dominance which requires an extremely long period for ecosystem recovery extending for decades or possibly centuries.

The response of plants and animals to disturbance in the Southwest deserts is not the only slow process of this arid region. The soil, especially the soil surface, has taken an extensive period to develop and stabilize. The surface, through wind and water erosion, has become a stable layer of small rocks called desert pavement. This layer prevents accelerated erosion by water and development of dust through wind turbulence. Disruption of the surface layer through any form of perturbation will increase dust in the area, cause changes in the texture and microtopography of the soil surface and alter surface albedo.

The generally clear, warm, dry climate of the Southwest which makes the deserts so fragile and slows down any biotic recovery following disturbance, also attracts many visitors and new residents. This increasing population has created a demand on the limited energy resources of the region. Solar energy has become a real potential for helping solve the predicted energy shortages of this rapidly developing area.

Design and construction of solar energy conversion facilities in the arid Southwest will create a form of perturbation which is new to this region. Farming, grazing, industrialization, and urbanization are established forms of perturbation in the Southwest. Development of large solar powered electrical systems will add to the ecological disruption of a desert area that is already near the critical edge of an environmental shift. Although the Southwest has been dominated by deserts for centuries and the ecosystems appear stable, many areas have been shown to have been modified within a short time period due to man's activities (Martin 1963, Hastings and Turner 1965).

If the solar energy conversion systems are to be developed on a large scale basis in the Southwest, then it is important that the ecological disruption created by these systems be understood. It should be emphasized that the ecological changes caused by the solar conversion systems are not necessarily deleterious and might be used in an economically beneficial fashion. There are many types of solar conversion systems from thermal powered solar concentrating systems to photovoltaic dispersed power systems. Considering the wide variety of these systems and the great diversity within the Southwest desert ecosystems, the potential for different types of ecological impacts is unlimited.

This project was designed to review the potential ecological sensitivity of the desert and correlate the types of environments to be created by the various solar conversion systems with the desert variables. Through developing theoretical responses of the desert ecosystem to perturbations similar to solar conversion facility construction and operation, and proposing hypotheses that, if tested, will show the desert ecosystem response, a research program can be established that will enable prediction of ecological impacts of solar conversion systems on the desert ecosystem.

This report in a stepwise fashion attempts to establish a properly designed research program to accomplish this objective.

II. TYPES OF SOLAR CONVERSION SYSTEMS

The types of solar conversion systems in operation, under construction and planned for the desert Southwest are variable enough that a brief description is presented to enable evaluation of the potential habitat changes created by the systems and thus analysis of the ecological impacts. This section is not designed to offer details of the existing or planned conversion systems for these are available from the contractor's engineering specifications or from the Department of Energy. This section is limited to direct solar energy conversion systems and does not include home units or other conversion systems such as wind or ocean thermal.

Systems in Existence

There are very few functioning solar conversion facilities in existence. Two types that are of interest to this study include the solar powered irrigation pumping facilities which are considered dispersed solar powered conversion systems and the 5MW thermal solar power tower at Sandia Laboratory near Albuquerque, New Mexico which is termed a solar powered central receiving system.

The solar powered irrigation pumping systems use parabolic-trough collectors to concentrate solar radiation on a pipe containing oil. The heated oil is used to "power" a pump which moves water for irrigation. The parabolic collectors are each between 1.5 and 3 meters wide and no more than 25 meters long, depending on the system. They track the sun, rotating on a horizontal north-south axis. During tracking the edge of the reflectors come within about 0.5 meters of the ground. The series of reflectors are spaced to avoid shading each other after about 9 AM in the summer. Other times of year, shading may continue later into the day.

The sites of the solar powered irrigation systems are small. Neither of the two sites observed near Gila Bend, Arizona and Willard, New Mexico exceeded one hectare. In both cases the substrate of the site had been prepared by scaping and compacting. The Gila Bend site had a builtup, compacted substrate because it was located in the middle of irrigated fields.

The 5MW solar thermal test system at Albuquerque, New Mexico consists of an array of reflectors or heliostats which concentrate reflected solar

radiation at a point on a tower. This system is designed primarily to test different heliostat styles and configurations. The area around the tower has been thoroughly disturbed during construction and will remain that way and therefore is of little interest in terms of ecological impacts or changes over time. The total impacted area where the heliostats and tower are located does not exceed 30 hectares. This area has been asphalted for convenience of heliostat testing and therefore all potential ecological responses on site have been eliminated.

The heliostats at the 5 MW solar thermal test facility, as of July 1977, were manufactured by Martin-Marietta and consisted of a 7' x 6.5 m (22' x 21') panel of 25 mirrors (each 4' x 4') with spacing between the mirrors. When horizontal the panel was approximately four meters off of the ground surface but when vertical the lower edge was only one meter off of the ground. The heliostat tracked the sun by pivoting on both vertical and horizontal axes. When stored horizontally the heliostats were spaced approximately three meters apart (E-W) and six meters north-south. Shading of adjacent panels occurs in the early morning or late afternoon. The array of heliostats at this site is not very extensive so that the packing factor varies only slightly from near the tower to the area farthest from the tower.

Systems in Planning

A variety of solar conversion systems are in the planning stage to be constructed in the next few years for smaller units and in the next decade for larger systems. These systems include larger solar thermal power tower systems and small photovoltaic solar electric systems.

The system that is due for initiation of construction in the next year or two is a 10 MW_e solar thermal power tower (central receiver collector) system near Barstow, California. This system is not unlike the 5 MW STPS at Albuquerque. It does have some differences in design that will have a different influence on ecological responses. The overall area being impacted is three to four times as large (about 100 Ha). Because of the large area the heliostats near the power tower have a higher packing factor than those on the perimeter of the array. The ground surfaces of the site will probably not be permanently sealed (e.g., asphalt) but the surfacing has not been

determined. The heliostats are designed by McDonnell Douglas and consist of two rectangular reflectors (each approx. 6.5 x 3 M) spaced 0.7 M apart. The heliostats rotate on both vertical and horizontal axes. When vertical the lower edge of the heliostats will be 0.7 M off of the ground. There will be 1760 heliostats on the site.

A 100 MW_e central receiver collector system is planned to be started in the next decade. This system may be composed of two 50 MW_e power towers but the general design will probably be very similar to the Barstow 10 MW_e STPS. Basic differences will be the same as the differences between the Albuquerque 5MW STPS and the 10 MW_e STPS. The area will be considerably larger creating a very large altered habitat that has a greater potential of becoming ecologically stable than some of the smaller sites. The larger site size will also require a greater variation in packing factors of the heliostats as they will be located farther from the central receiving tower. Because of the size of the location selected, the terrain will probably be less disturbed as a result of construction and operation but this is difficult to predict.

Photovoltaic solar dispersed power systems will probably also begin to be constructed in the next decade. These will initially start out as small units such as the 500 kW_e system planned for the Phoenix, Arizona airport. The area disturbed is small and because of the location the ecological impact of this particular system is not worthwhile evaluating. However, larger systems will be planned and ecological consequences will then be worth considering. The photovoltaic panels may well look like those described by Johnston (1977). The panel is 3 x 5 M with 135 plastic Fresnel lenses concentrating the sunlight on small photovoltaic cells. Peak electric output is about 1 kW per panel. The panel can adjust slightly both vertically and horizontally to track the sun. It does not have a horizontal stow position.

In time, both solar thermal central receiver collector systems and photovoltaic systems may cover hundreds or thousands of hectares. These extensive systems will not only have major ecological impacts within the array of collectors but perhaps more importantly will have a significant environmental consequence on the surrounding region. Although the microhabitat changes may be predictable at the time of construction of the very large

systems, the regional impacts can only be conjectured and these changes will have to be measured after the systems are completed.

III. THEORETICAL ECOLOGICAL IMPACTS OF SOLAR

CONVERSION SYSTEMS

Ecosystem Structure

In order to study the response of an ecosystem to some form of perturbation, the components of the ecosystem as well as ecosystem processes and functions must be taken into account. An ecosystem has two major components, the organisms (biotic part) and the environment that controls or influences the functions and processes of the organisms (mostly abiotic). Because ecologists are biologists by training, they set a primary emphasis on the organisms, considering the other parameters as controlling, limiting, or triggering factors. Changes in organism behavior or function within an ecosystem is, in all probability, a response to a change in one or many of the influencing factors. For this reason great interest might be placed on physical or chemical factor changes but only because these changes ultimately cause biotic change.

Biotic Components of the Ecosystem. The biotic part of an ecosystem can best be described by following biological energy flow through the system. The organisms in an ecosystem are divided into producers and consumers. One set of organisms produces food or energy for another set which is the consumer. The plants are the primary producers. They convert solar energy to usable biochemical energy that is then available for all other food (trophic) levels in the ecosystem. Only those few types of ecosystems that have an inflow of biochemical energy from outside the system, such as an

heterotrophic stream system, can function with few plants. Plants, in a sense, are the energy driving force of an ecosystem, second only to the sun. The plants are of many types. Some grow for many years and are woody while others carry on their whole life cycle in a few weeks and survive only in a seed form. In the desert ecosystem both of these types are common. In addition, plants in the desert have adapted in many ways to drought or water stress conditions. These adaptations include, for example, deciduousness, small leaves, heavy pubescence on the leaves and succulence. For each plant species, the period of primary production varies. Some produce year around while others are seasonal. Any composition change in the plant species within an ecosystem may alter the periods and amounts of primary production.

The organisms in an ecosystem that are dependent on the primary producers for energy are the animals and the decomposers. The animals that eat the plants (herbivores) are often referred to as secondary producers because the energy they store is available for the next trophic level, the carnivores. Animals play many roles in the transfer of energy through the ecosystem. These roles can be partly related to the types of animals, that is, whether they are large browsing or grazing mammals or small sap sucking or detritus eating invertebrates. Many of the animals also play an active role in the below ground portion of the ecosystem.

In the desert ecosystem the larger animals are found in both the herbivore and carnivore levels. Some of the major herbivores are the lagomorphs (e.g., jack rabbits) and rodents (e.g., ground squirrels, wood rats and kangaroo rats). Insects such as grasshoppers also may play an important role in energy flow from plants to consumer. The carnivore consumer level varies widely from large carnivores, such as coyotes, to smaller vertebrates, such as the lizards and snakes, to small invertebrates such as beetles and spiders. Birds in the desert function in both herbivore and carnivore roles.

Extremely important in the function of the desert ecosystem is the role of the detritivores, for example, termites. In order to have a constant energy and nutrient turnover, primary and secondary production must be reduced to a form again usable to the primary producers. Often the dead organic and waste material is too large for rapid breakdown by decay organisms. The organisms that reduce the organic waste material and speed up the potential decay are the detritivores. These organisms are found both above and below ground.

It should be obvious from this brief discussion of the biotic aspect of an ecosystem that all organisms play an important role. Any alteration in the number or diversity of the various groups of organisms can have a dramatic effect on the normal function of the ecosystem.

Abiotic Factors. The functions of plants and animals in an ecosystem are directly related to interaction with other organisms as well as the physical and chemical environment in which they live. For example, variations in abiotic factors control the reproductive, mortality, and physiological rates and behavioral patterns of the animals. All organisms require moisture to survive. This moisture comes from the environment or other organisms that are consumed. For this reason moisture availability above and below ground in an ecosystem is extremely important to the survival and functioning of both plants and animals. This is especially true in semi-arid and arid regions such as the deserts of the Southwest.

Most of the functions of plants and animals are directly influenced by the temperatures of their surroundings. For example, the poikilotherms (cold blooded animals) maintain the correct body temperature by moving to the proper environment. Rates of physiological function as well as behavioral and distributional processes are also directly correlated with temperature variations. Environmental temperatures are, in turn, a result of many other abiotic factors. For example, soil temperatures are influenced by soil moisture, soil color, wind movement over the soil surface and shading or sun exposure. Air temperatures at any one location are also a result of many of these same factors, i.e., amount of solar insolation, air movement, humidity, etc.

Moisture and temperature are probably the two most critical abiotic environmental factors in controlling the functions and diversity of plants and animals. They are obviously closely interrelated with other factors. Some have been mentioned such as solar radiation, air movement and soil type, but other factors can also be important. These factors can be characteristic of a particular habitat. Topographic and geological features, for example, influence the amounts of solar radiation soil moisture retention and potential nutrients in the soil. The interaction of all of these factors as well as many others that are difficult to measure produce the interwoven aspect of the environmental complex. They can be separately studied but

they must be analyzed in relation to the complexity of the ecosystem.

Ecosystem Cycles. Each function or response of a plant or animal in relation to abiotic factors is not totally separate from the responses of other organisms or other factors. All processes within an ecosystem are, in some way, related and cyclic in nature. For example, solar energy flows in from outside the earth's atmosphere, is transformed into different physical or biochemical forms and through various conversions is ultimately lost again as heat to outerspace. The rate of flow of the energy through these cycles controls the physiological and growth processes of the organisms as well as many abiotic factors such as evaporation, temperature and air movement.

Although energy and the energy cycle are driving forces in the ecosystem, other cycles are of great enough significance to be considered in research on ecosystem responses. In the arid regions the water or hydrological cycle is of great importance. In this cycle both physical and biological factors play an important role. For example, air temperature controls the amount of moisture in the air and the potential for precipitation as well as evaporation; soil texture and structure control the amount of water maintained by the system while plants intercept precipitation, control runoff and remove quantities of water from the system through transpiration. The water cycle can thus be considered the flow of water from a physical state through a biological function and back into a physical state with all facets of the ecosystem acting on the processes.

Other cycles such as the nitrogen or carbon cycle are important to proper functioning of an ecosystem but they are closely related to energy and water flows. It should be obvious that an understanding of ecosystem response to perturbation such as construction and operation of solar collectors is not dependent on analysis of the response of a single animal or plant species or a single physical factor but requires a study of those factors that most significantly influence biotic functions and an analysis of the accompanying biotic changes. These changes occur most often as changes in animal and plant species composition (diversity) as well as species density. These two measurements are indicators of the organisms ability to grow and function within its original or newly created environment.

Environmental Modifications

Environmental modifications are of two types, short and long term. Short term or immediate changes in the microenvironment of a structure in the desert can be readily demonstrated by appropriate instrumentation. These are, however, only physical changes and might quickly be reversed if the modifying structures were removed. On the other hand, if these short term microenvironmental changes are permitted to continue for any length of time, they will then trigger, both directly and indirectly, longer term modifications of the ecosystem that are not so readily reversible.

Long term modifications are considered to be ecological changes because not only is the microenvironment altered but the biotic components of the ecosystem are also changed. Although ecological changes may take many years to occur, the ecosystem once stabilized under new conditions will remain changed unless man again alters the overriding controlling conditions.

Ecological changes resulting from construction and operation of solar collector systems are impossible to quantify without taking some actual measurements. It is possible to estimate changes in such factors as solar input, energy budgets and soil moisture using equations based on hypothetical structures and environmental processes, but every ecosystem is variable and it is this variability that will cause hypotheses based on theoretical calculations to be in great error. Other ecological factors such as wind movement, soil erosion and biotic processes are impossible to predict. One can draw hypothetical conclusions based on the literature and the theoretical calculations of variations in physical processes, but this is only a preliminary step. From these early predictions one must design tests to prove or disprove established hypotheses.

As a first step in developing hypotheses, the literature was thoroughly searched for all relevant data or ideas that might help with analysis of solar conversion system impacts. This literature search was not limited to solar collectors or to the Southwest but reviewed all worldwide literature that might pertain to structures, either natural or artificial, and their influence on arid or semi-arid ecosystems. In addition, the basic and applied ecological literature as well as appropriate engineering literature were reviewed for conceptual matter that might be even peripherally considered pertinent to this study.

The literature review presented many differing views on the possible consequences of construction and maintenance of solar collector arrays in a desert ecosystem. Not all data agreed but by using the most reliable information, theoretical impacts of solar collectors were developed. The approach taken was to break the impacts down into major categories and subcategories and develop theories within each of these. The major categories are:

1. Shading
2. Wind Deflection
3. Physical Disturbance

Shading

Solar Radiation

Solar radiation, the environmental variable which is probable in least demand to living organisms in the southwestern deserts, will possibly be the most affected by arrays of solar collectors. How much of the incident solar radiation is intercepted by collectors, and thus redirected away from the

ground surface, will depend on the types of collectors used, and the spacing (or "packing factor") of the collectors along east-west and polar axes.

Black and Veatch (1977) analyzed a hypothetical photothermal collecting facility, and determined that an array of heliostats covering between 42% and 56% of the ground surface would intercept 59% and 78% of the annual daily direct radiation, respectively. Their calculations were made at the equinoxes, and thus did not account for changes in azimuth of the sun with season. They assumed that interception of diffuse radiation would be equal to ground coverage of the heliostats (i.e., 42-56%), although acknowledging that this is probably an underestimate because tracking mirrors should intercept a greater proportion of the more intense diffuse radiation from the sunward part of the sky than would a horizontal surface. Assuming total incident radiation in the desert Southwest to be 80% direct and 20% diffuse (Liu and Jordan 1960), between 55% and 73% of the total incident radiation will be intercepted by heliostats and removed from the desert ecosystem (based on Black and Veatch 1977). A reduction of such proportion is highly significant.

A more recent study of the "power tower" type of solar collection facilities indicates that only 25% of the ground area will be covered by heliostats (Hildebrandt and Vant-Hull 1977). The heliostat coverage will vary from 40% near the tower to approximately 10% near the periphery of the heliostat field, because with increasing distance from the tower greater amounts of blocking of reflected sunlight by adjacent heliostats occur. With reduced ground cover there will be less shading than the figures given by Black and Veatch (1977). The design suggested by Hildebrandt and Vant-Hull (1977) would probably result in removal of less than 50% of the total incident radiation from the system. Unfortunately, we were unable to obtain any values for ground coverage of projected photovoltaic arrays.

Photovoltaic arrays may suffer greater penalties from shading loss due to adjacent collectors, and thus should be installed at reduced packing factors compared to photothermal systems (Arizona State University 1977). If so, solar radiation losses would be reduced in photovoltaic arrays but still should not be substantially below 50% of total incoming radiation.

Since solar arrays are designed to operate year around, packing factors should be designed to enable the solar facilities to produce sufficient quantities of energy in the winter, when shading losses from neighboring collectors will be highest. During the peak growing season in late spring to early fall, the amount of intercepted radiation, and thus shading of the ground, would be expected to be less than values estimated at the equinoxes due to the higher azimuth of the sun. On the other hand, shading of the ground surface in the winter months, also a very productive season in the Southwest desert ecosystems, could be nearly complete, especially during the morning and afternoon.

The types of solar collectors used will play an important role in how much of the ground surface is shaded, and how that varies on a temporal basis. For instance, heliostats (designed by Martin Marietta) tested at the Sandia Laboratories, Albuquerque solar thermal test site had spacing between the mirrors while others to be tested may be solid. This difference in reflectors may not cause significant differences in absolute incident radiation reaching the ground surface, but could be important with regard to duration of shading of a given area of ground, as sun spots will move across the desert floor as the system tracks the sun.

Different types of proposed photovoltaic collectors will produce different seasonal patterns of shading of the ground surface (Arizona State University 1977). Collectors which rotate on a single horizontal axis will produce almost complete shading of the ground surface within the collector array in the winter (with collectors rotating on a polar axis) or on a diurnal basis (early morning and late afternoon for east-west axis rotation of collectors). Conversely, a collector tilted at 45° from the zenith and rotating around a vertical axis to track the azimuth of the sun (similar to the simulators constructed in Phase I) will not exhibit significantly different seasonal shading (Arizona State University 1977). Collectors rotating on vertical and horizontal axes simultaneously exhibit the smallest shading losses, and thus can be placed at the highest packing factors. It is evident that knowledge of specifics involved with collector design is a necessary pre-requisite in order to predict interception of incident radiation, and thus energy loss from the ecological system.

Solar collectors will also affect the thermal (long-wave) radiation emitted by the ground to the sky. In a normal open desert system, intense heating of the ground surface during the day is followed by a high rate of reradiation at night from the ground to the "cold" sky (Sellers 1965), resulting in rapid cooling of the ground surface. If 10 to 40% or more of the sky is blocked by solar collectors, then approximately the same percentage of long-wave reradiation would be intercepted. If the collectors are in a stow (inverted) position at night (Hildebrandt and Vant-Hull 1977), then the thermal radiation intercepted will be redirected back toward the ground.

Therefore, solar collector arrays will substantially decrease incoming solar radiation in the daytime, as well as reduce outgoing thermal radiation in both the day and night. The result will be reduced net radiation under the collectors on a daily basis, and a substantial reduction in average hourly radiation flux. Several related studies support these predictions.

Bajza *et al.* (1977) found an irrigated landscape (i.e., with trees and large bushes) to have lower incoming radiation at the ground surface than a desert landscape during the day, as well as having lower long-wave emitted radiation at night due to less sky exposure (as well as cooler surface and subsurface temperatures). Net radiation on the irrigated landscape never fell below zero, while on the desert landscape it was very high during the day, and fell well below zero at night.

Results by Lowe and Hinds (1971) are similar. They found a palo verde tree in winter in the Arizona desert to reduce incoming radiation by 50% compared to the open, while also reducing effective outgoing radiation at night by the same amount. The result was a maximum diurnal net radiation flux under the tree of just 44% of that observed in the open. Patten (1975) found similar reductions of incident radiation by palo verde trees in the Sonoran Desert near Phoenix.

Of potential importance is the amount of radiation a given area of ground will receive as bands of sun and shadow move across the desert surface. When an area is in shadow (i.e., shielded from direct beam radiation), the area will still be receiving diffuse radiation. How much will depend upon

elevation of the sun. As the sun increases in elevation, the amount of diffuse radiation received in shade spots should increase. A given area of ground in a patch of sun may also receive greater amounts of solar radiation than it would in the open desert. For example, Rosenberg (1974) found areas near a tree shelterbelt to receive amounts of daily radiation equal to an area remote from the shelterbelt. Although shaded for several hours in the morning, the site near the shelterbelt received additional reflected energy off the shelterbelt in the late afternoon. Furthermore, Patten and Smith (1975) note that solar radiation can be extremely high (approaching the solar constant) when scattered cumulus clouds provide large amounts of diffuse radiation in addition to direct radiation. Such a phenomenon will possibly occur due to reflection off nearby collectors, and could have significant ecological effects. Although solar radiation under collectors will be greatly reduced on a daily basis, it may be intense at certain times of the day.

Temperature

Daytime air temperatures under heliostat fields and photo thermal and photovoltaic arrays will probably be only slightly lower or not significantly different than in the open desert. Air temperatures in shaded microhabitats are generally slightly cooler during the day (Patten and Smith 1973, Hanson and Ravzi 1977, Bajza *et al.* 1977), with the differences being more pronounced in the dry season (Patten and Smith 1974). Daytime air temperatures near the ground surface should be substantially cooler under solar collection arrays (Black and Veatch 1977); this has also been observed under large Sonoran Desert shrubs (Patten and Smith 1974). Also of potential importance in collector fields is the observation of Tuller (1973) that areas shaded from morning sun have a higher mean daily temperature than areas shaded from afternoon sun. In winter months, air temperatures may be warmer than the open desert due to reduced losses of thermal radiation.

Night temperatures in areas shaded during the day are not as well documented. Bajza *et al.* (1977) observed nocturnal air temperature to be higher in a shaded microhabitat, evidently because the tree canopies which produced the shade also reduced the amount of escaping long-wave radiation at night.

Patten (1975) obtained similar results for microenvironments beneath palo verde trees. Nighttime temperatures under collector field may not be as easy to predict due to the complication of wind deflection by arrays of collectors, and their effect on nocturnal inversions, which will be discussed later. Although early evening temperatures should be cooler under collectors (assuming cooler temperatures during the day), interception and possible reradiation of long-wave emitted radiation should retard nocturnal cooling relative to that in the open desert. ERDA (1977b) predicts no significant difference in nighttime temperatures.

When comparing temperature and organism function, Terjung *et al.* (1970) state that total environmental radiant temperature is more important in determining organism heat gain or loss than the popularly used air temperature. Radiant temperature is the temperature that a black body would have to be at to produce thermal radiation equal to the downward counterradiation of the sky (Terjung *et al.* 1970), and is calculated from the total radiation flux using the Stefan-Boltzmann equation (Schmidt-Nielson *et al.* 1965). Studies using this parameter have shown significant reductions in radiant temperatures in shaded desert habitats. Dawson and Denny (1969) report radiant temperatures beneath the canopies of black oak and mulga (*Acacia*) trees in arid Australia to be 55% and 49% of that in the open, respectively. Lowe and Hinds (1971) found palo verde trees in Arizona to reduce this parameter an average of 37% in the winter with respect to daily maximum value. Furthermore, Lowe and Hinds (1971) found winter nocturnal radiant temperatures associated with the infra-red flux to be much higher under a palo verde canopy than in the open, once again due to the canopy blocking the sky and thus limiting loss of thermal radiation from the surface.

Surface and soil temperatures should be influenced far more than air temperatures due to shading. Cloudsley-Thompson (1965) and Patten and Smith (1974) observed desert surface temperatures in the shade to be similar to air temperatures, while exposed temperatures may reach 80°C (Cloudsley-Thompson 1965), with a diurnal range of up to 55°C (Geiger 1965). Although trees and shrubs in arid regions are known to significantly reduce surface temperature in the warm season when they are fully leafed out (Shreve 1931,

Hinds 1967, Hinds and Rickard 1968, Patten 1975, Bajza *et al.* 1977), Lowe and Hinds (1971) have also shown reductions of up to 13°C in the winter from shading of deciduous desert trees.

Soil temperatures are reduced in shaded areas during the day (Shreve 1931, Hinds and Rickard 1968, Patten 1975), and possibly at night as well due to the time lag of soil temperature fluxes in relation to air and surface temperature (Shreve 1931, Hadley 1970). Further supporting the concept of reduced soil temperatures in the shade is a study by Abd El Rahman and Batanouny (1966) who found soil temperatures in an arid watershed to be more highly correlated with incoming radiation than with air temperature. A further ameliorating effect of shading is the fact that shaded areas tend to have less diurnal (and possibly seasonal) variation than do exposed areas (Patten and Smith 1974, Bajza *et al.* 1977).

In conclusion, of the four temperature variables discussed (air temperature, radiant temperature, surface temperature, and soil temperature), air temperature is the only variable which should not be substantially reduced due to shading by solar collector arrays, based on studies of natural desert systems. Interestingly, air temperature is probably the temperature variable of least importance with regard to physiology, behavior, and distribution of desert organisms. Also, shading of the desert surface has a more significant influence on diurnal variability of environmental temperatures than on absolute or mean values, further indicating the ameliorating effect of shading on temperature.

Soil Moisture

Studies in arid and semi-arid regions generally indicate shading by vegetation to cause a decrease in evaporation rate and thus increase soil moisture relative to open areas (Shreve 1931, Abd El Rahman and Batanouny 1965, 1966, Bajza *et al.* 1977). Although Shreve (1931) found evaporation rates in the open and in the shade of a palo verde tree to be similar in all months of the year, he did observe the shaded microhabitat to exhibit higher soil moisture content following heavy summer rains as well as following light rains in the cooler months of the year.

With the exception of Shreve (1931), evaporation studies indicate shading significantly reduces water loss from arid soils. Hellwig (1973) concluded that solar radiation input far outweighs air temperature and relative humidity as a factor affecting evaporation from arid sandy soils, while Krishnan and Thanvi (1972) found the number of hours of daylight to be an important variable in predicting evaporation. Transpiration studies further support the role of radiation in water loss, as Abd El Rahman and Batanouny (1965) found shaded vegetation to exhibit less water loss per gram of tissue than plants in the open when both populations were well watered.

With respect to arrays of solar collectors, Black and Veatch (1977) and Sears *et al.* (1977) predict that soil moisture under the array fields will be significantly higher than in the adjacent open desert. Furthermore, additional water may be available between the collectors for short periods following rain storms due to precipitation runoff (Meinel and Meinel 1972) and possibly due to water used to clean the heliostats (Black and Veatch 1977) or photovoltaic collectors (Sears *et al.* 1977). The amount of inter-space soil moisture compared to that under the collectors is unknown and should be determined. In conclusion, removal of a majority of the incident solar radiation from an arid ecosystem should tend to prolong favorable moisture conditions, and reciprocally shorten the duration of adverse (i.e. drought) conditions.

Plant and Animal Response

The desert Southwest is considered a harsh environment for plant and animal life in which the major limiting factor is moisture. Most of the growing season is characterized by low soil moisture and high evaporitvity (Noy-Meir 1973). If shading by solar collectors, through interception of a large proportion of incoming solar radiation, increases soil moisture due to suppression of evaporation rate, profound changes could possibly occur on the desert floor underneath the collector arrays.

In the open, water-limited desert, plants generally have adaptations which increase the efficiency of water use. Morphological adaptations such

as hairy leaves, which increases albedo of the leaf (Billings and Morris 1951), are the product of evolution and may not be expected to be plastic in response to environmental changes. However, physiological adaptations also occur, such as the "behavioral" adaptation in which desert shrubs use diurnal stomatal control so that metabolic activities (related to open stomates) occur mostly, or exclusively, in times of low evaporitvity (Caldwell *et al.* 1972, Evenari *et al.* 1972, Kappen *et al.* 1972), such as the early morning, or at times of more favorable soil water potential (Syvertsen *et al.* 1975). In these situations, radiation input could possibly be a limiting factor to primary production (Noy-Meir 1973). If soil moisture conditions were substantially improved under a collector array, and stomatal rhythms were indeed a plastic response, then stomatal opening could occur at more optimal times (i.e., when solar radiation was at maximum levels). With overall reduced solar radiation input in collector arrays, and occasional periods of high radiation input between collectors, stomatal rhythms appear important.

Meinel and Meinel (1972) feel that increased moisture conservation under collector arrays may improve the ability of an arid land to support growth of grasses of commercial importance to ranchers. These grasses, perennial bunch grasses, are well known to respond only to adequate soil moisture levels in the warm summer months (Schreiber and Sutter 1972, Mott 1973, Cable 1975). At the present, perennial grasses are scarce or nonexistent in areas earmarked for large solar collection facilities. Thus, without major seeding efforts, it appears that many years of significantly increased soil moisture in the summer would be required for such a change to take place. If grasses were unsuccessful, desert shrubs of economic importance, such as Jojoba or Guayule, could potentially be farmed.

If a change in vegetation occurs due to shading, the most immediate vegetation response will be an increase in ephemeral forbs and grasses. Desert annuals are well known to respond with pulses of biomass after significant inputs of precipitation (Went 1949, Noy-Meir 1973, Beatley 1974b, Slade *et al.* 1975). Furthermore, their tendency to accumulate underneath shrubs (Shreve 1931, Muller 1953, Patten 1975) indicates a certain degree of tolerance to shading, or perhaps a requirement for shading. Even in a wet season, Patten (1975)

observed annual productivity to be greater under shrubs, although increased nutrients under shrubs could be implicated in such a case (Muller 1953). According to Shreve (1931), shading is important for success of herbaceous plants in arid areas due to the more favorable conditions provided during the very critical rainless periods in their early history.

Accurate prediction of possible successional changes in plant populations due to decreased solar radiation and increased soil moisture is difficult, especially considering the significant abiotic modifications possible in collector arrays. Many desert plants have precisely evolved germination requirements (e.g., McMillan 1970, 1973) and phenological dynamics (e.g., Davies 1976) dependent upon moisture, photoperiodic, or thermoperiodic signals. Drastic, long term changes in these cues could make the plants which have adapted to the open desert situation not as adaptive, potentially resulting in a relative increase of secondary species with more plastic responses, or invasion of "opportunistic" species such as weeds.

Change in animal populations will, to a large degree, depend on vegetation changes as well as man's activities. An increase in forbs and grasses will result in an increase in rodents, as rodent reproduction is known to be tightly coupled to annual production in the Southwestern deserts (Reynolds 1958, Beatley 1969, 1976, Soholt 1973, Van De Graaff and Balda 1973). High production of annuals could then result in large numbers of rodents near the collector site. Relative proportions of heteromyid rodents and lagomorphs on the sites could depend on the relative success of forbs versus grasses.

Amelioration of the radiation balance by collector arrays on a diurnal and seasonal basis may make the areas under collectors a desirable habitat for surface animals. Dawson and Denny (1969) correlated movements of kangaroos in Australia to reduction in radiant temperature by small trees, as previously discussed. Animals of the immediate area around a collector field could seek the shade of collectors during bright, cloudless days in the summer months. This assumes a lack of constant maintenance activity by man. The collectors could also provide a warmer environment on cold winter nights due to a decrease in thermal long-wave radiation from the soil, resulting in

a less negative, and possibly even a positive nighttime radiant temperature (Lowe and Hinds 1971).

Shading, due to its effects on radiation input, thermal flux, and soil moisture, could have profound effects on the biota of the southwestern desert ecosystems in which large-scale solar collector arrays are placed. If soil moisture is indeed significantly increased (or at least droughts decreased) the desert literature indicates the possibility of significantly greater plant production, potentially of an economically beneficial nature. However, prediction of change in altered systems with a history of disturbance will be difficult, as short term changes are not necessarily indicative of site potential.

Although not directly related to shading, an increase in man's activities at a solar collector site could cause dispersal of many of the existing animal populations; however, historically it has been shown populations of some mammal species such as rats and coyotes increase as a result of man's activities. Reptile species with small territorial ranges may increase in population because of the ameliorated environment created by the solar collectors.

Wind Deflection

Velocity and Turbulence

It is generally assumed that arrays of solar collectors will decrease local wind speeds in both heliostat fields (Black and Veatch 1977, ERDA 1977b) and in photovoltaic or distributive photothermal arrays (ERDA 1977a, Sears *et al.* 1977). Wind flowing across a field of collectors will probably be forced upwards if striking the reflective surface of the collectors or downwards if striking the backside so that, although wind velocities may be greater than normal above the field, if the wind is from the South, they will be reduced below the array of collectors, although wind from the backside may also cause turbulence below the collectors. This area below the collectors is the area of importance when discussing ecological impacts of solar arrays in the desert.

Wind velocity in the southwestern deserts is more intense than most other areas of the continent. High wind velocity makes a region more arid

by increasing evaporation rate and desiccating plants. Thus, windbreak systems have been found to be useful in arid regions as a means of limiting the process of desertification (Van Eimern *et al.* 1964, Petrov 1966, Stepanov 1971).

Although windbreaks are designed and function to decrease wind velocity (Van Eimern *et al.* 1964, Rosenberg 1974), changes in turbulence due to windbreaks are not as easy to control or predict. Many studies have indicated turbulence to be reduced in the lee of wind shelters (Brown and Rosenberg 1971, Miller *et al.* 1973, Tuller 1973, Rosenberg 1974), while other studies have observed, despite a decrease in velocity, an increase in turbulence (Rosenberg 1966a, Van Hylekama 1970, Hanson and Ravzi 1977). Rosenberg (1966a) observed turbulence to vary diurnally being more unstable in sheltered areas during the day, but more stable at night. Also indicating diurnal variation, Bajza *et al.* (1977) found an irrigated landscape with irregularly spaced wind obstructions to have many more hours of calm than an open desert landscape, but also exhibiting higher maximum velocities and turbulence due to funneling of winds during periods of peak wind speed.

Prediction of changes in wind speed and turbulence will thus be an extremely complex problem, and is further compounded by the various heliostat configurations proposed for use in solar thermal plants (ERDA 1976). Heliostats proposed by Honeywell and Martin Marietta consist of rectangular flat plates with gaps between the plates, while Boeing and McDonnell Douglas propose circular concave heliostats, with Boeing's enclosed in a plastic bubble.

Small gaps in heliostats may reduce wind velocity under the heliostats, as porous windbreaks are generally more effective than nonporous due to the fact that air which passes through the gaps can prevent the turbulent return of air which has overtopped the windbreak (Miller *et al.* 1975). However, if the gaps are too large (e.g., Honeywell heliostat configuration, ERDA 1976), jetting effects may occur and increase turbulence (Rosenberg 1974).

Rows of photovoltaic collectors should reduce velocity and turbulence, although our discussions with ERDA technicians and observations at the

Willard, New Mexico solar irrigation site indicated that trough-shaped solar thermal collectors arranged in rows may have increased turbulence and wind erosion compared to adjacent open areas during periods of high wind velocity.

Temperature and Heat Flux

The effect of wind deflection by solar collectors on temperature may be an increase in daytime air and soil temperatures, based on shelter studies of sites leeward of windbreaks (Jensen 1954, Aslyng 1958, Rosenberg 1966a, King 1970, Hanson and Ravzi 1977). Warmer temperatures due to wind deflection are assumed to be the norm due to a decrease in turbulent exchange resulting in more intense vertical temperature gradients (Rosenberg 1974). An exception is the findings of Stepanov (1971), who found that shelterbelts reduce surface temperatures of sandy desert soils.

Night temperatures apparently are not as consistently affected as daytime temperatures. Although there are studies which have observed warmer night temperatures in sheltered areas (Rosenberg 1966a, Tuller 1973), Rosenberg (1974) concludes in a review of shelter studies that night temperatures will be lower in shelter due to more intense nocturnal air inversions. Since these inversions are common in the southwestern deserts, reduction of nocturnal air temperature due to wind deflection could be substantial.

Predictions of temperature changes under solar collectors tend to agree with the shelter studies in predicting increased daytime air temperatures under heliostats (Black and Veatch 1977) and photovoltaic arrays (ERDA 1977a). However, soil temperatures are predicted to be unaffected (Black and Veatch 1977), and nocturnal temperature will either be unaffected (ERDA 1977b) or slightly warmer (Black and Veatch 1977). Assumed decreases in turbulence will be a factor here, as various configurations of collectors and arrays of collectors will influence degree of turbulent exchange within the array field.

Regardless of whether temperatures will be warmer or cooler, the absolute changes of temperature in collector fields should be slight due to wind deflection. If, however, daytime temperatures are warmer and nighttime temp-

eratures cooler, then wind deflection would have a greater effect on rates of heat flux than on temperature *per se*.

Soil Moisture and Humidity

Wind speed has a major influence on evaporation rate (Penman 1948, Hellwig 1973), especially in arid regions (Krishnan and Kushwaha 1973). Quantitatively, Van Eimern *et al.* (1964) found evaporation from flat moist containers to be proportional to the square root of the wind speed. Thus, a decrease in wind speed and turbulence should result in reduced evaporation rates, and concomitant increases in soil moisture. This has been observed experimentally in numerous shelter-type studies (Jensen 1954, Van Eimern *et al.* 1964, Marshall 1974, Rosenberg 1974).

Reduction of evaporation by wind deflection in arid regions may be proportionally greater than the reduction of wind velocity. This is because a major beneficial aspect of wind deflection with respect to moisture conservation is the reduction of the advection of sensible heat from surrounding unsheltered areas (Miller *et al.* 1974). This is probably an important reason why planting of shelterbelts with the resultant wind reduction is considered more effective in arid and semi-arid regions (Siddoway 1969, Rosenberg 1974), and in regions with continental climates (Van Eimern *et al.* 1964, Marshall 1967).

The relevance of these studies to the microclimate of heliostat and collector fields is apparent. If soil moisture is higher under collectors than in the surrounding desert, then significant reductions in wind speed by the collectors could significantly reduce advective losses of moisture to the surrounding drier desert.

With increases in soil moisture will be increases in humidity and vapor pressure of the air under the collectors, as has been observed experimentally in almost all shelter studies (Rosenberg 1974). Increase in these variables, together with soil moisture increase, should result in a much more mesic microclimate relative to the open desert.

Plant and Animal Response

The effect of a more mesic environment in an arid region should be a significant increase in photosynthetic rate, and thus primary production. Because of reduced evaporative demand during periods of greatest water stress, and increases in water vapor pressure, plants should respond by maintaining greater stomatal aperture for longer periods of time than would be possible in the open desert.

Increases of stomatal aperture in sheltered crops are well documented (Rosenberg 1966a, Brown and Rosenberg 1971, Miller *et al.* 1973, 1974), as well as increases in water use efficiency (Rosenberg 1966a, b, Rosenberg *et al.* 1967, Miller *et al.* 1973). A combination of increased water use efficiency and increased soil moisture could result in substantial increases in primary production. Furthermore, nocturnal respiration rates may be lower in sheltered areas due to cooler leaf temperatures (Miller *et al.* 1973, Rosenberg 1974). A combination of cooler nighttime temperatures and increased daytime transpiration rate (and thus increased heat loss) would result in the cooler leaf temperatures.

It has been suggested that, at low wind speeds, the photosynthetic rate in a sheltered field may be decreased because of a shortage of carbon dioxide in the air surrounding the leaves (Lemon 1970). In a thorough study of this, Brown and Rosenberg (1972) concluded that if decreases occurred they would be slight, and may limit photosynthesis only in dense crop canopies. In the desert, with its sparse vegetation, carbon dioxide is not considered a limiting factor to plant production.

In conclusion, the influence on plant growth of reduced soil and atmospheric moisture stress and reduced mechanical motion should be beneficial in the water stressed desert habitat.

The response of animal populations to a more mesic environment with less advective water loss potential should increase the desirability of the habitat, especially in warm, dry seasons. Since certain desert species are highly adapted to extremely xeric conditions (Edney 1967), shifts in relative abundance of animals may occur in mesic microhabitats. Increases in plant production will also be conducive to increase in animal population numbers, as has been previously discussed.

Physical Disturbance

Future construction of solar collection "farms" on large tracts of desert land will have an impact on the environment of the construction site. These impacts will range from minor trampling by maintenance personnel to complete surface clearing of areas in the vicinity of structural supports of individual collectors. The total amount of disturbance in both construction and maintenance phases will have important consequences with respect to the ecological potential of the desert beneath the collector fields, and is suggested to be of significantly greater importance than the shading and wind deflection effects imposed by the collector arrays, at least in proposed photovoltaic systems (Sears *et al.* 1977).

The desert ecosystem has reached its relatively stable but delicate balance over a long period of time. The desert ecological literature presents ample evidence that where man has concentrated his activities in the desert, the desert ecosystem is drastically altered and, even though the activities may be discontinued, recovery may take many decades or centuries before the desert ecosystem again reaches a state of dynamic equilibrium. Some of these studies can be applied to the current problem of what changes may occur in soil structure, moisture regime, surface characteristics, and biota when large solar conversion units are placed and operated in the desert.

Soil Structure

Several parameters have been utilized experimentally by researchers to assess the effects of compaction on soil structure. Bulk density, macropore space, diffusivity, and penetration resistance are parameters which indicate changes in soil structure. Knowledge of changes in soil structure is important, due to its effects on water availability, root growth, and aeration of the soil.

There are numerous studies indicating that walkers (Bates 1935, Chappel *et al.* 1971, Liddle and Greig-Smith 1975) and off-road vehicles (Davidson and Fox 1974, Webb 1976, Wilshire and Nakata 1976) have caused substantial increases in bulk density and penetration resistance, and

decreases in macropore space. Liddle and Moore (1974) found walkers and vehicles to reduce diffusivity in wet soils, but not in dry soils.

Studies attempting to examine reversibility of compaction generally indicate that short term, even intense, compaction is reversible. Long term compaction tends to cause more serious changes in soil structure, especially in deeper soil layers (Liddle and Greig-Smith 1975), often resulting in a site which does not readily recover to its pre-disturbance condition. In the desert, vehicles tend to primarily disturb the surface, which still takes as much as a decade to repair (Vollmer *et al.* 1976, Webb 1976). Studies of off-road vehicle effects on structure of deeper soils indicate possible serious changes, effects of which may not become expressed ecologically until years after the original impact (Vollmer *et al.* 1976, Wilshire and Nakata 1976).

Studies of a wide variety of soils indicates that compaction has more serious structural changes in wet soils than in dry soils (Bates 1935, Parker and Jenny 1945, Martinion and Olmstead 1949, Jamison *et al.* 1950). Scheduling periods of heavy maintenance pressure during predictable dry periods could possibly reduce the potential for soil compaction.

In order to limit the amount of long-term compaction occurring after construction, vehicles should be excluded from as many areas as possible, being confined to specific roads in the collector fields. Vehicles have been found to significantly increase penetration resistance more than bulk density in sand (Liddle and Greig-Smith 1975). Increases in penetration resistance would decrease infiltration rate, and could inhibit penetration of the root systems of ephemeral plants. Deeper levels of soil would also be compacted by vehicles as opposed to limited compaction due to occasional trampling. Introduction of grazing is not recommended after a period of intensive construction-type surface disturbance, as soil recovery may be retarded (Lowe 1955).

Runoff and Erosion

In the southwestern deserts, a list of Candidate Sites for photothermal solar conversion units (Black and Veatch 1977) indicates topography to be an

important consideration in site selection. A vast majority of Candidate Sites are on plains with low mountains. They are typically located in low-land valleys or plains bordering more rugged terrain (Black and Veatch 1977). Thus many Candidate Sites will probably be gently sloping bajadas (alluvial fans), characterized by a desert "pavement" surface, a dendritic pattern of small ephemeral washes, and moderate to widely spaced desert scrub vegetation.

Shreve (1934) outlines factors which determine amount of runoff, the most important being: (1) intensity of rainfall, (2) degree of slope, (3) texture of the soil, (4) nature and density of the vegetation, (5) amount of litter or stones on the surface, and (6) moisture of the soil surface. Due to a combination of infrequent, high intensity rainfall events, presence of sparse perennial vegetation, and presence of a desert pavement surface, desert bajadas tend to have high runoff rates compared to other geomorphic surfaces, and moister regions (Shreve 1934). High runoff in the desert is also accompanied by increased erosion rates.

Some of the above factors will be influenced by soil compaction and above-ground destruction. Compaction, by increasing bulk density of the soil, will have an inhibitory effect on infiltration rate similar to that caused by a change in soil texture. Infiltration rate is known to increase with particle size increase (Fireman 1944), especially in arid regions (Evenari *et al.* 1971).

If substantial areas of the desert are cleared and graded, runoff will greatly increase. A cover of dead and/or living vegetation usually increases infiltration in arid zones (Tadmor and Shanan 1969) by reducing rain impact or through some physical or chemical modification of the soil surface (Lyford and Qashu 1969). To minimize erosion of the soils beneath collector fields, as much area as possible should be left undisturbed.

An important consideration when discussing erosion of desert areas is the common occurrence of a desert pavement surface. A desert pavement tends to form on desert bajadas due to loss of finer soil particles in runoff water, resulting in a stony cemented surface layer. Although it

tends to stimulate runoff due to its low infiltration rate, desert pavement surfaces protect the soft, friable soil underneath from erosion by wind and water (Davidson and Fox 1974). If disturbed, the protection afforded the desert pavement is for all practical purposes destroyed due to its slow rate of formation. Destruction and continued disturbance of desert pavement surfaces from construction activities and vehicles could thus lead to subsequent high erosion rates.

These factors, together with deep, irreversible structure changes from compaction, illustrate the desirability of using areas with little or no slope and coarse textured soils for future large solar conversion units.

Soil Moisture

Infiltration of water into the soil is inversely related to the runoff. Compaction and above-ground destruction of vegetation will tend to cause a decrease in infiltration rate, and thus decrease soil moisture. A possible exception would be that destruction of desert pavement could result in higher infiltration rates.

In addition to runoff changes, compaction will alter soil water conditions dependent on soil structural changes. Increases in bulk density of disturbed soils, with the resulting decrease in macropore space, probably decreases the amount of water that the soil can hold and the rate at which water can flow through the soil (Davidson and Fox 1974). The importance of texture in examining compaction effects is important due to its effect on soil moisture conditions. In fine textured soils, compaction results in a lower soil water potential and increased field capacity (Lutz 1945, Singh and Singh 1971). Effects of compaction on coarser textured soils are not as pronounced, with moderate compaction even improving water availability in some soils (Hill and Sumner 1967, Liddle and Greig-Smith 1975). However, severe compaction, which is readily achieved in sandy loams (Hill and Sumner 1967) will result in a decrease in moisture content at constant matric suction.

Although the possibility exists for short-term soil moisture increases in areas of disrupted desert pavement, serious compaction and above-ground

destruction will result in decreased levels of soil moisture. If soil compaction and surface disruption is not severe, significant changes in soil moisture may not occur due to construction and maintenance activities.

Temperature and Heat Flux

Few of the recent studies on impacts of walkers and off-road vehicles have examined potential changes in thermal conductivity of compacted soils, and thus the effects of compaction on overall heat flux in the desert ecosystem. Liddle and Moore (1974) found compaction of sand to increase its thermal capacity, as would be expected as density was increased. Conductivity was increased in dry soils, but was decreased in wet. The result was an increase in diurnal soil and air temperature ranges, which Liddle and Moore (1974) attributed more to vegetation removal than to compaction. In any case, significant above-ground destruction of desert habitat would appear to increase heat flux rates in the soil-atmosphere system throughout the day.

Significant compaction of soils may alter energy exchange in the desert ecosystem in the following ways:

1. Compaction will increase ground surface reflectivity, resulting in decreased soil heating from incoming radiation.
2. If compaction results in decreased surface emissivity, then more energy will be available for daytime heating of the air by sensible heat, and nighttime radiative cooling of the soil will decrease.
3. Compaction will increase ground conductive capacity resulting in decreased daytime heating and increased nocturnal cooling of the soil.
4. Compaction will increase dry density, resulting in increased ground thermal capacity and thus potential soil heating.

The contradictory nature of these processes points to the need for a thorough analysis of what changes may occur in the energy budget of desert ecosystems in which soil compaction occurs.

Compaction of soils, together with above-ground destruction of desert habitat, would appear to increase heat flux rates in the soil-atmosphere system throughout the diurnal cycle. It would not be expected, however, to offset the decreased heat flux rates due to the combined influence of shading and wind deflection by an array of heliostats or photovoltaic collectors.

Plant and Animal Response

Plant and animal response to construction and maintenance disturbance

will be two-fold, namely the response of biota to soil compaction and the abiotic changes it causes, and to actual destruction of individual organisms or populations of organisms. In the case of mobile animals, populations may not be destroyed, but destruction of habitat could result in removal of organisms via migration from within collector fields. Return of these organisms would thus be dependent on the degree of restoration of the habitat.

Compaction has been observed to inhibit growth of herbaceous plants by decreasing germination or inhibiting root growth (Kubota and Williams 1967, Davidson and Fox 1974). In very sandy soils, compaction has been found to be beneficial to plants (Liddle and Greig-Smith 1975). Unless serious compaction occurs on clayey or loamy sites, it should not be a major limiting factor on ephemeral populations.

Soil texture and pore volume are recognized as very important variables in determining distribution of shrubs in arid regions (Noy-Meir 1973). Although comparative water relations undoubtedly plays a major role, several studies have indicated aeration of roots as a reason for many shrubs with fibrous, near-surface root systems occurring exclusively on sandy soils (Cannon 1915). Several common types of plants requiring high levels of soil aeration are creosote bush (Lunt *et al.* 1973), and some of the cacti (Cannon and Free 1917). Several studies have noted decreases in oxygen content of soils due to compaction (Lutz 1945, Liddle and Greig-Smith 1975) but as yet, apparently no similar results are available for disturbed desert systems. Even so, succession of perennial vegetation in the desert due to compaction effects appears unlikely.

Complete above-ground destruction of desert sites is eventually followed by new populations of plants. The important question is what type of plants succeed on the site relative to what existed there before. Some studies indicate plant succession to be essentially lacking in desert vegetation (Muller 1940, Shreve 1951), i.e., if a creosote bush community is destroyed, then creosote bush will return. Indeed, desert studies have shown this (Wright 1970, Beatley 1974a, Mirpagel and Zembel 1976). Conversely, other desert studies have indicated distinct invader species to

occur (Wells 1961, Vasek *et al.* 1975a,b). These invader species are usually perennial forbs or subshrubs which were only secondary constituents of the previous undisturbed communities.

If invader species do occur, then regeneration of long-lived dominant perennials may be expected to return after clearing in a sigmoid fashion, i.e., slow initial regeneration followed by rapid intermediate development as the invader species begin to be outcompeted (Vasek *et al.* 1975b). This can be a time consuming process, as evidenced by clearing effects still being noticeable in a heavily disturbed desert area 33 years after the disturbance took place.

If seeding of perennial grasses is attempted in order to take economic advantage of the moderate microclimate under collector arrays, and in an attempt to discourage weed growth, then several considerations may be important. Desert grassland species are often soil texture specific (Herbel *et al.* 1973), and seeding is often not successful on highly erosive sites or ones which form a hard surface crust (i.e., desert pavement). Establishment of rangeland grasses is also generally unsuccessful on sandy soils of arid regions due to windblast destruction of seedlings (Fryrear *et al.*, 1973), although the shelter effect imposed by the solar collectors may give mechanical protection to seedlings from sand blast (Rosenberg 1974).

In general, the desert literature indicates that succession is a variable and often unpredictable phenomenon. This variability also tends to increase with disturbance, thus complete destruction of above-ground communities would be the hardest to predict with regard to revegetation. A further generality is that rate of revegetation from complete clearing is inversely related with the degree of aridity in a disturbed area, meaning that areas of higher relative production and diversity will revegetate more quickly. Thus, although significant areas may be cleared in the construction phase of these solar projects, the more mesic environment provided by shading and wind deflection should aid revegetation of the sites relative to disturbance in the open desert.

Succession of plant communities will have a profound impact on animal

population dynamics. Reproduction in desert animals has been documented to be highly correlated to abundance of food sources, as previously discussed. If food sources are available, animal populations which were formerly removed from sites due to intensive construction activities would be expected to return due to moderated microclimatic conditions under the collectors. These animal numbers could be significantly greater than what was originally there, assuming greater plant production and thus standing biomass. Such potential system imbalances (ERDA 1977a) would probably not be ecologically destructive, and may be of value in regulating standing vegetation biomass, which could become a problem to normal heliostat or collector operation and maintenance. Exclusion of animal migration by fences would result in an increased standing crop of weeds, possibly requiring application of herbicides over large tracts of desert land.

IV. RESEARCH NEEDS: A FUNCTION OF ECOSYSTEM CHANGES

Research required to accurately determine the impacts of solar conversion systems on desert ecosystems must be closely correlated with the ecosystem functions. The research should be designed in such a way that one can easily recognize what ecosystem functions are being studied, why particular data are being collected and how the data will lead to a better understanding of the ecosystem function. Data from properly designed research can be statistically analyzed to demonstrate inter-relations between and among factors. If not designed with numerical analyses in mind, research can lead to erroneous conclusions and improper management decisions.

Biotic and Abiotic Hypotheses

In order to delineate research needs necessary to evaluate biotic and abiotic changes in the desert ecosystem brought about by construction and operation of large solar collection facilities, hypotheses designed to test relevant environmental changes must be formulated. Biotic changes in the collector array of a large solar facility will occur due to alteration of the desert microclimate by individual collectors and the array as a whole, as well as the degree of initial site disturbance during site preparation and construction activities.

Two types of desert sites are envisioned as occurring subsequent to construction of the solar facility (a) a site which has been completely cleared and possibly graded and (b) one in which care has been taken to retain in an undisturbed condition as much of the original desert habitat as possible without significantly hampering construction activities. Assuming that plant succession will be allowed to proceed regardless of initial site condition (barring heliostat interference), then hypotheses advanced concerning changes in abiotic parameters on a moderate to long term basis should not be significantly influenced by initial site condition. However, due to the time consuming and variable nature of biotic succession in desert ecosystems, initial site condition is an important consideration when formulating hypotheses pertaining to biotic changes occurring due to presence and operation of the solar facility.

As a result, hypotheses advanced concerning the distribution, abundance, and function of organisms occurring in solar collector arrays will depend on site condition at the onset of operation of the facility. Specific discussions of hypotheses concerning biotic changes in collector areas will therefore be separated into different sections, depending on whether the site will be partially or completely cleared. General biotic changes will be discussed prior to advancing specific testable hypotheses.

Biotic Hypotheses: General

Changes in plant and animal composition in solar collector arrays is the primary concern of future monitoring and manipulative studies. It is important to realize that the driving variables governing these biotic changes are largely changes in abiotic variables. As a result there is a need to

monitor changes in the abiotic environment in order to quantify how solar collectors or heliostats are modifying the desert environment and producing new microenvironments for organisms.

Before presenting specific biotic and abiotic hypotheses, a brief discussion is necessary to delimit (a) major categories of biotic change that may occur, and (b) the biotic and/or abiotic factors that are driving variables and may change in function due to alteration. The general biotic changes are:

1. Plant photosynthesis and above-ground production will change. The driving variables governing this change will be changes in available soil water content and the physical effects of shading. Soil water will primarily be influenced by a change in evaporation rate, which is affected by shading and air movement. Shading will also reduce heat load on the plant by reducing heat flux rates between the soil and atmosphere on a diurnal basis. Therefore, changes in plant production will be a function of changes in soil water content, incoming solar radiation, environmental temperatures, and atmospheric humidity. Monitoring these variables will allow correlation of production changes with abiotic changes. Compaction effects on soil water content may also be important to consider for some soil types.

2. Plant species composition will change because the following changing factors will cause some plants to drop out and others to be enhanced. a) The degree of aboveground destruction of both plant individuals and habitat during construction phases is extremely important, as it will dictate the potential for succession of new species to occur on the site. Destruction of habitat will involve degree of disruption of the fragile desert soil surface, or "desert pavement", as well as degree of microtopographic manipulation of the site. b) The degree of soil compaction occurring during construction of the facility is important because desert perennials are known to occur in specific soils, as water relations, root oxygen requirements, and root penetration ability varies among species. Monitoring bulk density, penetration resistance, water availability, and "erodibility" is suggested if extensive soil compaction occurs. c) Shading is important because it may offer a competitive advantage to species better able to utilize the greater soil water content, or less tolerant of the normally severe conditions occurring in the open desert. This will again involve monitoring changes in the water and energy fluxes occurring in the environment.

d) Increased or decreased grazing and browsing by animals which alter plant productivity rates.

3. Animal species composition will change as a result of the following factors. a) Changes in plant production, which in turn will provide a change in food source and cover in the form of green biomass, reproductive parts, and surface litter. b) The presence of new "cover" which will provide shading in the day as well as potentially reduced long-wave radiation losses at night. Monitoring diurnal radiation and heat flux rates will quantify the protective "cover" aspect of solar collectors. c) The presence of man which will probably be the most important variable dictating animal composition, especially the larger, more visible animals with larger territories. Preliminary habitat disturbances, construction of fences, and maintenance activities will all be very important in determining the amount of recolonization of animals allowed by man's activities.

More specific biotic hypotheses are advanced below. Following each hypothesis a brief explanation of the suggested driving variables are presented, as well as which variables need to be monitored and correlated to the specific biotic alteration. The hypotheses are presented in an order of decreasing significance of occurrence and impact on the ecosystem.

Biotic Hypotheses: Site Preserved

Hypothesis: *Plant and animal density and diversity will increase with time.*

Animal populations should initially be reduced, but if allowed to immigrate onto the site, will do so due to the new "cover" provided by the collectors. Presence of fencing around the site will exclude the larger animals. Density and diversity are easily sampled in the field using one of a variety of standard techniques.

Hypothesis: *Photosynthetic productivity of plants on the site will be greater than in adjacent desert sites due to a microclimate more favorable for photosynthesis.*

Monitoring of the abiotic environment would allow mathematical correlation and possibly modeling of photosynthesis changes as affected by new microclimates. This hypothesis applies to most, but not all, of the

microenvironments present in a collector array. Sites immediately under the collectors may be bare due to the collector blocking incoming light and precipitation.

Hypothesis: *Individual shrub canopy volumes will increase.*

This is expected to be a long-term change due to the low production rates of desert shrubs. Reduced incident light could result in increased leaf production adding to shrub volume.

Hypothesis: *Density of desert annuals, weeds, and grasses will be increased within the collector arrays.*

Grass establishment would be dependent on amount of soil water present and degree of grazing pressure (from all animals). Many grasses tolerate low light conditions, and may occur abundantly in wet seasons. Other small herbs will be common, and weeds should dominate in areas that are regularly disturbed.

Hypothesis: *Insect numbers will increase in the collector areas.*

Not all types of insects will increase, but several major types may. Ants may become common in relatively undisturbed areas due to a potentially large seed source. More detritus may be available for surface Tenebrionid beetles and termites, flowers for Lepidoptera, and leaves for Homoptera.

Hypothesis: *Soil microorganisms and arthropods will increase with time becoming greater than in the surrounding natural desert area.*

Decomposition rate of the soil will also increase. The driving variables for these changes are increase in soil moisture and reduced soil temperatures.

Hypothesis: *Diurnal animal behavior and activity may shift.*

This is difficult to test except through observation and trapping, but this may occur due to cover and shading of the collectors.

Other hypotheses can be formulated in looking at more specific interactions, and further predictions of biotic changes. These hypotheses will also eventually apply to cleared sites, but only on a long-term basis. Short

and moderate-term changes on these sites will undergo "old field" type succession, which takes many years in desert ecosystems.

Biotic Hypotheses: Site Cleared

Hypothesis: *Animal populations will largely be removed.*

This change especially applies to the larger animals, and can be tested by periodic monitoring of the site for animal recolonization. Presence of fencing will again be important and will control any form of large animal migration.

Hypothesis: *Initial plant communities will be ephemeral and weedy in nature.*

Density and species composition is easily monitored. This community type may exist for some time depending on the degree of continuing surface disturbance.

Hypothesis: *Plant production will increase with time. Photosynthetic rates on a leaf area basis within the array will be greater than at adjacent open desert sites.*

Productivity increases will be due to an ameliorated microclimate. Herbaceous plants may be very productive in wet seasons.

Hypothesis: *Animal species composition will be significantly different than in the open desert.*

The presence of a denser herbaceous plant community within the array is probably the main reason for this, providing different food sources and microhabitats.

Abiotic Hypotheses

Changes in abiotic variables should be monitored at the solar conversion facilities not in order to examine abiotic changer per se, but to understand the effects on plant and animal populations of complex microenvironmental changes produced by arrays of large solar collectors. Dynamics of the biotic component of the ecosystem will be highly correlated to dynamics of the abiotic environment. Priority of addressing and testing abiotic hypotheses will be due to their relative importance in producing significant biotic changes in the desert environment.

Hypothesis: *Both direct and diffuse solar radiation input at the ground surface will be substantially reduced in collector arrays.*

Incoming direct and scattered radiation should both be substantially reduced within the arrays. Shading, as a direct and indirect factor, is probably the major modification of the environment which produces biotic changes.

Hypothesis: *Compaction of soil will be considerable, and largely irreversible.*

Soil compaction is mainly a result of construction activity. It can be tested by examining changes in bulk density and penetration resistance after construction activities. Impact of maintenance activity on soil compaction should also be examined.

Hypothesis: *Soil moisture will increase with site succession and will be greater than in the open desert.*

Soil moisture should be monitored with one of various indirect methods such as soil moisture blocks, neutron probes or directly through gravimetric sampling. Increase of soil moisture is due to shading and wind deflection, and directly affects biotic changes, particularly plant functions.

Hypothesis: *Air, surface and soil temperatures will be reduced in the day within the collector array and will have less diurnal fluctuation.*

All three temperatures are biologically important. Reduction of heating and cooling rates, as well as maximum temperatures, should be beneficial to most organisms, and may provide new habitats for new or uncommon species.

Hypothesis: *Soil erosion will increase with increased surface disturbance. It will decrease as site succession proceeds due to increased density of rooted plants.*

Compaction and surface disturbance will accelerate soil erosion. Overall, soil erosion may be greater than in open desert areas due to maintenance activities. Soil erosion will be much greater on sites completely cleared during construction. This can be determined by sampling surface texture and microtopography.

Hypothesis: *Wind speed will be reduced, but air turbulence will increase.*

Analysis of wind changes within the array will be very difficult because of the complexity of air movement around the collectors. It is possible, however, by utilizing a number of small anemometers. The overall array should reduce wind speed in interior areas, but turbulent mixing within the array may increase turbulent transfer, particularly under windy conditions. Periods of low wind may allow stable inversion layers to develop within the array and not in open desert areas.

Hypothesis: *Long-wave radiation emitted and lost from the soil surface will be reduced.*

Interception by stowed heliostats or collectors will redirect emitted radiation back to the ground surface. Monitoring net all-wave radiation under collectors will determine if it is significant enough to provide warm micro-sites during periods of rapid cooling. Temperature profiles will give added information.

Hypothesis: *Albedo from the collector area will decrease with time.*

The decrease in albedo which means more radiation held in the system will be due to increased density of plants causing more light absorption by the ground area in the array fields. This could increase the temperatures. Measurement of solar reflection from areas within the array will give information to test this hypothesis.

V. RESEARCH PROGRAM

The research program presented in this section is based on the background material and hypotheses presented in earlier sections. The research program is considered in two parts. The first part includes a chronological sequence of events and data gathering that should lead to an adequate understanding of the environmental problems resulting from various solar conversion systems. If followed, this chronological approach will allow establishment of a broad analytical program that will include existing, proposed and future solar conversion systems.

The second part of this section presents specific types of research manipulation and monitoring that should be done at various solar conversion sites or at simulation sites. This second part gives detail to the general research program recommended in the first part of this section.

Chronological Program

Development of a comprehensive research program must follow logical steps so that the information collected is part of an integrated analysis that cannot be refuted because of poor research design. The stepwise research program presented (Figure 1) is designed to build on information and validation developed, over time, within the program. If research or data collection is initiated out of sequence, it is likely that there will be wasted effort as well as duplication of information.

Ecosystem Parameters: Establish a Theoretical Base

In order to develop a properly designed research program, it is essential to determine what information is already available that might be used as a guide. Based on this background material, it is possible to establish a theoretical base on which to build research hypotheses.

The construction and operation of solar conversion systems are anticipated to have many impacts on ecosystem parameters. Because there is no history of environmental studies of solar conversion systems and the few systems that were developed in the first half of the 20th century were not of significant size to be concerned with altering the surrounding

Figure 1. Research Program: Chronological Steps.

Key

- B = Baseline Study
- M = Monitoring Studies
- C = Construction Phase
- O = Operation Phase

environment, actual background data on environmental or ecological impacts of solar conversion systems are not available. Background information can be based on data from types of impacts similar to those anticipated from construction and operation of solar conversion units. Similar activities such as development of wind breaks, and artificial or natural shading of the desert can be used for ideas.

By separating the impact activities into broad categories such as shading, wind deflection and physical disturbances, it is possible to develop theoretical ecological consequences of solar conversion system construction and operation. These theoretical consequences identify various ecosystem parameters that will be altered through solar conversion system establishment. Theories are then developed to show how much and how significantly these parameters might change.

Progress. This first step in the suggested research program has been completed and is presented in Section III of this report. It is based on a thorough review of the literature including ecological, meteorological and engineering journals as well as journals from more peripheral disciplines. Theoretical responses of ecosystem parameters include changes in plant and animal functions, diversity and density as well as suspected changes in physical and chemical factors. It should be noted that this phase in development of the overall research program is theoretical and the ecological consequences presented cannot be considered to be totally valid because they are based on other activities of man or natural phenomena and are not directly a result of solar conversion system construction and operation or simulation of such activities.

Ecosystem Parameters: Validate Responses

Identification of ecosystem parameters that might be altered by construction and operation of solar conversion systems is not enough on which to establish a research or monitoring program. These parameters were identified based on ecological responses to other non-solar conversion type activities or natural phenomena. The significance of the parameter response relative to needed research can only be validated through testing the flexibility or variability of the parameter in response to construction and operation activities of actual or simulated solar conversion systems within

a desert ecosystem. The significance of the ecological parameter responses must be established prior to developing detailed environmental monitoring programs for the large scale solar conversion systems under construction or planning.

At present (January 1978) there are only two methods available to validate the significance of ecosystem parameter responses. The parameters identified in the theoretical bases section can be tested at the existing solar powered irrigation pumping sites or by simulating solar collectors in a desert ecosystem. Both of these methods have limitations but they are vastly superior to trying to use the Albuquerque 5MW STPS because this system is so modified by construction and asphaltting of the surface that there is no desert ecosystem remaining immediately on site to measure.

The limitations of the two systems to be used for validation are primarily due to small size and limits in flexibility. The irrigation sites use a parabolic trough concentration system and are set in terms of solar tracking and the types of shading and wind deflection created. Simulating a solar conversion system is useful in that different forms of collectors (or reflectors) can be used, but imitating all forms of solar collectors is impossible and thus any data on validation obtained from a simulation system still might not be totally applicable to all types of future solar conversion units, but the flexibility of a simulation system is great enough to permit qualified evaluation of ecosystem parameter responses that will be useful in establishing later research and monitoring programs.

Progress. Two solar powered pumping irrigation systems are available for testing ecosystem responses. Both use parabolic solar concentrating systems. One near Gila Bend, Arizona was built on a raised, compacted soil "platform" surrounded by irrigated fields. This station might be useful for determining shading and wind deflection effects but the substrate and surrounding area are too unnatural for comparison with larger solar conversion systems to be constructed in more natural desert ecosystems. The solar irrigation project near Willard, New Mexico is more likely to give useful ecosystem response data. Although the substrate was disturbed, plants are reinvading and much of the surrounding area is natural desert. Both biotic and abiotic ecosystem parameters could be studied at this site.

The beginning of a solar collector simulation site has been established near Phoenix, Arizona. This site is in a natural desert ecosystem and the simulation collector panels are more like photovoltaic panels than heliostats or parabolic solar collectors. The panels can be manipulated to represent a variety of solar collector systems. A limited amount of data has been obtained from this simulator site and these data are presented in the Appendix of this report.

Monitoring Ecosystem Parameters: Alternative Methods

Once the significance of the responses of ecosystem parameters have been established, or at least set in some form of priority, alternative methods for monitoring these parameters under varying circumstances should be designed. The variabilities that dictate what alternative forms of monitoring should be established include: (a) different types of solar collectors and construction and operation methods, (b) different sizes of the collector area and (c) different desert or semi-arid ecosystems in which the solar conversion systems are constructed. For example, a large solar thermal power system using heliostats will have different effects on the ecosystem due to the method of construction and the amounts of shading and wind deflection than a small concentrating system or photovoltaic system.

The level of detail in the monitoring data is also another factor for choosing between alternative monitoring methods. Monitoring ecosystem parameters can be accomplished in a very simple fashion or extremely refined techniques can be used. Some examples on variation in sampling biotic changes include from the simplest to most detailed: (a) qualitative observation of changes in animals and plants, (b) simple counts of animal occurrence through signs such as pellets or tracks and widely spaced measurement of vegetational standing crop, (c) trapping of each trophic level of animal (trap, mark and release the larger animals down to lizard size) and regularly sample and harvest permanently marked plant stands counting species density, diversity, and productivity.

Abiotic ecosystem parameters can also be measured in a general or detailed fashion. General sampling of temperatures, soil moisture and air movement can be accomplished with a limited amount of inexpensive equipment but the data obtained will give only trends in changes of abiotic characteristics of the ecosystem. In order to determine flows or fluxes in the water

cycle or energy budget at various locations within the solar collector array and adjacent control areas more sophisticated equipment is needed and regular intensive periods of measurement are necessary.

Progress. The level of sophistication of instrumentation and data collection techniques to be used in monitoring ecosystem response to solar conversion system construction and operation has not been fully determined. Alternative methods of general trend measurements and intensive detailed data collection were initiated on the small collector simulation site near Phoenix, Arizona. Periodic measurements at the solar powered irrigation sites might enable speculation on the sophistication of data collection needed at any future large STPS or photovoltaic system but there continues to be a need to compare the usefulness of general trend data with more specific detailed ecosystem parameter responses. The data collected to determine the significance of parameter response (see preceding part) should enable evaluation of alternative monitoring methods. In all likelihood, a combination of general data for some parameters and detailed data for others will turn out to be the best combination of monitoring techniques. These will vary according to the variabilities of the solar conversion system to be monitored. It is unlikely that a monitoring program designed for one type of solar conversion system will give all the information needed to analyze ecological impacts at other types of solar conversion systems.

10 MW_e STPS: Baseline and Monitoring Program

Although all determinations may not be made as to significance of ecosystem parameter responses or alternatives for monitoring prior to site development for the 10 MW_e STPS near Barstow, California, it is imperative to establish a baseline study and design a monitoring program for the site as early as possible. The baseline study should include an analysis for on-site and an adjacent area of the existing biotic community including the composition, density and diversity of species and the major abiotic factors including soil surface and textural characteristics and temperature profiles. During the period of baseline analysis, the future monitoring program for the site should be established. This will include both biotic and abiotic data collection on the actual STPS site and at an adjacent control site.

Progress. Neither the baseline study nor the monitoring program have

been established. The type of data and the time sequence for both of these programs are suggested in the following section of Specific Monitoring and Manipulation Programs. The actual location of instrument placement and biotic sampling will have to be determined by the team that is contracted to study the 10 MW_e STPS Barstow site although instrument location should be in a wide variety of habitats.

10 MW_e STPS: Manipulations and Site Variables

The variables that will occur at any of the planned STPS sites should be used to gather additional data beyond those obtained through the regular monitoring program. In some cases the variables are a regular part of the planned collector system or are a normal aspect of the ecosystem on which the collector array is constructed. In other cases variables may be created by varying some process in the construction or operation phases of the STPS.

Examples of the first instance where no manipulation or variation in construction or operation procedures will be necessary include: (a) variation in the packing factor within the heliostat field, (b) variability in ground surface microtopography and (c) variation in soil type over the area of the STPS. Examples of construction or operation activities that might be manipulated or altered in order to create additional test variables in the first large scale STPS constructed on a more or less natural ecosystem (i.e., no total destruction through asphaltting) include: (a) variation in the size of vehicle or number of trips required for certain operation or maintenance phases, (b) varying the type of ground surface material from unaltered after construction to surfacing with different size and color sand or gravel particles and (c) altering maintenance cycles and wash water quality. By manipulating these variables and monitoring the changes in ecosystem response that they create, it will be possible to use the first large scale STPS as an environmental test site beyond the routine monitoring program.

Progress. The ecosystem parameters that might respond to the manipulations or alterations suggested above and the time sequence for measuring are presented in the following section on Specific Monitoring and Manipulation Programs. Establishment of this manipulation program should come early in the construction phase at Barstow to enable creating as many variables as possible within the engineering design of the 10 MW_e STPS at that site.

Future STPS and Photovoltaic Systems: Monitoring Programs

Establishment of ecological monitoring programs for future STPS or photovoltaic systems should wait until at least a year's worth of data have been obtained from the 10 MW_e STPS and data from the ecosystem parameter response studies at the solar powered irrigation sites and simulation sites have been fully analyzed. It is entirely possible that the 100 MW_e STPS to be constructed within the next decade will not have to have a monitoring program but for future environmental planning the following steps at such a site would be advisable. (1) Do an ecological baseline study at the proposed 100 MW_e STPS site. (2) Based on data from the baseline study and the 10 MW_e STPS monitoring program and simulation site ecosystem response study predict the ecological changes that might be expected to take place. These should include biotic and abiotic changes as influenced by the proposed construction and operation methods and geographic size of the unit. (3) Develop a simple monitoring program to validate the ecosystem changes predicted. (4) Establish a post-project analysis of the accuracy of the original prediction. This should be done at least two years after beginning the monitoring program. If it can be shown that the original predictions were significantly accurate, then future ecological monitoring programs for this type of solar conversion system will probably not be necessary. If the predictions were not accurate, then additional monitoring will be necessary. It is likely, however, that solar conversion systems completely different from the 10 MW_e or 100 MW_e STPS proposed, such as large scale photovoltaic systems, will have to have additional monitoring programs unless the data from studies simulating photovoltaic systems proves to be generally applicable.

Progress. A general monitoring program for a 100 MW_e STPS is suggested in the following section. This is a limited program and should be altered based on data obtained prior to the time of establishment of the program.

Specific Monitoring and Manipulation Programs

The research programs presented in this part specify particular ecosystem parameters that should be measured during baseline, monitoring or manipulation studies at various solar conversion systems. These ecosystem parameters are selected from a large number of potential factors (Appendix Table 1) to be measured over the time span suggested in the accompanying figures. The particular parameters have been selected to help test the hypotheses on ecological impacts of solar energy conversion systems presented in Section V - Research Needs. In that section it is shown how research on these parameters will produce data that will elucidate the potential ecological changes at the varying test sites.

Solar Powered Irrigation Pumping Site (Willard, New Mexico) (Figure 2)

At the end of 1977 this solar powered irrigation system was in full operation. As a result it is impossible to take baseline data on site but it is recommended that the equivalent of baseline data be taken on the density and diversity of the plant component of the ecosystem on a control site adjacent to the irrigation pump station. This control site should be selected to best represent what ecologically is perceived to have been like the pump site prior to construction. The animal portion of the biotic aspect of the ecosystem has been altered through site preparation to the point where exclusionary fencing now in place will restrict return of some of the larger animals. Concentrated activities on the site also will restrict reinvasion by animals. As a result baseline data and periodic monitoring of animal density, diversity or behavior are not recommended for this site. Because the plant portion of the ecosystem does not instantaneously respond to the presence of man, it is recommended that vegetational invasion on site be monitored on a periodic basis (at least four times a year) and compared with equivalent vegetational data collected at the adjacent control site.

A limited amount of abiotic data should also be monitored on site and at the control site. These data include the factors that control, or are a response to, the water cycle; that is, surface texture and changes in surface microtopography due to construction activities and runoff from the solar collectors, and soil water content. The factors that will allow estimation of the energy budget should also be monitored. These include solar radiation, long wave radiation loss and air and soil temperatures.

Figure 2. Specific research needs for ecosystem impact data at the solar powered irrigation pump system Willard, N. Mexico.

	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1990	2000
SOLAR CONVERSION SYSTEM	Operation												
Irrigation-Solar Power	-----												
BIOTIC PARAMETERS													
<u>Plants</u>													
Density and Diversity -	○▽			▼									
Productivity and Phenology -													
Physiological Functions -													
<u>Animals</u>													
Density and Diversity -													
Behavior and Migration -													
<u>Soil Organisms</u>													
Density and Diversity -													

DATA COLLECTION

○ Baseline,

△ Monitoring on Site Only

Open Symbol = Single or begin measurement.

□ Manipulation,

▼ Monitoring on Site and Adjacent Control Site

Closed Symbol = End of measurement period.

Figure 2 (cont.)	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1990	2000
ENVIRONMENTAL PARAMETERS													
<u>Energy Flux</u>													
Solar Radiation -	▼			▼									
Long Wave Loss -	▼			▼									
Albedo -													
Temperature (air, surface, soil) -	▼			▼									
Wind Velocity and Turbulence -	▼			▼									
<u>Water Cycle Factors</u>													
Precipitation -	▼			▼									
Infiltration Rate -													
Water Content -	▼			▼									
Water Potential -													
Water Quality -													
<u>Soil Characteristics</u>													
Bulk Density -													
Penetration Resistance -													
Surface Texture -	▼			▼									
Microtopography -	▼			▼									

Air movement and turbulence influence both the water cycle through evapotranspiration from the soil and plants as well as the energy flux in the ecosystem. The energy budget of the ecosystem directly controls the function and behavior of the animals and plants.

The duration of monitoring should be at least for three years in order to better determine plant response and plant invasion of the site. Biotic recovery is a slow process and changes continue to occur until the plant and animal community is in balance with the newly created environment.

Solar Conversion System Simulation Sites (Figure 3)

The use of solar conversion simulation sites is primarily to determine the validity of the theoretical hypotheses about which ecosystem parameters are most responsive to modification of the desert ecosystem by construction and maintenance of solar conversion systems. The solar conversion system simulations can be used to manipulate and monitor a great variety of system functions on site which would be impossible to accomplish at an actually operating solar conversion system. Through comparison of on and off site ecosystem fluctuations, it is possible to determine the relative significance of a particular type of structure or activity modification based on the relative degrees of change in that activity.

The simulation sites should be used to measure all of the apparently significant ecosystem parameters under standard and manipulated processes. Initially the simulation solar conversion systems should be treated as standard solar conversion sites with monitoring of ecosystem parameters taking place on both the site and an adjacent control area. After a minimum of a year or two, various manipulations should be incorporated into the "operation and maintenance" processes of the simulation conversion panels. These manipulative changes should include (a) modifying maintenance activities, (b) changing the ground surface texture in part of the panel array, (c) modifying "washing techniques" and washing compounds and (d) using alternative arrangements of the solar collector panels such as stationary position or solar tracking. If heliostats are simulated, modifications in stow position should also be attempted.

Changes in biotic parameters should be carefully monitored. These not only include density and diversity of the various species, which is an

	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1990	2000
SOLAR CONVERSION SYSTEM	Const.		Operation										
Collector Simulation													
BIOTIC PARAMETERS													
<u>Plants</u>													
Density and Diversity -	○	▽		□		▼■							
Productivity and Phenology -		▽				▼							
Physiological Functions -		▽				▼							
<u>Animals</u>													
Density and Diversity -	○	▽				▼							
Behavior and Migration -		▽				▼							
<u>Soil Organisms</u>													
Density and Diversity -		▽	□			▼■							

DATA COLLECTION

○ Baseline,

△ Monitoring on Site Only

Open Symbol = Single or begin measurement.

□ Manipulation,

▽ Monitoring on Site and Adjacent Control Site

Closed Symbol = End of measurement period.

TABLE 1. MANIPULATIVE OR ALTERNATIVE CONTRUCTION OR
MAINTENANCE ACTIVITIES

- A. Manipulate and alter maintenance activities such as vehicle size or number of trips on site.
- B. Modify ground surface through use of alternative surface materials.
- C. Use alternative methods for washing heliostats including quality of wash water.
- D. Use alternative heliostat stow positions.
- E. Gather data in heliostat areas with different packing factors.

indicator of biotic community change, but also productivity, phenological and physiological functions of plants and behavior and migration patterns of animals. This latter set of functions can be used to explain the fluctuations in biotic diversity and density.

Figure 3 indicates the wide variety of abiotic parameters that should be monitored both prior to any manipulation and during manipulation procedures. Most of the abiotic parameters relate to energy or heat flux patterns within the collector array or to factors controlling the water cycle on the site and at an adjacent control area. Some factors such as penetration resistance of the soil and surface texture relate directly to construction or operation disturbance activities and are only indirectly related to organism response to perturbation. However, these factors do influence the potential for plant invasion of the site and the long term survival of plant species.

Another reason that so many parameters are to be measured at the simulation sites is that this type of site is best used to validate the theoretical impacts of solar conversion site perturbations. There is not the need to make certain that the "site" continues to operate and produce electricity, thus permitting a wide potential of manipulative possibilities.

Simulation sites, if maintained for a reasonable length of time, can also be used to test for beneficial consequences of solar conversion system construction and operation. Following the initial validation of ecosystem responses and accompanying manipulations on the site, additional modifications might be made to produce beneficial responses of ecosystem parameters.

If it is determined that particular life forms of plants such as grasses or shrubs respond to the new environment created by the solar collector array through increased productivity, these plants and other similar plants might be purposely grown within the "beneficial" habitats. If it turns out that water is a limiting factor in these habitats, then through modification of the terrain around the solar collectors runoff water can be directed to areas where plants might be grown. Depending on the type of plant grown, the modified ecosystem in the solar collector array can be improved as a naturally productive ecosystem or as an economically productive system.

10 MW_e STPS: Barstow, California (Figure 4)

The proposed 10 MW_e STPS site near Barstow, California should be used primarily for monitoring the response of ecosystem parameters to construction and operation of the solar conversion system. The site also has the possibility for testing alternative activities either through built in manipulations where engineering feasibility permits or through selection of different monitoring sites within the heliostat array where ecosystem parameters such as soil or engineering design such as heliostat packing factors may vary.

Figure 4 suggests the ecosystem parameters that should be monitored in relation to normal construction and operation procedures as well as manipulated (modified) or varied operations or site selection. Because this is the first "normal" operational STPS, it should be thoroughly monitored as discussed in the preceding Research Chronological Program section. From the monitoring data obtained at this site, along with other earlier environmental impact studies, assessments of the ecological impacts of future solar conversion systems can be made.

Baseline studies must be made of many of the ecosystem parameters. These include biotic parameters, especially density and diversity of plants, animals and soil organisms. Abiotic baseline data can be limited to soil factors and albedo. The soil on site will be altered by construction and the albedo of the soil surface will change along with the soil modifications. Other biotic factors such as temperatures or air movement vary so much over time that monitoring should start on these factors on and off site after construction is coming to a close and the testing and operation period is about to begin.

During testing and operation, manipulation or alternative maintenance activities should begin. These include, as indicated on Figure 4, (a) altering maintenance activities such as vehicle size and number of trips, (b) changing ground surface through addition of different colored and textured materials, this could be accomplished during construction, (c) modifying heliostat washing techniques, (d) using variable heliostat stow positions to change shading effects, (e) taking impact data in areas with different heliostat packing factors. Natural ecosystem changes, over time, should continuously be monitored at an off site location to make comparisons with the on site changes taking place under normal operating and maintenance

Figure 4. Specific research needs for ecosystem impact data and monitoring at the 10 MW_e STPS, Barstow, Calif. See Table 1 for explanation of letters.

DATA COLLECTION

O Baseline, Δ Monitoring on Site Only

□ Manipulation, ▽ Monitoring on Site and Adjacent Control Site

Open Symbol = Single or begin measurement.

Closed Symbol = End of measurement period.

Figure 3. Specific research needs for ecosystem impact data at a small solar collector simulation site. See Table 1 for explanation of letters.

procedures and at locations where modifications or manipulations are being activated.

The duration of the monitoring activities at the 10 MW_e STPS should be for a long enough period to permit evaluation of the potential long term biotic changes that are expected to occur. Because the expected active period of the 10 MW_e STPS is only seven years, monitoring should continue for this full period.

100 MW_e STPS: Proposed

Designing a specific monitoring program for a large 100 MW_e STPS years ahead of the engineering specifications or site selection is difficult if not impossible. The basic procedure should be similar to the proposed 10 MW_e STPS monitoring program. Baseline data should be obtained on the biotic components of the ecosystem and the parameters, such as soil, that would not vary much over time if there were no site disturbance. The baseline data should also be taken at a similar adjacent control site.

As discussed earlier in the Research Chronological Program section, selection of the ecosystem parameters to be monitored should be based on data obtained from the simulation studies and the 10 MW_e STPS monitoring program. Because this will be the first very large 100 MW_e STPS, adequate monitoring should be carried out to validate ecological changes that were predicted for the site based on results from earlier studies.

Again, biotic parameters should be monitored for at least three years and hopefully for many more. The large amount of acreage being modified will not just create an island effect, but will establish a whole new environmental "sub-biome" at the site. It is possible that many exotic or non-native species of plants and animals will invade the site as others move or die out.

Broad abiotic measurements may be all that are necessary to take if they can be correlated with the more detailed data obtained at the 10 MW_e STPS and the simulation or irrigation sites. Basic measurements that should be taken under the heliostats, within the heliostat array and at the control site include soil moisture; temperatures in the ground, at ground surface and approximately 50 cm above the ground; and air movement at 20 to 50 cm. These data can be easily compared to the quantities of abiotic data from earlier studies and are some of the prime factors that will control any changes in the biotic structure of the ecosystem.

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GLOSSARY

- Abiotic - The non-living parameters of an ecosystem.
- Advection - The process of transport of an atmospheric property solely by the mass motion of the atmosphere.
- Aeration (Soil) - Oxygen content of the soil.
- Albedo - Reflectivity. The fraction of incident radiation at a given wavelength (or wavelengths) reflected by a surface or body.
- Annual Plants - Plants which germinate, grow, set seed, and die in a single year. Desert annuals are short-lived mesophytes that live only when soil moisture is present and produce seed before the onset of soil drought.
- Arid - An ecosystem which receives from 60-100 mm to 150-250 mm annual precipitation, depending on whether a majority of the precipitation occurs in the season of low evaporitvity (winter) or high evaporitvity (summer), respectively.
- Azimuth - The angle between true north and the projection of the sun's rays onto the horizontal. At solar noon the azimuthal angle is 180° (true south).
- Bajada - Alluvial fan.
- Biomass - Weight of living material, usually expressed as a dry weight, in all or part of an organism, population, or community. Commonly expressed as weight per unit area.
- Biota - The living components of an ecosystem.
- Biotic - Variables pertaining to the biota of an ecosystem.
- Bulk Density - The dry weight of a given volume of undisturbed soil.
- Bunch Grass - Tall, perennial grass characteristic of the tallgrass prairie. Differs from annual and short statured perennial grasses.
- Clay - Soil in which the average particle size is less than .002 mm.
- Community - An association of interacting populations, delimited by their interactions or by spatial occurrence.
- Desert Pavement - Desert surface structure common on arid watersheds in which a relatively impervious cemented layer of coarse particles is formed due to the loss of finer particles in runoff water.
- Desertification - The process of succession of large ecosystems, or biomes, into "deserts".
- Desiccation - The loss of water by a body to its environment.
- Detritivores - Organisms which feed mainly or exclusively on detritus,
- Detritus - Freshly dead or partially decomposed organic matter.
- Diffuse Radiation - That portion of solar radiation that reaches the earth's surface after having been scattered from the direct beam by molecules or suspensoids in the atmosphere. Also termed sky radiation.

- Diffusivity (thermal) - The ratio of a material's ability to transport energy over its capacity to store energy.
- Direct Radiation - Direct beam radiation which has not been previously reflected, scattered, or absorbed by other objects.
- Diurnal - Of or in the daytime.
- Diversity - A measure of the variety of species in a community that takes into account the relative abundance of each species.
- Ecosystem - An energy-driven complex of a community of organisms and its controlling environment.
- Emissivity - The fraction of blackbody emission at a given wavelength emitted by a surface.
- Energy Budget - Disposition of radiant energy and heat in an environment. Can be applied to the energy exchange between an organism and its environment.
- Environmental Radiant Temperature - Actual heat load of an environment. Equivalent to the measured radiation flux, and is computed as the black body temperature which emits the same total radiation flux.
- Ephemerals - Plants which exhibit above-ground biomass only in certain favorable seasons. Includes annuals and perennial forbs.
- Equinox - The time when the sun passes directly over the equator. Occurs twice annually.
- Evaporitivity - Potential evaporation.
- Evapotranspiration - The sum total of water lost by a given area of land over a given time period, taking into account evaporation from the soil and transpiration from plants.
- Field Capacity - The percentage of moisture when the drainage of a wetted soil diminishes sharply to a very slow rate. Indicates the point at which the forces of capillarity (cohesion) are equal to the forces of adhesion, and water becomes essentially immobile.
- Flux Rate - Rate of change with space and time of a variable such as heat, moisture, etc.
- Forbs - Non-grass herbaceous angiosperm plants.
- Herbaceous Plants - Non wood producing plants.
- Heteromyid Rodents - A family of rodents which includes the kangaroo rat (*Dipodomys* spp.) and pocket mice (*Perognathus* spp.).
- Homoptera - A plant feeding order of insects which includes cicadas, hoppers, aphids, and scale insects.
- Hydrological Cycle - The cycle of water as it passes through the ecosystem.
- Incident Radiation - Total radiation from the sun, sky, and surrounding environment impinging upon a surface or body.
- Infiltration - The percentage of precipitation falling on a surface which enters the soil profile. Precipitation minus runoff.

Inversion Layer - An environmental anomaly in which air temperature increases with elevation from the ground surface.

Lagomorphs - Rabbits and hares.

Latent Heat - Heat tied up in liquid water, which is released to the environment as evaporation occurs. Thus, organisms dissipate latent heat as they lose water vapor to the environment.

Lepidoptera - An order of insects, composed of the butterflies and moths, which feed mainly on nectar and plant-derived liquid food.

Loam - Soil texture classification intermediate between clay and sand.

Macropore Space - Percentage of soil volume taken up by large soil interstices.

Mesic - Pertaining to, or growing in, a moist habitat.

Microclimate - The climate in which plants and animals live.

Microenvironment - The specific environment in which an organism lives.

Microhabitat - The amount of a total habitat which is utilized by a given organism.

Microtopography - Topography of an organisms microenvironment.

Morphology - The specific form, shape or structure of an organism.

Net Radiation - The difference between total upward and downward radiation fluxes. Is a measure of the energy available at the ground surface.

Nocturnal - Pertaining to the nighttime.

Penetration Resistance - Related to bulk density of the surface layer of a soil. Measured by recording the number of impacts required by a penetrometer to reach a soil depth of 6 cm.

Perennial Plants - Plants which live longer than one year.

Perturbation - A disturbance of normal processes in an ecosystem.

Phenology - Periodic phenomena in organisms as related to variation in climatic factors.

Photoperiod - Length in time that the sun remains above the horizon.

Photoperiodism - Seasonal responses by organisms to change in the length of the daylight period.

Photosynthesis - The conversion of radiant energy into bound chemical energy by green plants.

Photothermal Systems - Central collector systems in which arrays of reflecting surfaces direct incident solar radiation to a central receiving tower, which collects and stores the energy.

Photovoltaic Systems - Distributive solar collecting facilities in which silicon cells mounted on individual collectors individually directly convert solar energy into electrical energy.

Primary Productivity - Rate of dry-matter production by photosynthesis in an ecosystem.

- Pubescence - Having a covering of hairs.
- Respiration - Metabolic assimilation of oxygen accompanied by release of energy, carbon dioxide, and water, and by breaking down of organic compounds.
- Sand - Soil particles greater than .02 mm diameter. Sandy soils have an average particle size greater than that.
- Scrub Vegetation - Physiognomic classification of short-statured, small-leaved shrubs which are very woody in nature.
- Semiarid - Climatic zone in which precipitation varies from 150-250 mm to 250-500 mm annually, depending on annual evaporitvity of the area.
- Sensible Heat Flux - Flow of heat between surface and air.
- Shrub - Perennial woody plant without a central tree-like trunk.
- Stomatal Rhythms - Rhythms of opening and closing of stomates as a function of microenvironmental conditions.
- Stomates - Pores through which gas exchange occurs in the leaves of higher plants.
- Succession - Change in composition in populations of organisms at a given location through time.
- Surface Texture - Particle size distribution at the surface of a soil.
- Tenebrionid Beetles - Family of beetles in which both adults and larvae are scavengers.
- Thermal Capacity - Ability of a medium to store energy.
- Thermal Conductance - Rate at which heat flows through a substance.
- Thermal Conductivity - The amount of energy which can flow across a unit area if the temperature gradient is unity.
- Thermal Radiation - Longwave ($> 4 \mu$), or infrared, radiation.
- Thermoperiodism - Seasonal responses by organisms to warming or cooling cycles in the environment.
- Transpiration - Water loss by plants.
- Turbulence - Non laminar (non layerlike) wind flow.
- Vapor Pressure - The pressure produced by water molecules in the vapor state.
- Water Potential - The chemical potential of water (free energy per mole) in a system.
- Water Use Efficiency - The ratio of primary production over transpirational water loss.
- Weeds - Troublesome or aggressive plants that intrude where not wanted, especially plants which vigorously colonize disturbed areas.
- Xeric - Pertaining to, or growing in, a dry habitat.

APPENDIX TABLE 1

ECOSYSTEM PARAMETERS: Potential variables in those areas considered important from which significant factors were selected to be measured in the research program.

BIOTIC PARAMETERS

Plants

Density: species and total community

Diversity: species and community composition changes

Community pattern: individual and species distribution

Phenology: germination, leaf set, flowering, leaf fall, mortality

Productivity: standing crop, caloric accumulation

Photosynthetic rates: carbon accumulation

Transpiration rates

Water use efficiency

Litter fall and accumulation

Nutrient uptake and transfer

Herbivory

Animals

Density: species and total community population

Diversity: species, composition changes

Behavior patterns

Habitat selection

Browsing and grazing rates: plant selection

Migration: patterns, rates, occurrence

Physiological rates: respiration, water use

Secondary productivity: animal biomass

Soil Organisms

Diversity

Density

Composition changes

Decomposition activity

ABIOTIC PARAMETERS

Energy Budget

- Solar radiation: direct and diffuse
- Sky reflection
- Long wave reradiation
- Long wave radiation from the sky
- Albedo of plants and soil surface
- Energy loss and gain from evaporation and condensation
- Energy loss by convection
- Energy flux by conduction
- Energy storage in the soil and plants
- Temperature air and soil profiles

Atmospheric Components

- Wind velocity
- Wind direction
- Convection currents
- Air turbulence
- Air pressure
- Oxygen and CO₂ composition
- Particulate composition
- Vapor pressure (relative humidity)

Hydrological Cycle (Water Cycle)

- Precipitation: amount, intensity, duration
- Interception by plants
- Stem flow and drip through
- Runoff: amount and intensity
- Infiltration-percolation rate
- Soil water content
- Soil water potential
- Soil water flux
- Soil water quality
- Condensation: dew formation
- Evaporation rates from the soil
- Evapo-transpiration rates from plants

ABIOTIC PARAMETERS (cont.)

Soil Characteristics

Texture

Structure

Penetration resistance

Bulk density

Moisture holding capacities

Nutrient content (e.g., N, P, K, Ca)

Organic matter content

Surface texture

Microtopography

Erosion (quantity, intensity and particle size)

DATA FROM SOLAR COLLECTOR SIMULATION SITE
PHOENIX, ARIZONA

Field Set-up

Figure A-1 presents the lay-out of how various abiotic parameters were spatially sampled in the simulated collector array. In order to minimize overall site disturbance, two collectors were chosen between which all the abiotic sampling was conducted. The collector under which measurements were made is the central collector in the 9-collector array now present on the desert site near Phoenix. This collector was sampled in order to minimize edge effect as much as possible. The dashed arrows indicate the presence of neighboring collectors as shown in the small diagram in the corner of the figure.

Figure A-1 shows the placement of soil moisture blocks, maximum-minimum thermometer stands, and a cup-type anemometer. The control site is located approximately 100 meters to the north of the array. The location of the open desert control site was selected in order to remove the influence of climatic variables caused by the array and yet still be close enough to have test and control sites with the same soil type and geomorphology.

Air Movement (Wind)

Two totalizing cup anemometers were placed in the field in order to get estimates of relative daily wind speeds. The anemometer in the collector array was placed mid-way between two panels on a north-south axis (Figure A-1) so that it would only be influenced by wind penetrating the array. The cup level of each anemometer was approximately 20 cm off of the ground.

Table A-1 gives a summary of air movement for the two sites during three sampling intervals in December. In all three cases air movement at 20 cm was reduced within the array. This reduction appears to become more significant as total air movement decreased. An explanation for this is the possibility that increased turbulence in the array counteracts the shielding effect of the array, causing surface air movement to approach what is occurring in the open. However, with reduced wind, calm conditions appear to be more prevalent within the array, as small gusts are apparently deflected by the collectors.

Figure A-1. Placement of micrometeorological instrumentation at the solar collector simulation site established in the desert near Phoenix, Arizona. Nine simulator panels each approximately 4 x 5 M (12' x 16') are evenly spaced 7.3 M (24') on center. Area around two panels was selected for intensive micrometeorological data collection.

Table A-1. Air movement within the solar collector simulator array compared to that in the control open desert site at 20 cm above ground surface.

<u>Dates (1977-78)</u>	<u>Site</u>	<u>Total Mileage</u>	<u>Miles Per Day</u>
Dec. 16-20	Array	78.1	19.5
	Open Desert	117.9	29.5
Dec. 20-30	Array	73.3	7.3
	Open Desert	147.4	14.7
Dec. 30 - Jan. 3	Array	7.8	1.95
	Open Desert	56.0	14.0

Cup-type anemometers are not very accurate at low wind speeds though, being unable to measure wind below 0.5 mph. Therefore the milder winds in the array may have gone unrecorded at times. Nevertheless, the data point conclusively toward a reduction of surface air movement caused by the collector arrays, at least for moderate to low wind velocities.

Air Temperatures

Air temperatures were monitored by constructing stands which contained maximum-minimum type thermometers at 10, 30 and 100 cm above the soil surface. These stands were placed in representative microclimates within the array (Fig. A-1), as well as in the control area.

In general, these preliminary data on air temperature (Table A-2) indicate an unexpected increase in air temperature within the array. This could be due to the blocking by collectors of long-wave radiation loss, which may be more significant in winter than in other months. Reduced air movement may also cause a heat buildup. The variation in temperatures between heights for each site does not agree with theoretical temperature profile curves, and so are difficult to explain with these limited data.

More intensive testing is needed in order to determine if indeed these solar arrays have the potential to create "heat islands", as these preliminary data indicate.

Soil Temperatures

An extensive network of Colman soil moisture blocks (which also measure temperatures) were placed in the soil in the collector array (Fig. A-1), and three blocks were placed in a similar soil type in the adjacent open desert site. The blocks in the array (Fig. A-1) were subdivided into three types according to the geometry of the array: immediately beneath collectors, shaded gaps, and sunny gaps. This enables an analysis of specific microclimates within the array. Although some areas of the gaps are alternately shaded, blocks 5-7 are almost always shaded, and blocks 8 and 9 were usually in direct sunlight. The temperature sensing element in a Colman block is a thermistor. Temperatures were taken at approximately 1500 hours.

Figure A-2 presents soil temperature data averaged for all sites in the array and at the control area for 5 and 30 cm depths. It can be seen that the control area is consistently warmer, particularly at the 5 cm depth, and

Table A-2. Averages of maximum and minimum air temperatures ($^{\circ}\text{C}$) taken periodically over a six week period in November and December at three different heights above the ground within the collector simulator array and in the open.

<u>Height</u>	<u>Site</u>	<u>Average Maximum</u>	<u>Average Minimum</u>
100 cm	Array	24.6	3.3
	Open Desert	21.5	5.3
30 cm	Array	24.0	3.05
	Open Desert	22.4	3.05
10 cm	Array	23.5	4.6
	Open Desert	20.0	3.5

Figure A-2. Average soil temperatures at 5 cm and 30 cm within the solar collector simulator array and at the central site.

is possibly more variable. Of interest is the close correlation of the array and control site at 30 cm depth ($r = .988$), indicating that the array may have little effect on diurnal soil temperature fluctuations at that depth, even though the control temperature is consistently higher. At the 5 cm depth, the correlation is not as evident ($r = .923$), since the control site appears to heat up rapidly as well as lose heat rapidly on cold days (e.g., Dec. 22).

Further evidence of the ameliorating effect of the array is the higher correlation of 5 and 30 cm depth in the array ($r = .956$) than in the open desert ($r = .855$). Heat flux rates into and out of the soil are apparently significantly higher in the open desert than in the array as a whole.

Figures A-3 and A-4 show soil temperatures within the collector array based on different microsites, as previously discussed, compared with the open desert. Of interest is the fact that at both depths the sunny gaps within the array have warmer soils than in the open desert. This is especially true at 30 cm, and supports our previous hypothesis concerning the possibility of microsites within the array receiving more intense radiation than would occur in the open desert.

The shaded gaps are consistently and significantly the coolest soils at both depths. Why these soils are so much cooler than the soils immediately under the collectors is not obvious at the moment, but further studies may provide an explanation. A possibility is that more intense shading occurs there, as the soils underneath the collectors receive direct sunlight in the early morning and late afternoon hours.

Soil Moisture

The Colman blocks used for soil temperatures also give values that can be converted into the percent of soil moisture available. Therefore the same microsites were sampled for soil moisture as for temperature within the array (Fig. A-1) and at three control locations.

1977 was one of the driest years on record in Phoenix, and so the only significant rainfall event during the fall occurred on October 28-29, in which the average rainfall from the two nearest weather stations was 7.1 mm (0.28"). This rainfall event was not of sufficient magnitude to completely wet the dry desert soils except in front of the collectors where runoff down the panels

Figure A-3. Soil temperatures at 5 cm depth at different micro-sites within the solar collector simulator array compared to soil temperatures in the control site.

Figure A-4. Soil temperatures at 30 cm depth at different micro-sites within the solar collector simulator array compared to soil temperatures in the control site.

occurred. As a result, blocks 8 and 9 in the sunny gap (Fig. A-5) were in the only microsite with a significant amount of soil water following the storm.

Another significant rainfall event did not occur until December 28, so between those rainfall events the relative rates of water evaporation from the soil was monitored by examining changes in soil water availability.

Figure A-5 shows that the areas under the collectors never received precipitation, and the 30 cm depth did not become wetted in the shaded gap. Of the blocks which did show soil moisture, those in the soils in the open desert appeared to dry out faster than did those in the different sites within the array, all of which appeared to lose water at approximately the same rate. Of interest is the fact that the soils in the sunny gap lost water much more slowly than did soils in the open desert, even though soil temperatures were higher in the gap. Surface air movement differences may be implicated. More significant rains with more thorough wetting of the site are needed before firm conclusions can be drawn regarding comparative evaporation rates.

Figure A-5. Soil moisture (percent available) at 5 cm and 30 cm at different microsites in the simulator array and at the control site. ☆U.S. GOVERNMENT PRINTING OFFICE:1979-640-014 4026 REGION NO. 4