# Natural Resources and Development in Arid Regions

edited by
Enrique Campos-López
and Robert J. Anderson

Westview Special Studies in Natural Resources and Energy Management

# Natural Resources and Development in Arid Regions

edited by Enrique Campos-López and Robert J. Anderson

Westview Press / Boulder, Colorado

*Westview Special Studies in Natural Resources and Energy Management*



Published in 1983 in the United States of America by
Westview Press, Inc.
5500 Central Avenue
Boulder, Colorado 80301
Frederick A. Praeger, President and Publisher

Library of Congress Catalog Card Number 82-63172
ISBN 0-86531-418-7

Composition for this book was provided by the editors
Printed and bound in the United States of America

# Contents



* Translated from Spanish

PART II. RESOURCE ASSESSMENT



* Translated from Spanish

* Translated from Spanish

* Translated from Spanish

* Translated from Spanish

* Translated from Spanish

# Preface

Almost one third of our planet is made up of zones with varying degrees of aridity. The origin, structure and dynamics of the arid systems are as diverse as the effects of man's activities upon these systems. These arid systems are shared by around 50 countries, forming a colourful mosaic of social, economic and environmental situations. Consequently, the development policies and the strategies for the utilization of natural resources present a wide range of manifestations. In some developed countries, such as the USA and the Soviet Union, arid zones constitute only a small part of their vast territory and their level of economic development permits the carrying out of large, well-organized resource projects with a high science and technology content. Other countries are not so fortunate - in many African countries their economic space completely coincides with intensely arid zones and their scarce social and economic resilience intensifies the effects of the sometimes dramatic droughts in accelerated desertification processes.

The dynamics of arid systems are the product and origin of the low availability of renewable resources - water, soil, flora and fauna - which leads to a low primary productivity of their ecosystems, or, in other words, a reduced capacity to fix, through basic biological mechanisms, the solar energy required for the organization of the ecosystem.

Modern science has notably increased the stock of knowledge about renewable resources and arid ecosystems but a great part of this knowledge is still to be used. Technological development has opened up new opportunities for increasing the availability and sustainability of renewable resources but there are many problems in the transfer and utilization of this technology. Despite its abundance, much of this knowledge and technology is difficult to integrate into the development of numerous arid regions, where the fragility of their natural environment associates with the lack of experience and institutional capacity to diffuse new technologies and to promote the innovations necessary for the integral management of natural resources.

The increasing complexity of the human activities and the development needs in marginal regions require new tools, as well as science and technology, to assist in the integral and sustained management of the resources.

In many countries, the arid zones constitute vital spaces for experimentation with new development strategies. The last few decades have seen the appearance of explosive urban growth associated with massive migration and in many countries the arid zones are experiencing the highest rate of urban growth. Industrial development and the concentration of services have attracted people seeking new development options. The new options for development should be based on a wide and profound knowledge of the availability, sustainability and increasing interdependence of the resources.

Scientific research will play an increasingly important role, but many procedures will need to be modified. It is essential to design new kinds of investigation, intimately linked to the planning and policy design processes for the use of natural resources. The traditional research and development schemes which were carried out during the past decades in numerous countries with arid zones should make way for new interdisciplinary research concepts - research which not only makes possible the generation and management of scientific and technological information but which promotes new procedures for social, environmental and economic assessment and which at the same time develops the regional capacities for policy design in the integral management of resource systems. Experimental research and development, assessment, and policy design are three interacting levels intimately linked as a social learning process.

Applied systems analysis should be incorporated within a social effort for widespread training in the planning of the utilization of the resource systems, seeking sustainability, equity in distribution, cost and productivity and opportunity in their availability.

A great effort will have to be made to integrate these multiple perspectives - technical, individual and institutional - as pointed out by Linstone. This book is a small effort towards this end. It contains the papers presented at a conference which attempted to integrate various perspectives of resource management. The conference "Renewable Resources and Regional Development: The Case of the Semi-Arid Zones" was held in Cocoyoc, Morelos, Mexico, in October 1980, was organized by the Applied Chemistry Research Centre (CIQA) of Saltillo, Mexico, and the International Institute for Applied Systems Analysis (IIASA) of Laxenburg, Austria, and was supported by the Mexican National Council for Science and Technology

(CONACYT) and the National Commission for Arid Zones (CONAZA). Distinguished scientists from various parts of the world and from Mexican agencies involved in the development of arid regions presented papers ranging in subject from the general climatic framework and diverse techniques and concepts in the exploitation of natural resources to the discussion of methodologies for technology assessment. The aim is to present a comprehensive view of aspects relevant to the management of renewable resources.

*Enrique Campos-López*
*Robert J. Anderson*

# Acknowledgments

The conference was financed by the National Commission for Arid Zones (CONAZA) and the National Council for Science and Technology (CONACYT) and we thank them for their support.

The editors would also like to thank Sharon Rivera for typing the manuscripts and for editorial assistance.

*E. C.-L.*
*R.J.A.*

# Part I

# Arid Climates

# 1
# Semi-Arid Regions in the World

*William G. McGinnies*

## INTRODUCTION

It is difficult if not impossible to arrive at a satisfactory and universally accepted terminology for arid climates. In addition to differences among scientists as to names that might be applied, the literature is cluttered with such terms as sub-humid, semiarid, semidesert, and the recently proposed hyper-arid.

Although my assigned topic is to discuss the semiarid regions, I shall have to admit that I am opposed to the use of semi whether it refers to arid or deserts. If a climate is only semi or half arid what is the other? I think nearly everyone would object to calling it half humid.

## CLASSIFICATION OF ARID CLIMATES

For the purpose of this paper, I propose we begin our classification following Köppen's primary division of climates into humid and dry, the division between them being determined by a balance between precipitation and potential evapotranspiration. This is also an important dividing-line in soil development, one that separates pedalfers and pedocals with precipitation on the humid side penetrating below the root zone, but not on the arid side, resulting in the accumulation of carbonates or the development of saline conditions.

The next step is to divide the dry or arid climates into divisions that will not be too much in conflict with common usage. To do this I shall start with the term desert, which has been used in different ways by different scientists. There has been a conflict, for instance, between the authorities of Africa and Asia and those in other countries. The former believe that the term desert should be applied only to areas with less than 100 mm of precipitation and with periods in excess of a year without precipitation. Scientists in other countries, who are inclined to take a broader view, set the upper boundary with precipitation of 250 mm or more.

To bring these divergent views together I suggest that we follow the concept of Forrest Shreve, who suggested that the term desert be used in much the same way as we use the term forest. He pointed out that the term forest is used to cover a wide range from needle-leaf or xerophytic ever-green forests, through broadleaf deciduous forests to tropical rain forests. Forests, though varying greatly in their vegetational composition and climatic relationships, are held together by their dominant life form.

Similarly, common denominators can be found for desert plant communities by using the suggestions of H.L. Shantz, who grouped plants as drought escaping - the ephemerals; drought evading because of small size wide spacing and reduced leaf surface; drought resistant by storing moisture; and drought enduring by being able to remain alive during extended periods without available moisture. These basic characteristics of desert plants may be considered the common bond of the desert.

The desert as a biological entity is held together not only by physiognomic characteristics, but also by plant family relationships. The list of typically desert families includes Zygophyllaceae, Cactaceae, Euphorbiaceae, Chenopodiaceae, Amaranthaceae, Agavaceae, Asclepidaceae, Crassulaceae, Capparidaceae and others. Grasses are largely absent with the notable exception of Panicum turgidum and some aristidas in Africa and Asia, spinifex grasses in Australia, the Hilarias in North America and a few other drought enduring species.

Following a classification by Le Houerou (1979) in a recent International Biological Program publication, I suggest we accept the term Saharan to designate that portion of deserts with less than 100 mm precipitation. Other portions of deserts with greater precipitation might be designated as succulent deserts, shrub deserts, or arborcescent deserts, the last being typical of the Upper Sonoran Desert near Tucson, Arizona, with precipitation ranging up to 300 mm.

There is no insurmountable reason why we could not apply the term Saharan to the very dry conditions around Yuma, Arizona and Death Valley, California in the United States of America. Conditions, including low and variable precipitation, scarcity of vegetation, and the presence of sandy areas, are much the same as they are in the Sahara.

I next propose we use the term steppe as conceived by African and Asian scientists to include all vegetation types within what has been designated as the semiarid region. Toward the drier side of this region there seems to be little difficulty in the application of this term except that North American scientists have preferred to limit it to regions characterized by herbaeceous types of vegetation.

As the humid zone is approached, however, there is a diversity of vegetation that does not fit into the definition of steppe. Here I am referring to matorral, chaparral, woodland, savanna, and other woody plant communities. As a broad umbrella to cover these I suggest the term savannarral, representing its major vegetative components. Because placing all these woody communities under the same umbrella may raise questions as to interrelationships, perhaps more study will suggest that a further breakdown would be advantageous.

## PHYSICAL LIMITS OF ARID SUBDIVISIONS

On the basis of these suggestions the physical limits as proposed by Thornthwaite and used as the basis for Meigs' maps would still apply with values of -20 to -40 (precipitation/potential evapotranspiration) for steppe and >-40 for desert. The savannarral would extend into the 0 to -20 category, but the upper portion of the so-called sub-humid would possibly include dry forests and dry grass-lands, that would give way to deciduous and other humid forests or prairie grasslands after crossing the line into humid climates.

A recently published MAB-UNESCO map divides the arid world into semiarid, arid and hyper-arid with an extension into sub-humid. In general I am in agreement with delineation of these divisions, but would apply the terms steppe for semiarid, desert for arid, and include hyper-arid as a Saharan desert subdivision of desert. The text accompanying the map lists my savannarral species as extending into the sub-humid noting that the sub-humid is "not bordered toward wetter zones because the transitions are extremely variable."

TABLE 1.
Subdivisions of Dry Climates

| | | |
|---|---|---|
| | <u>Desert</u> | |
| Saharan | | Arborescent |
| | <u>Steppe</u> | |
| Shrub | | Mixed |
| | <u>Savannarral</u> | |
| Matorral<br>Chaparral | | Savanna<br>Woodland |

Mapping is based on precipitation/evapotranspiration (P/ETP) ratios, largely on the contributions of Thornthwaite and Penman. The upper limit of the desert as I have defined it is 0.20, the limits of the steppe 0.20 to 0.50, and the savannarral in the 0.50 to 0.75 category. This still leaves a void between 0.75 and 1.0, representing a transition from arid to humid.

While precipitation alone is considered to be a less exact indicator than indicators based on evapotranspiration, it is often used as a guide to arid climates subdivisions. As approximate values, precipitation from 0 to 250 mm might represent desert conditions, 250 to 500 mm steppe, and 400 mm to 600 mm savannarral. These figures might be reduced by 100 mm for Mediterranean climates with winter precipitation and increased by 100 for regions with hot season precipitation.

Based on the above limits for arid land subdivisions, the Saharan would occupy about 4 percent of the total land of the world, the desert (including the Saharan) 19 percent, and the steppe 15 percent. At this time there is not sufficient information on which to base the areal extent of the Savannarral.

The homoclimatic maps developed by Pevril Meigs that have been the standard for showing the distribution of arid climate during the past 25 years, show three levels of aridity designated semiarid, arid, and extremely arid. In addition, by a system utilizing letters and numbers, the seasonality of precipitation and mean temperature of the coldest and warmest months are indicated.

The MAB-UNESCO map portrays essentially the same information by the use of colors. The resulting rather psychedelic combination may appeal to some and not to others. I find it difficult to keep in mind all the color combinations and to associate some of the combinations with degrees of aridity. For example the deserts of North America are shown in four different colors, although three of the deserts have Larrea in common. In my opinion it would be better to show deserts as the common denominator and temperatures the variable.

I also question the use of the term sub-humid. If 0.50 marks the wet side of semiarid, would it not be logical to designate higher values as representing semihumid, and to designate values above 0.75 (which is the upper limit of MAB-UNESCO subhumid) as representing the sub-humid?

## DIVISION OF ARID SUBDIVISIONS ON A BIOLOGICAL BASIS

I think perhaps a better idea on the division of dry climates as used presently would be to use a biological basis. So far we have allowed mathematically minded individuals to set the boundaries on what amounts to an empirical basis. Wouldn't it be better to make the divisions on a biological basis? In which case I would set up desert as a region where grazing is not economically feasible without too much danger to the environment. I would lower the upper boundary of steppe and make it the region where grazing is the dominant land use. Then I would set up a farming region that would overlap the present steppe or semiarid extending into my semi-humid area to include the agricultural small grain crop area that is presently the bread basket of the world. It would also include much of the vineyard, orchard, and vegetable land. It is an area of high but hazardous crop production and vulnerable to misuse but which, at the same time, offers the greatest economic returns from improved land use practices. Above this, on the humid side, would be the crop, pasture and forest region, possibly including tropical agriculture.

## STEPPE CHARACTERISTICS

The vegetation of the steppe is dominated by many species of grass and grasslike plants, forbs and shrubs. Members of Leguminoseae and Rosaceae are prominent, also assorted members of the Compositae, notably species of Artemisia.

The steppe landscape is commonly flat and monotonous, sometimes rolling, rarely hilly. The steppes of Siberia, Outer Mongolia, the Sahel, Veld plateaus of Southern Africa, the dry grasslands and upper brushlands of South America, the grassy high plains and shrubby Great Basin in North America (above the desert) are examples. When mountains intrude, the increased moisture at higher elevation results in a more humid type of vegetation; when the plain is dissected by geologic or recent erosion, a more xerophytic vegetation is found.

Soils are dominantly immature, light in texture, with low clay and humus content. Salinity is of common occurrence and carbonate layers may be formed because of shallow water percolation.

The daily and yearly range of temperature is great, humidity is relatively low, and strong and persistent winds are common. Steppe lands, once the home of many large wild herbivors, are now grazed mostly by domestic livestock including cattle, sheep, goats, horses, burros and camels. The steppes are the traditional home of the nomad, gaucho and cowboy. The grazing of livestock is the dominant agricultural enterprise, but rainfed farming is carried out in areas of favorable precipitation and where additional moisture is made available from improved watersheds. Small cereals, sorghums and other drought-enduring species are the basis of sedentary agriculture in many localities.

The savannarral is dominated by woody plants even though they are not always the most abundant members of the community. Quercus is an outstanding component, but is joined by a host of other plants including xerophytic Gymnosperms, members of the Rosaceae, Leguminosae, Rhamnaceae and other sclerophyllous trees and shrubs. It is not always a climax formation but may owe its existence to forest degradation or to the invasion of grasslands by woody species. Livestock grazing is a common land use, often with disastrous results. Fire is a destructive factor in maintenance of woody components. Under better conditions the savannarral supports vineyards and orchards along with assorted non-woody crops.

## LOCATION AND CLIMATE OF STEPPE REGIONS

The steppe regions of the world are mostly adjacent to and partly surrounding desert areas. On the basis of temperature they can be divided into four groups:

1. those designated as 01, 02, 03 and 04 are classed as cold steppes with cold winters and frequent freezing;
2. those designated as 12, 13 and 14 as cool steppes with cold winters;
3. those designated as 23 and 33 as warm steppes with mild winters and warm summers;
4. those designated 24 and 34 as hot steppe with warm usually frostless winters and hot summers.

The steppe areas of northern Africa (Figure 1) north of the Sahara are cool to warm with winter precipitation. South of the Sahara they are warm to hot with summer precipitation. The steppes of southern Africa are generally warm with summer precipitation.

The steppes of western Asia (Figure 2) are subject to winter warming influences and winter precipitation of a Mediterranean climate but still range from cold to cool. The steppes of the Indian subcontinent are hot with mild to warm winter temperatures and summer precipitation.

The steppes of central and eastern Asia (Figure 2) generally have cold and often severe winters. Summer temperatures however are usually warm.

The steppes of Australia (Figure 3) generally have mild winters and warm summers except in the northern part. In this region summers become hot.

The northern steppe areas in South America (Figure 4) have mild winters and warm summers. In the south winters become cool to cold, but the summers remain warm. Rainfall generally occurs in summer. The Brazilian steppe locally called caatinga has mild to warm winters, warm summers and summer rainfall, all being conditions favoring aridity.

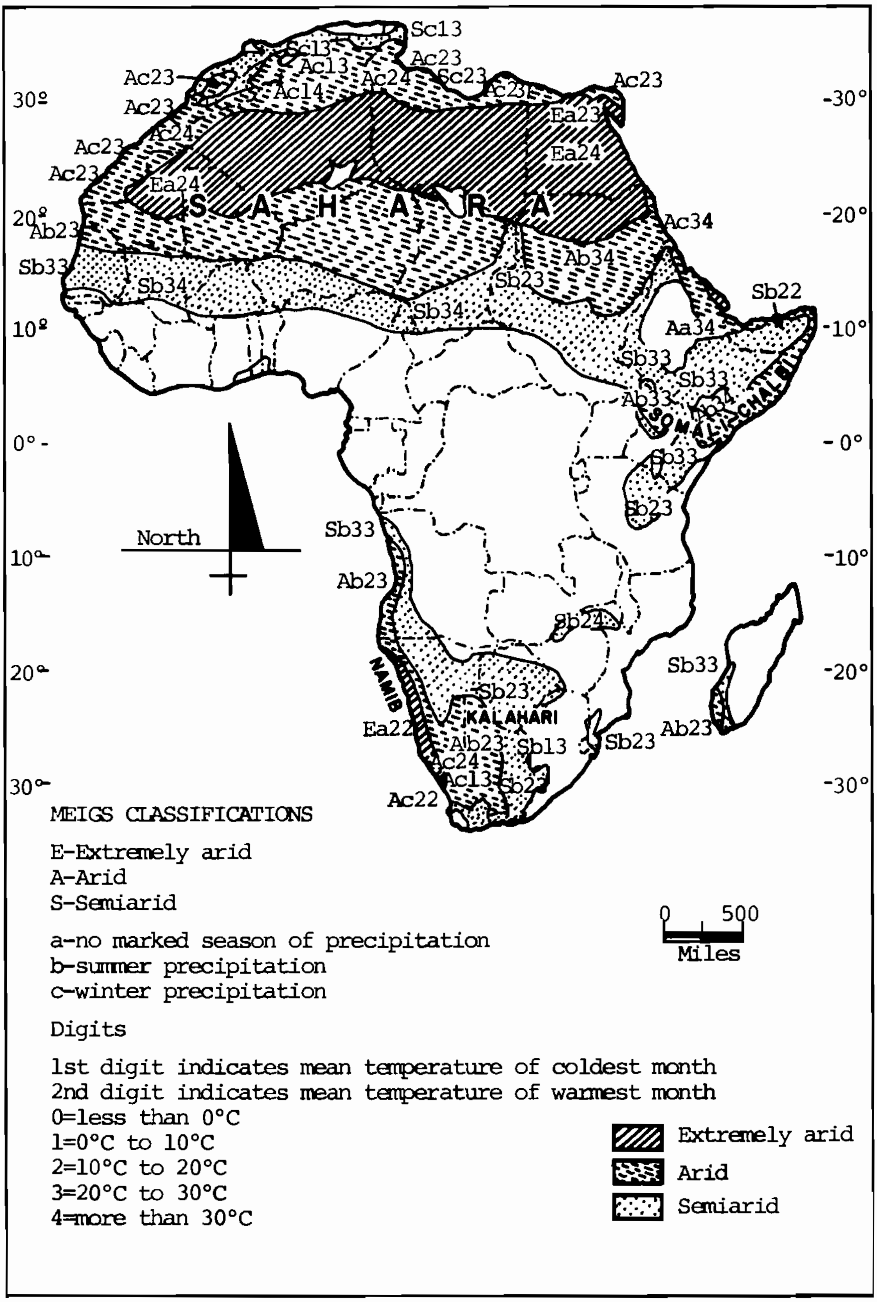



FIGURE 1. Arid lands of Africa (after Meigs)

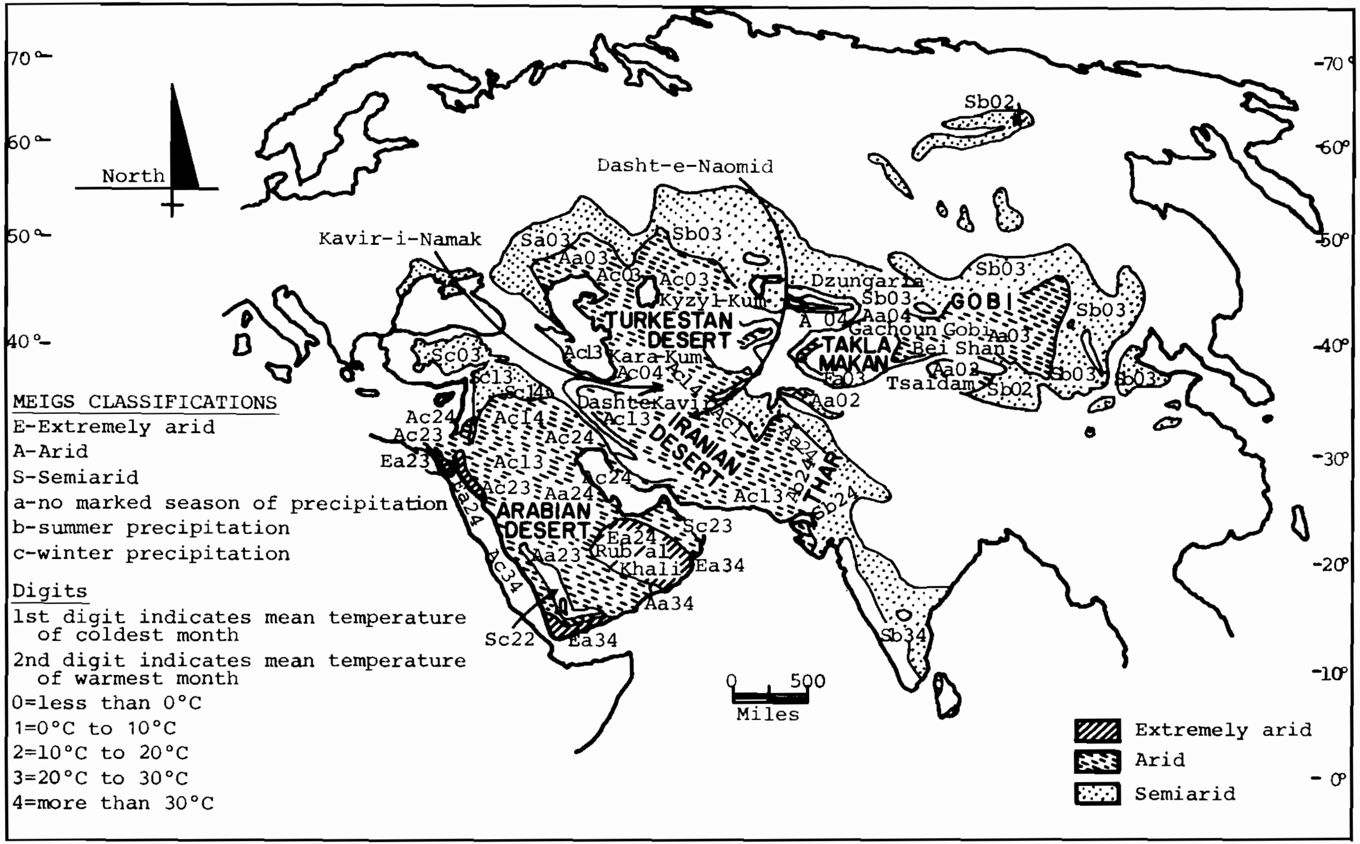



FIGURE 2. Arid lands of Asia (after Meigs)

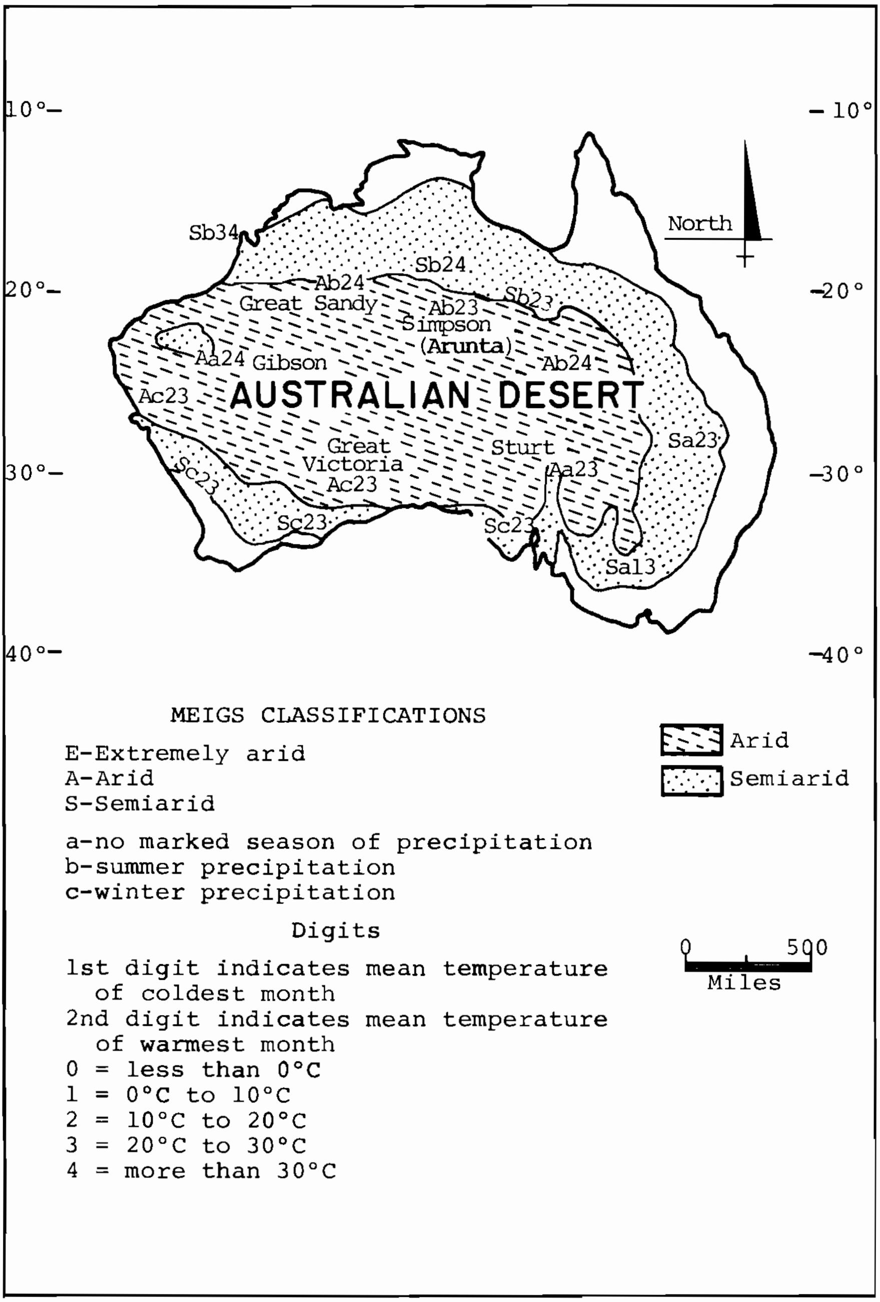



FIGURE 3. Arid lands of Australia (after Meigs)

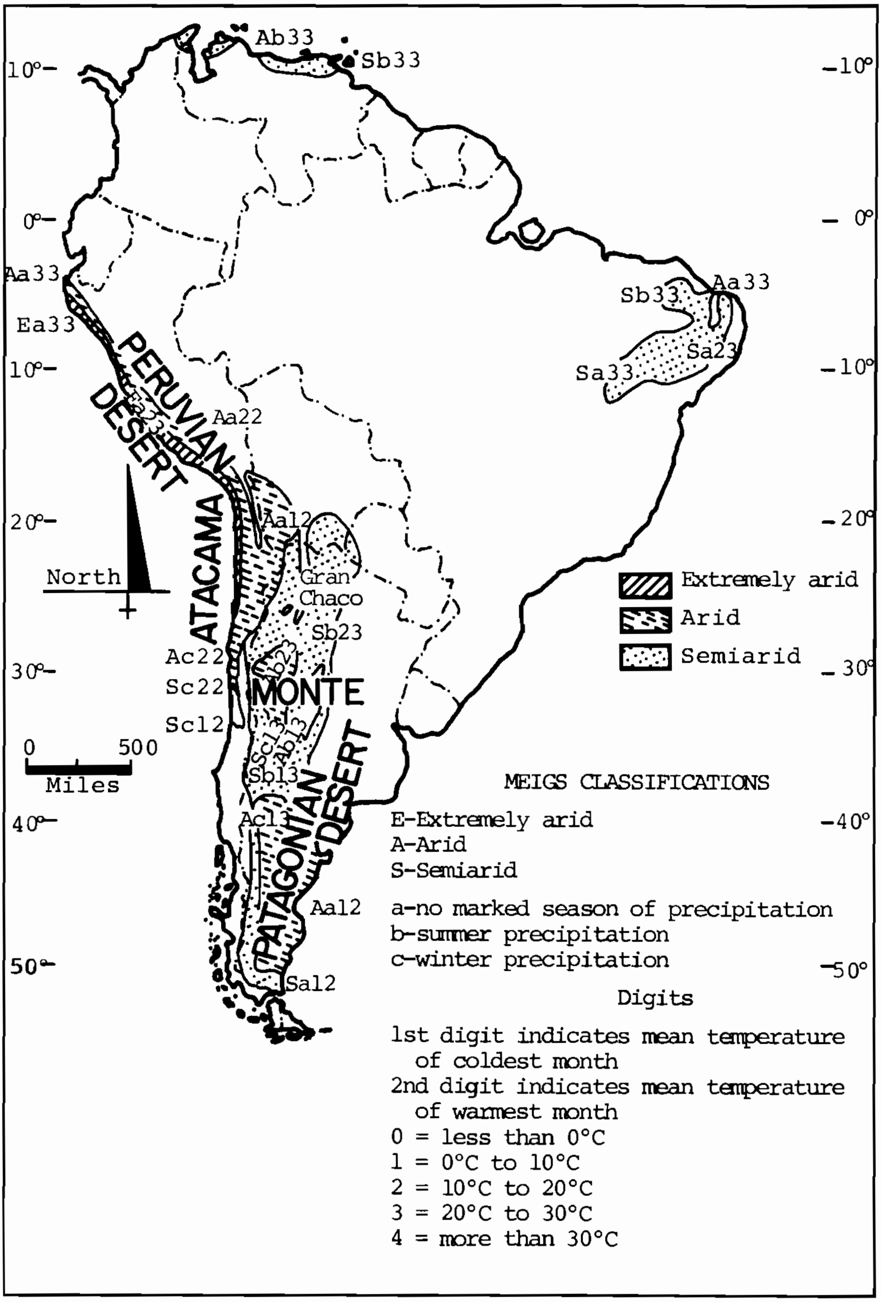



FIGURE 4. Arid lands of South America (after Meigs)

The steppes of North America (Figure 5) exhibit a variety of climates. These range from cold winters and a short growing season in the north to warm steppes with mild winters and warm summers in the south.

## IMPROVEMENT VERSUS DETERIORATION OF STEPPES

A major reason for the identification and description of arid regions is to provide a basis for improvement, especially where deterioration has occurred. Desertification has been the catch word of the seventies, but I have mixed feelings about the use of the term. First I am not sure it expresses accurately what is happening. It might be more accurate to start with humid climates and note that through deterioration, sub-humidification takes place; in the subhumid region, there is semi-aridification; and in the semiarid region there would be true desertification, to be followed by hyper-desertification - and that would be the end. While it is possible for complete desertification to occur in the sub-humid regions, even there it is by stages rather than happening in one step. The other thing that bothers me is that desertification points out the problem but offers no solution.

I believe that two concepts used by forest and range scientists could well be more widely used in dealing with problems of deteriorating environments: these are the problems of "site" as an evaluation of potentiality, and "condition and trend" as an evaluation of processes currently taking place.

Site is the term applied to an area considered as to its biophysical factors with reference to its producing powers for forest, range, or cultivated crops. It represents the interaction of climatic, edaphic and biotic factors. Site quality is an expression of the potential productivity of an area. It may be high or low and expressed either in terms of present conditions or potential capacity.

Condition is the present state of the site in relation to either climax or potential optimum plant community for the site. The latter might include introduction of species not belonging to the natural climax or the establishment of a stable vegetation such as grassland in a forest climax area, or the conversion to crop production.

Trend is the change in condition of the site or resource production observed over time. The terms <u>up</u>/<u>down</u> may be applied to describe trend.

These concepts could be used on a worldwide basis. Downward trend as a substitute for desertification could be shown on large scale maps, while site and its condition and trend could be expressed for local areas that might consist of variations in soil or use. The advantages of this system are that it identifies both regional and local

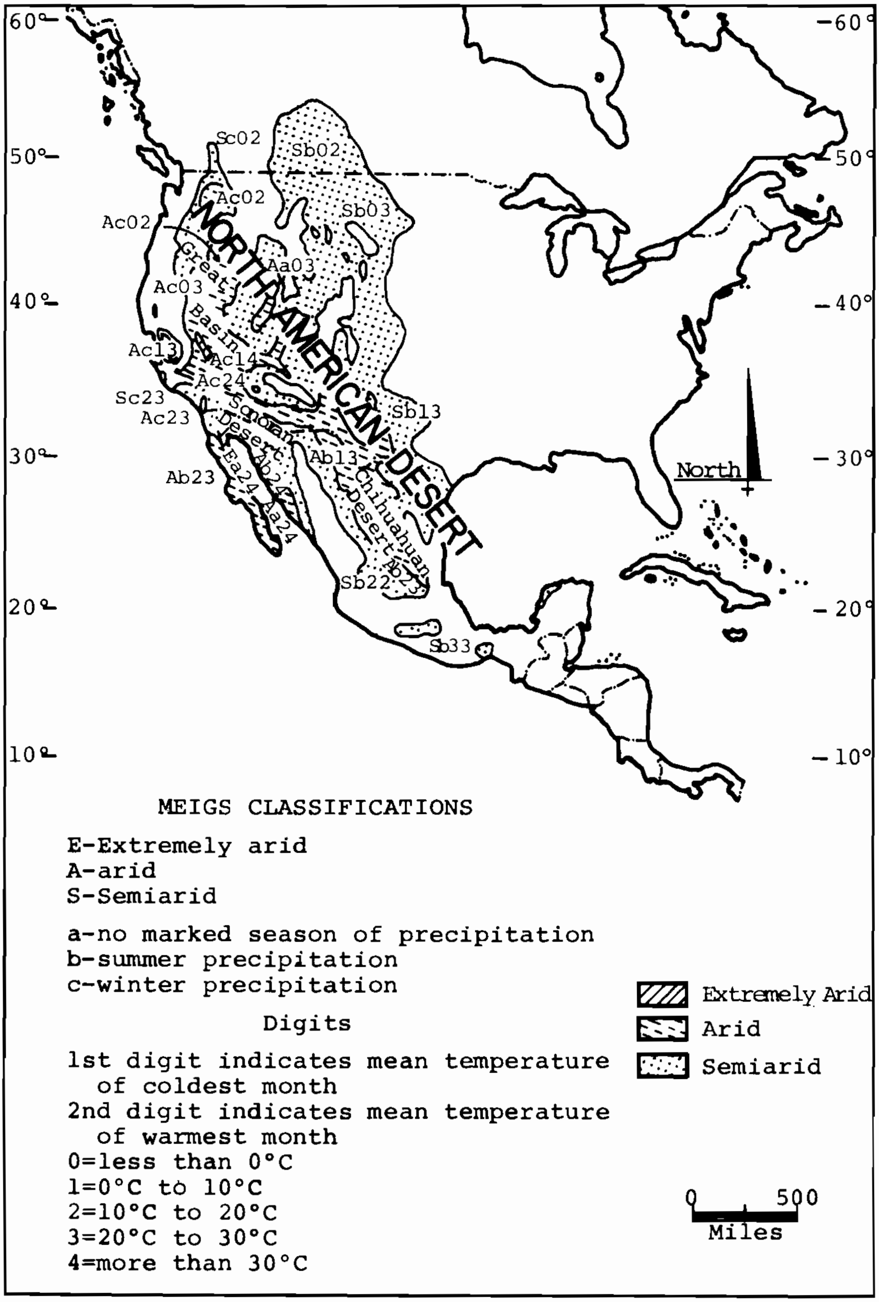



FIGURE 5. Arid lands of North America (after Meigs)

conditions together with a positive evaluation not only of the amount and rate of deterioration but also potentialities for which goals may be set.

## BIBLIOGRAPHY


Le Houerou, H.N., North Africa in R.A. Perry and D.W. Goodall (eds.), Arid Land Ecosystems: Structure, Functioning, and Management, International Biological Program, Volume 1, Cambridge University Press, (1979)

McGinnies, William G., Goldman, Bram J. and Paylore, Patricia,(eds.), Deserts of the World: An Appraisal of Research into their Physical and Biological Environments, University of Arizona Press, Tucson, (1968).

McGinnies, William G., General Description of Desert Areas in Perry, R.A. and Goodall, D.W. (eds.), Arid Land Ecosystems: Structure, Functioning, and Management, International Biological Program, Volume 1, Cambridge University Press, (1979).

Martonne, E. de, Nouvelle Carte Mondiale de l'Indice d' Aridite, Annales de Geographie 51 (288): 242-250, (1942).

Meigs, Peveril, World Distribution of Arid and Semi-Arid Homoclimates, in Reviews of Research on Arid Zone Hydrology, Arid Zone Programme, 1, UNESCO, Paris, (1953), p.203-209.

Nir, Dov, The Semi-Arid World: Man on the Fringe of the Desert, Longman Inc., New York, (1974).

Petrov, M.P., Deserts of the World, translated from the Russian by the Israel Program for Scientific Translations, Jerusalem, John Wiley and Sons, New York, (1976).

Thompson, R.D., The Climatology of the Desert World, University of Reading, Dept. of Geography, Geographical Paper 33, (1975).

Thornthwaite, C.W., An Approach toward a Rational Classification of Climate, Geographical Review 38, 55-94, (1948).

UNESCO, Map of the World Distribution of Arid Regions (Scale 1:25,000,000) accompanied by explanatory note, MAB Technical Notes, 7, UNESCO, Paris, (1979).

U.S. Dept. of Agriculture, Climate and Man, Yearbook of Agriculture, U.S. Government Printing Office, (1941).

Walter, H., Vegetation of the Earth, translated from the 2nd German edition, English Universities Press, London, (1973).

# 2
# Mexico's Semi-Arid Zones*

*Fernando Medellín-Leal*

## LOCATION

The semi-arid zones of Mexico extend in a discontinuous form over approximately 580,000 $km^2$ of the country's surface. The largest such zone is a natural prolongation of the Sonoran and Chihuahuan Deserts. With the exception of the northern extreme of the Baja California peninsula, this zone lies within one continuous strip which starts at the coast of northwest Baja California Norte and continues clockwise partially covering, in the U.S.A., the states of Arizona, California, Nevada, Oregon, Wyoming, Idaho, Colorado, New Mexico and Texas and, in Mexico, the states of Tamaulipas, Coahuila, Nuevo Leon, San Luis Potosi, Guanajuato, Zacatecas, Aguascalientes, Durango, Chihuahua and Sonora, ending up in the ocean and appearing again as a spot in the southern extreme of the Baja California peninsula.

For practical and political purposes, the Mexican portion of this strip may be divided into four areas. They include: one area which occupies the far end of Baja California, with climate Sb23 according to Meigs' classification; one wedge with climate Sc23 in the extreme northwestern part of Baja California, whose classification as a semi-arid zone is disputable; and one strip of irregular north-south direction in the center of the state of Sonora. The three above-mentioned areas are part of the Sonoran Desert. The remaining semi-arid area extends from the Chihuahuan Desert and starts in the northwest of the state of Chihuahua with a climate of Sb13 and, proceeding in a counterclockwise direction, penetrates the northeast of Sonora in a narrow tongue shape, from where it almost immediately returns to Chihuahua in form of a belt, then turning toward the southeast and changing to Sb23 more or less where Durango starts, continuing in Durango's eastern portion, passing to the east of Zacatecas, north of Aguascalientes, west of San Luis Potosi, extreme northwest of Guanajuato, southwest of Nuevo Leon, west of Tamaulipas, where it becomes Sb24.

*Translated from Spanish

Mexico also has many smaller semi-arid zones. Following the bend of the continent, toward the south, we find the semi-arid regions of Queretero and Hidalgo. Both are situated more or less in the center of their respective states, have a climate of Sb23 and - due to their biogeographic characteristics - should be considered as satellites of the Chihuahuan Desert.

More to the south, the Neovolcanic Axis crosses the country from east to west between the parallels 19 and 20 north, functioning as a good bio-geographic barrier that produces the greatest differences between the semi-arid zones situated above and below it.

The east of Puebla, a small fraction of the western part of Veracruz, and the northwest of Oaxaca make up the Pueblan semi-arid zone with a predominantly Sb23 climate. Southwest of this the upper part of the Balsas River Basin forms the semi-arid zone of Guerrero with a climate of Sb34 and includes portions of the states of Guerrero and Michoacan, although many authors do not agree that the semi-arid condition goes as far as this latter state. To the southeast of the semi-arid zones of Guerrero and Puebla, and corresponding more or less to the lowest part of the Tehuantepec River Basin, there is the semi-arid zone of Oaxaca with a climate of Sb33.

It is very possible that originally the zones of Puebla, Guerrero and Oaxaca were connected and formed a continuous semi-arid region. However, there is not enough evidence available to fully prove this. The main difficulties in proving this are that one part of this possible connecting territory is barely accessible, and another part has long suffered strong demographic pressures and is completely disturbed. These difficulties make it impossible to establish the extent to which the present semi-aridity is natural and the extent to which it has been induced by man.

In the east of the Republic and occupying more or less the extreme north of the Yucatan Peninsula, there is the small Yucatan semi-arid zone with a climate of the Sa33 type.

## CAUSES

The semi-arid zones of the Sonoran Desert find their origin partly in the cold ocean current that comes down from the pole more or less parallel to the Continent, partly as a consequence of climatic effects of the Tropic of Cancer, which crosses one of these zones, and partly because of the orographic shadow of the mountains that run along the Peninsula and of the Sierra Madre Occidental situated to the east of Sonora. The semi-arid zones adjoining the Chihuahuan Desert are partially induced by tropicality - since the Tropic crosses them in Zacatecas, San Luis Potosi and Nuevo Leon - and are also partly due to continentality - since they border the center of the widest part of the country. Mainly, however, the semi-arid zones are due to orographic shadow - since they are surrounded by both the Sierras Madre and the Neovolcanic Axis.

The existence of the zones of Puebla, Guerrero and Oaxaca also can be attributed predominantly to the orographic shadow. In contrast, the Yucatan zone originates from a completely reversed situation, since, as it lies along the coast line at the end of a large plain almost at sea level, the humid and hot winds circulate freely without depositing precipitation.

## PHYSIOGRAPHY

Of the zones of Baja California, the portion at the extreme northwest of the Peninsula - which we consider semi-arid but which is classified as sub-humid by other authors (e.g. Garcia-Castaneda (1)) - is characterized as being the only one in the country with rains that predominate in winter, a characteristic that separates it from all the others. Many kinds of rocks can be found, forming a mountainous countryside, with some old peneplains inclined toward the ocean. There is a well-formed drainage system, but the flow is intermittent.

The Baja California region of the Cape is mainly formed by metamorphic lands that originate in Mesozoic intrusive rocks and Terciary volcanic rocks which have produced Terciary-Quaternary sediments. Even though the drainage could be at least potentially very active, given the irregular topography, precipitation is very scarce.

The semi-arid zone of Sonora penetrates into the country more or less in the center north of the state and continues over the western spurs of the Sierra Madre Occidental. Formed principally by sedimentary Terciary rocks overlaid with Terciary-Quaternary sediments, it is formed by many slopes and ephemeral creeks. To the northwest it comes together with the truly arid zone and to the south with vast irrigation installations that disguise the real boundaries. The drainage, when there are flows, is generally good.

The semi-arid zone that borders on the Chihuahuan Desert, being the largest in the country, presents the most complicated physiography. Enclosed by both Sierras Madre and the mountainous zone that to the north of the Neovolcanic Axis extends over the entire center of the Republic, this zone exhibits a varied topography, changing from vast plains to rolling hills and truly rugged zones. The Sierra of Parras crosses it, now in the real semi-arid zone, from east to west, almost connecting both Sierras Madre and dividing the Chihuahuan Desert into two parts. Because of its bad accessibility, this sierra was practically unknown to science until a short time ago, and a large number of authors have excluded it systematically from their studies and do not even consider it to be an arid or semi-arid zone. However, due to its very old origin, it could possibly be one of the zones of greatest scientific importance.

The geological substratum of the Chihuahuan semi-arid zone is extraordinarily varied: it is possible to find deposits from the superior Paleozoic to recent Paleozoic: igneous, metamorphic and sedimentary. However, it consists mainly of sedimentary rocks from the Mesozoic, mainly Cretacic, and igneous rocks from the Terciary and Quaternary.

The hydrological system belongs to the Atlantic Basin via the Gulf of Mexico and is only well-developed in the northern part along the River Bravo and its tributaries, mainly the Conchos. Perhaps the drainage was much more active in the past and comprised all or almost all the zone. However, due to a greater aridity at the end of the last glaciation, the collecting capacity contracted and left some interconnected basins with partial drainage which finally lead into a closed basin, as in the case of the Aguanaval-Nazas system, and also some strictly endorreic basins like the many so-called "bolsones" that are so characteristic of this semi-arid zone. These "bolsones" are closed basins in the lowest parts of which the flows concentrate, when they appear, causing the formation of ephimeral lagoons which are usually salty.

With respect to the two satellites of the Chihuahuan Desert, the one in Queretero occupies a depression and the one in Hidalgo a valley between mountains. They belong to the high parts of the Panuco River Basin and are sited on Mesozoic limestone, interrupted here and there by Terciary avalanches, generally rhyolitic and Cenozoïc deposits originating from the oldest rocks.

The Puebla semi-arid zone is also sited on a geological mosaic, but Cretacic deposits dominate with occasional outcrops of superior Paleozoic, upon which rest the logical Cenozoic sediments. There is practically no drainage and therefore salt deposits are frequent, although the basin is not really closed as it belongs to the Papaloapan system through the Salado or Tehuacan Rivers.

The semi-arid zones of Guerrero and Oaxaca occupy areas on bedrock, classified in principle as "Paleozoic Metamorphic" in contact with "sediments of the Cenozoic", which actually does not mean anything (2). As they form part of open basins - the Balsas and Tehuantepec River Basins - the drainage is good.

The very small Yucatan semi-arid zone is a plain, almost at sea level, on Terciary calcareous sediments and is practically arreic, despite deep natural wells here and there.

## CLIMATE

The range of meteorological conditions that characterizes the Mexican semi-arid zones is mainly determined by the altitude and the latitude, which act irregularly, favoring the variety of climates. As far as temperature is concerned, for example, Cape San Lucas in Baja California Sur at 22°53' latitude north and at sea level presents an annual average temperature of 24.4°C, whereas a little further south the City of Zacatecas at 22°47' latitude north presents an annual average temperature of 13.5°C due to its altitude of 2612 meters above sea level.

Generally speaking, only the semi-arid part of Baja California Norte (Ensenada 16.7°C) and the eastern belt of the Chihuahuan Desert can be considered temperate, with annual average temperatures below 18°C and the lowest annual average temperature registered in this zone being 10.2°C in Valerio, Chihuahua. However, this is not a universal characteristic and depends on the altitude. The same applies to frost which does not occur in all our semi-arid zones, but where it appears it can do so as early as September or as late as May.

The rest of the Mexican semi-arid zones can be considered hot, reaching their maximum temperature in the Yucatan zone with an annual average temperature of 25.4°C.

The annual average precipitation in Mexican semi-arid zones varies between 259 mm in Casas Grandes, Chihuahua, and 684 mm in Sochipila, Guerrero. In all of the zones the rainy season is in the summer except in Baja California Norte where rainfall is principally in winter. Precipitation in all zones exhibits the characteristics of rain in arid zones, including great variations from one year to another, long periods of drought, very short torrential rains, sudden floods, etc. Fog can be observed quite frequently in Baja California but is scarcer in other areas. Snowfalls occur only in the western part of the Chihuahuan Desert and have a gradient north-south which ranges from about 10 light snow falls per year down to one snowfall every 20 years. Hail may or maynot occur, depending on the zone, and where it occurs can repeat itself up to four times a year. Occasionally it can be very destructive.

The rainy season starts around May, reaching a first climax in July. August tends to be a more or less dry month, but in September there are new showers resulting from the hurricanes in the Caribbean, which usually make this month the wettest. However, as already mentioned, there are great variations from one year to another. The driest months are generally November, February, and April. It rains lightly in December, January and March. These rains are related to the advance of polar masses towards the south.

There are eight climatic types according to the classification by Meigs: Sa33, Sb13, Sb14, Sb23, Sb24, Sb33, Sb34 and Sc23. It should be noted that the climate Sa33 has been assigned to the semi-arid zone of Yucatan because, even if it is true that the largest quantity of rain falls in the months of June and September, it is also certain that without ceasing to be semi-arid it rains throughout the year at the most unexpected moments. We note this specifically because some other investigators may consider that this zone has a climate of the type Sb33, and in this case there would be seven different climatic types.

If instead of Meigs' system, Köppen's system - which was modified by Garcia (3) - were applied, the existing climatic types in the Mexican semi-arid zones would be $BS_0$ and $BS_1$, each of them with its innumerable subdivisions. According to DETENAL (4), the $BS_0$ climate is the driest of the two, with a ratio of precipitation to temperature of less than 22.9. It covers 280,000 $km^2$, equivalent to 14% of the surface of the country. On the other hand, the climate $BS_1$, which is the less dry of the two, has a ratio of precipitation to temperature higher than 22.9 and covers 320,000 $km^2$, or about 16% of the country. Both climates together cover 600,000 $km^2$, or 20,000 $km^2$ more than the semi-arid zone land area of 580,000 $km^2$ reported at the beginning of this paper. This extra 20,000 $km^2$ includes parts of Sinaloa, Jalisco, the state of Mexico, Tlaxcala and the Federal District, besides the areas that have been enumerated.

It is important to reiterate the differences that result from the application of two different climatic systems, because they are a true reflection of the enormous subjectivity that goes along with all our concepts when we speak of arid and semi-arid zones, especially of the latter.

## SOILS

The soils of Mexico's semi-arid zones have not been sufficiently studied. In an attempt made by us in earlier years to put together the available and creditable information in order to construct a synthetic map, we found that the surface that would have to be left blank was greater than the one for which studies are available. Anyway, the most frequent soils are the Aridisols, Lithosols, Inceptisols, Molisols and Alphisols. The saline and sodic soils, even though they are less frequent, cover small areas in some depressions.

## VEGETATION

The innumerable types of vegetation that have been described for semi-arid zones in Mexico (5) can be reduced to seven basic types: desertic microphilic brush, desertic rosetophilic brush, succulent brush, hillside brush, grasslands, chaparral and pine-oak forests. The philogenetic relationships of the flora of the semi-arid zones are predominantly neotropical, but in a much smaller proportion there are also autoctonous, pantropical, pandesertic and neartic elements.

## Desertic Microphilic Brush

This is possibly the type best adapted to the conditions of aridity, and, therefore, is the background curtain of all the arid and semi-arid zones of Mexico. It is mainly formed by shrubby species with small leaves or foliage, frequently resinous. The characteristic genera are: Larrea, Flourensia, Celtis, Rhus, etc. Sometimes, if the humidity of the subsoil permits, Prosopis is present, forming clumps of Mesquite shrubs; and sometimes over large extensions the most notable element of the countryside is the Chinese Palm (Yucca).

## Desertic Rosetophilic Brush

This is also very well adapted to aridity and especially to good drainage. Therefore it can be found most frequently in calcareous highlands, but, since it cannot tolerate the cold very well, it is less ubiquitous than the microphilic shrub and more concentrated toward the south and toward low sites. The typical genera of this brush are: Agave, Yucca, Hechtia, Dasylirion and large cacti which tend to the spherical shape.

## Succulent Brush

This is characterized by the abundance of cacti and other fleshy plants, sometimes in very dense groups. It is an entirely plastic type of vegetation which apparently, and by anthropogenic action, is invading sites in which it did not exist originally, in such a way that is is now difficult to determine its natural distribution. The genera are: Opuntia, Carnegia, Lemaireocereus, Neobuxbaumia, Myrtillocactus, Cephalocereus, etc.

## Hillside Brush

This is very rich in species of shrubs and small deciduous trees that have relatively small leaves or foliage, mixed with some cacti of the column or candelabra type. The most frequent genera are Leucaena, Cordia, Bumelia, Helietta, Gochnatia, Celtis, Flourensia, Mimosa, Colubrina, Lysiloma, Lemaireocereus, etc. The hillside brush represents the transition toward more humid and hotter zones.

## Grasslands

The types of vegetation that make the transition toward less arid zones start with the grasslands. There are two main types of grasslands: those that are mainly determined by the climate and those that are principally determined by the soil. The first group consists of a great variety of Gramineae genera, among which the following are emphasized: *Bouteloua*, *Muhlenbergia*, *Buchloe*, *Sporobolus*, *Lycurus*, *Heteropogon*, etc. Within the second group there are, among others, *Distichlis*, *Eragrostis*, etc.

## Chaparral

This type of vegetation consists mainly of very dense groups of shrubby oaks with small coriaceous leaves which belong to different species of *Quercus*. They are accompanied by other plants of similar characteristics such as *Arctostaphylos* and *Amelanchier*. The chaparral represents a type of transition toward more humid and colder zones.

## Pine-Oak Forests

This is also a community of transition toward colder and more humid zones, especially present in the north, and whose most conspicuous elements are small trees of the *monosperma* group of the *Juniperus* genus and some pines, mainly of the *Pinus cembroides* group.

# FAUNA

The fauna in the Mexican semi-arid zones has been very irregularly studied and up to the moment no sufficiently complete inventory is available. As a result some groups are better known than others. For instance, it can be said that butterflies, birds and big mammals do not present any great surprises; some groups of the molluscs and all fish, reptiles, rodents and bats have been the matter of attention lately, and are better and better known. On the other hand, there is practically no information available about certain entire groups of insects, and all the edaphic fauna. It has to be pointed out here that, except for another study on ants, fish, rodents and lagomorphs, the zoological investigations tend more to the taxonomic identification than to the ecological interpretation. Nothing is known about the trophic chains of the semi-desert, but very little is known about this in other zones and, without fully justifying it, we understand the strongly prevailing taxonomic orientation in a zone in which practically everything that is being described is new.

We have already noted that the flora is predominantly neotropical. With respect to the fauna, the semi-arid zones of Mexico - like the rest of the country - are a mixture of neotropical lineages which are moving from south to north and neartic lineages which move in the opposite direction. This can be explained considering the biogeographic corridor which is Mexico.

Almost all the big mammals have been much hunted and now they are a rare find. The carnivorous animals have been systematically eliminated which sometimes has brought about ecological disorders, due to the growth of the rodent and lagomorph populations.

## HUMAN OCCUPATION

The greater part of the semi-arid zones in Mexico has been occupied by man since olden times. As a matter of fact, it is almost certain that at least one of them, the Puebla zone, was the cradle of agriculture in Mesoamerica. Therefore it is not unusual to find signs of this occupation. The appearance of agriculture represents a landmark in ecological history, even though in the majority of our semi-arid zones it was not practiced until the Conquest of America. Further ecological modification occurred after colonization due to imports, cattle raising and mining on a large scale.

Due to the Revolution, a new change in the production systems was brought about in these zones from 1910 onwards. The ever-inadequate management was more or less generalized. Medellin-Leal and Gomez-Gonzalez (6) in a recent study made an analysis of the causes and consequences of the changes in vegetation over time in these zones.

## STATE OF KNOWLEDGE

The semi-arid zones in Mexico are not completely known. All of them have been the subject of numerous studies but under very different conditions. We have a general vision but, when it comes to making comparisons and practical applications, the available information turns out to be quite superficial: what is extensively known about one zone is completely unknown about another.

The entire country is covered by images of the satellite ERTS-1 on the bands 4,5,6 and 7, scale 1:1,000,000 and available to the public at DETENAL. Most of the country is covered by aerial photography in black and white and in color at the scales of 1:25,000; 1:35,000; 1:50,000; 1:70,000 and 1:90,000. There are no aerial photographs (at least easily available ones) for the semi-arid zones of Michoacan, Guerrero, Oaxaca and Yucatan.

Neither is the interpretative technology of these pictures easily accessible. From the cartographic point of view there is sufficient, however not complete, information on Baja California Norte, part of Sonora and almost the entire Chihuahuan Desert. This information is available in the form of topographic and geological maps, maps on soil use, edaphological maps and potential use, climate, urban and touristic maps, etc.

The climate has been quite well studied and interpreted, with results as subjective as the ones mentioned previously but the data supplied by these studies are adequate and have been applied.

There are innumerable works on geology from diverse angles and of varying quality. Unfortunately, a large part of this information cannot be consulted because it is contained in confidential reports of mining companies.

The soils, as already mentioned, have not been studied sufficiently, but there are already some edaphological maps for the south of the Chihuahuan Desert and a considerable quantity of data for the Altiplain of San Luis Potosi.

Almost all the semi-arid zones of the country have been botanically explored and studies of plant synecology and phytogeography have been undertaken by numerous authors with varying results, in a manner reminiscent of the conflicting results of studies, i.e. with a strong degree of subjectivity - which by the way is not only explainable but even necessary. The vegetation is possibly the best known aspect about these regions.

With respect to the flora, there are various research programs under way and knowledge is becoming progressively more exact. However, there is still a long way to go.

The status of zoological investigations is very different and has been mentioned already in the section entitled Fauna.

With respect to human population, there are so many and such varied problems and programs for their solution that this topic could be the subject of several seminars.

As far as institutions are concerned, there are almost 200 which in one way or another are engaged in research on aspects of semi-arid zones. However, the number engaged exclusively and comprehensively in research on semi-arid zones number fewer than a dozen. I do not want even to attempt to mention their names, in order not to risk deplorable omissions.

Inspite of the serious gaps in our knowledge it should be mentioned here that there are few nations in the world that have had as much experience as Mexico in the intelligent utilization of native plant resources of semi-arid zones. This is an invaluable heritage of which CIQA, true to Mexican tradition, is a worthy guardian and sponsor through the implementation of the most modern techniques.

REFERENCES


1. García-Castañeda, Fausto, Marco Geográfico de la Desertificación en México, in La Desertificación en México, Medellín-Leal, Fernando (ed.), Instituto de Investigación de Zonas Desérticas, Universidad Autónoma de San Luis Potosi, (1978).
2. Comité de la Carta Geológica de México, Carta Geológica de la República Mexicana 1:2,000,000, Instituto de Geología, Universidad Nacional Autónoma de México, (1960).
3. García, Enriqueta, Modificaciones al Sistema de Clasificación de Köppen para Adaptarlo a las Condiciones de la República Mexicana, publication of the author, (1964).
4. DETENAL, Plan de Acción para Combatir la Desertificación, Zonas Aridas y Semiáridas de México, Secretaría de Programación y Presupuesto, DETENAL, México, (1977).
5. Rzedowski, Jerzy, Vegetación de México, LIMUSA, México, (1978).
6. Medellín-Leal, F. and Gómez-González, A., Management of Natural Vegetation in the Semi-Arid Ecosystems of Mexico, in Management of Semi-Arid Ecosystems, Walker, B.H. (ed.), (Developments in Agricultural and Managed-Forest Ecology 7), Elsevier, Amsterdam, (1979).

# 3
# The Climates of Mexico with Emphasis on Arid Zones*

*Enriqueta García*

## DIVERSITY OF THE CLIMATES OF MEXICO

The climates of the Mexican Republic vary from very humid to desert, and from very hot to that of perpetual snow. Among the principal causes of such diversity, the following are outstanding:

1. Location of the country in the transition zone between the wind systems of the median latitudes and those of the lower latitudes, which also causes the variation of the climatic elements (temperature, precipitation, humidity, atmospheric pressure and winds) from one year to the next;
2. The mountainous relief and the large differences in altitude, which change the climatic elements in relatively short distances; and
3. The enormous territorial extension of the country, which exhibits marked contrasts between the southern and northern regions and between continental and coastal regions.

## CAUSES OF THE ARID ZONES IN THE MEXICAN REPUBLIC

The meteorological causes of the extension of the arid zones in Mexico can be summarized as follows:

(1) By its location between 14°and 32° north latitude, it is affected in its boreal portion by the belt of high subtropical pressures of the Northern Hemisphere, which consist of two enormous anticyclonic cells: that of the Atlantic or the Bermuda Azores and that of the northern Pacific with deviations over the continent, especially in winter. In the entire length of that band the air is descending and inhibits all types of precipitation (rain, snow and hail).

(2) Stabilization of the atmosphere by marine currents and surges of cold water: the arid zones of the

*Translated from Spanish

north-west of the Peninsula of Baja California owe their existence to the marine current that is displaced from north to south, parallel to the coast of the Pacific Ocean, with the consequent formation of a layer of inversion of temperature some 700 meters thick, and in which horizontal clouds, which do not release any precipitation, are formed. The coastal deserts of the Sea of Cortes, in Sonora as well as in Baja California, are due in part to this surge of cold water from the bottom of the sea, which also has a stabilizing effect on the atmosphere.

(3) The effect of pluviometric shadow caused by the mountainous barriers is felt in practically all the interior areas of the country where the mountains are obstacles to the penetration of the humid winds from the sea.

The prevailing winds during the hot part of the year are the trade winds of the Northern Hemisphere, which have their origin in the southern margin of the high pressure cell, the Bermuda Azores. They blow persistantly from east and north-east and originate from the Northern Atlantic and from the Gulf of Mexico. They are humid winds that are reinforced in velocity and humidity by the tropical cyclones from the Gulf of Mexico and from the Sea of the Antilles in summer and fall.

During the cold part of the year the prevailing winds are from the west, and they are high winds, usually dry, which proceed from the high layers of the troposphere over the Pacific Ocean. On meeting the obstacle of the Sierra Madre Occidental they suffer orographic ascent and cooling, which is turned into more or less abundant precipitation over the above-mentioned sierra, but which pass dry to the Mexican high plains.

Also characteristic of the cold season of the year are the northern winds from the Gulf of Mexico. These are masses of modified polar air that come from the north of the United States and southern Canada to invade our territory as cold and humid winds after crossing over the waters of the Gulf of Mexico.

The prevailing wind directions described above, combined with the complicated relief of our country, create areas of scarce precipitation in the shadow of the mountains. Thus, the hillsides of the sierras inclined directly toward the course from which the humid winds originate receive much more rain than the opposing hillsides.

## THE STUDY OF THE ARID ZONES OF MEXICO

The climatic study of Mexico's arid zones presents two basic problems: one is delimitation of the geographical confines of these arid zones and the other is characterization (or rather the knowledge of the peculiarities of) these zones with the object of providing the policies for their better management.

## Delimitation

The boundary between dry and humid is relative and approximate, and can only be established by convention. Aridity is the result of a series of physical factors which are difficult to evaluate exactly. It has been found that the best indicator of aridity is vegetation because its organisms, not being able to move from one place to another, find themselves in intimate harmony with the environment in which they grow.

In order to delimit the arid zones of Mexico, diverse formulas or indices, some more complicated than others, have been employed which attempt to include the variable and complex conditions of the environment. The majority of these indices are of restricted use in our country given the scarcity of the required data for their calculation.

Therefore, from the point of view of delimitation of the climatic areas in general, and of the arid zones in particular, our country has been studied until just recently only in a very general way. Moreover, it has not been possible to use these studies in general planning, since none of the systems of climatic classification nor indices applicable to Mexico have given sufficient detail when mapped.

Thus arose the necessity of applying a climatic system that would utilize meteorological data over a long time period from the greatest number of stations possible and that were based on the vegetation, since, as we have noted, this is the best indicator of environmental conditions. The chosen data were temperature, precipitation and Köppen's system, which is based on the distribution of the principal vegetal associations.

With more than 2000 observations on temperatures, it was possible to sketch isothermic maps, using an altimetric map of the country as a basis for interpolating and extrapolating the temperatures, taking into account the altitude through computation of thermal gradients. This resulted in temperature maps that were much more detailed than those already in existence and which are much more realistic due to having taken relief into account.

The same can be said of the outline of the isohyetal line maps or of the precipitation distribution maps. These outlines were again based on the relief, in that the mountains act as barriers to the penetration of the humid winds of the sea; that is to say we took into account the effect of the pluviometric shadow.

When the detailed maps of temperature and precipitation were outlined, we wanted to relate these two elements by means of Köppen's original system and we realized that the detail obtained in the outline of the climate map was not comparable with the detail obtained only with data. In other words, the system was too general and was not capable of showing the climatic differences at the same scale as that of the above-mentioned maps.

Thus, the necessity arose of adapting and modifying the Köppen system to the particular conditions of the Mexican Republic, resulting in the Modified System. The modifications consist of the adding of new climatic descriptions to the divisions of the Köppen system, calculating their limits and introducing adequate symbols to represent them, and in subdividing by statistical methods some of the fundamental types of the system in order that they might correspond with the characteristic, but important, variants of those types in the Mexican Republic. In some cases it was necessary to introduce new formulas with the object of delimiting special types of climates of Mexico that Köppen did not take into consideration. These formulas resulted, in some cases, from the relationships between climatic variants and vegetation. Here it is worth mentioning our work entitled "Larrea y Clima", which represents an example of the relationship which exists between the distribution of vegetation, in this case the shrub Larrea tridentata, and one of the indices included in the modified system.

The practical result of the modified system was the finding of an acceptable correlation between the sub-types of climate - established by us - and the distributions of the climatic conditions which were deduced from the meteorological data and from the distribution of diverse vegetal associations.

Through utilization of the modified system, the Climate Map was outlined by DETENAL/Institute of Geography at a scale of 1:500,000, which delimits the arid zones in more detail than any map existing up to this moment. And, due to the good relationship of the types of climate with the vegetation, this map is employed as a basis for the elaboration of other DETENAL maps, such as those on Soil Use and Potential Use.

The Climate Map consists of 45 pages that cover the national territory and contains the following information:

1. The meteorological stations are shown by means of a circle with a number which represents, in code, the state and the station;
2. Mean annual temperature in degrees centigrade and normal annual precipitation in millimeters. The annual isotherms appear as annotated red lines, outlined every 2°C. Some of these lines, such as those of 22°C, 18°C, 12°C, 5°C and -2°C, are considered in the classification as limits among the diverse thermal zones. The annual isohyetal lines are marked on the map by annotated blue lines in millimeters which represent annual normal rainfall;
3. The colors represent different degrees of humidity which result from considering statistically the relationship between precipitation and temperature, forming thereby a map of aridity indices. The

colors blue and gray represent the humid climates, three shades of green correspond to the three degrees of humidity in the subhumid climates, brown represents the semidry, orange the dry and yellow the very dry;

4. The small symbols placed over each color separate the climates according to temperature, in diverse thermal zones. Thus the joint use of color and symbols define the principal climatic types and subtypes;
5. The description is complemented by groups of letters at the side of each station, as well as in visible places of the diverse climatic zones, and whose significance is given on the reverse side of the map;
6. On the reverse side of each sheet a summary of the modifications made to the original Köppen's system is given. In addition the reverse sides contain a series of temperature and precipitation graphs of all the stations utilized in the elaboration of each sheet.
7. The rainy season or regime of rainfall is indicated by means of parallel lines of different orientation on a small map found on the right side of each sheet of the map. The regime of rainfall is marked individually at each station by a group of letters (climatic symbols).

## Characterization of the Arid Zones of Mexico

The studies carried out by the climatology group of the Institute of Geography, in collaboration with DETENAL, entitled "Precipitación en la República Mexicana y Evaluación de su Probabilidad", are useful in characterizing precipitation in Mexico's arid zones. In these studies, the Gamma distribution, which can be expressed by a family of curves, was fitted to the precipitation data. Its formula is complex and laborious to apply but, with the help of a computer, we achieved its calculation and representation in a series of graphs fitted to the precipitation data collected over a long time period from the weather stations.

This published work describes the distribution of rainfall in the Mexican Republic and evaluates the probability of occurrence of desired quantities in the monthly periods, in the year, and from May to October and from November to April. It consists of 19 volumes which completely cover the national territory. Each volume contains a series of graphs and maps. The maps contain the mean isohyets for each of the months of the year, the annual isohyet, and isohyets for two periods - the humid one from May to October, and the dry period from November to April. The maps also contain iso-lines of probability from which is represented an equal or greater precipitation to that mean value.

The graphs contained in the volumes relate the quantity of rain to the probability of occurrence of any quantity or more; there is a graph for the precipitation in each one of the months of the year, for annual precipitation, and for the two above-mentioned periods. In total there are fifteen graphs for each of the 1800 stations which we had up until 1970.

One very important point to consider is the form of the curves, which depends on the value of the Gamma parameter estimated in the process, and which can be obtained easily from the variation coefficient included at the foot of each graph. Other data included are: the maximum and minumum precipitations obtained in the considered period, the mean precipitation, the probability of a rainfall greater than that mean, and the standard deviation of the series calculated by the Gamma function.

The curve has the form of an S in the humid months or years, as is the case in the month of July which is humid at the Puebla station. It has the form of an inverted J in the dry months, years or periods, and this is the form most common in Mexico's arid zones. Thus, an idea of the aridity can be obtained simply by examining the form of these curves. A quantification of aridity can be made as a function of the parameter of the Gamma distribution ($\gamma$) which we have included in a study cited further on.

The usefulness of this work is principally in agriculture. For example, if for a particular crop in a certain area a precipitation greater than or equal to X (quantity) is required during one or more months, one can consult both the maps and the graphs corresponding to the stations nearest to the area under examination in order to obtain estimates of the probability, the risk of the enterprise, and the probable water deficit in order to make up the difference with irrigation.

This work served as a basis for the studies mentioned below which we conducted in collaboration with Engineer Mosiño, Director of the Center of Atmospheric Sciences of the National University of Mexico.

1. "Caracterización del Régimen Pluviométrico en las Regiones Aridas y Semiáridas de México, mediante la Distribución Gamma". In this we propose the use of the statistical mode in place of the arithmetic mean to evaluate the monthly quantity of rainfall, especially in arid zones.
2. "Anomalías de la Lluvia en México y América Central durante el Año de 1972". In this work we employ the mode obtained from the Gamma function to calculate the annual as well as the monthly anomalies.

3. "La Moda como Valor Estadístico para Evaluar la Precipitación en México" is a series of maps recently published by DETENAL at a scale of 1: 4,000,000. There is a map for each one of the months of the rainy season (May to October), one for the annual mode, one for the period November to April, and other maps, such as one for the factor by which the mean is multiplied in order to obtain the mode of any place in the Republic.

The probability study, entitled "La Variabilidad de la Lluvia en México por medio de la Distribución Gamma", also served as a basis for our work. This probability study includes a diagram of risks which relates the Gamma, the variation coefficient, and the probability of having values less than or equal to the mean and to fractions of the mean. It also includes a general graph applicable to the entire country, including the arid zones.

Also, studies for analyzing the behavior of precipitation over time are being carried out.

It can be concluded from the statistical study of data over relatively long periods that precipitation behaves in a cyclical manner, and that there have been various dry periods followed by humid ones. Currently we find ourselves at the end of a rainy age, after which will follow another age of relatively little precipitation. Nevertheless, one must note that the years of maximum precipitation are not the same in every region of the country. For example, the years of maximum precipitation in the north of the Altiplanicie appear out of phase by two years with respect to those in the south of the Altiplanicie and of the Balsas river basin.

At the same time we are trying to find the relationships between the climate and various crops in selected areas of the country with the object of collaborating in the agricultural growth of the nation.

# 4
# Climate and the Chihuahuan Desert

*Robert H. Schmidt, Jr.*

## INTRODUCTION

The Chihuahuan Desert is a large, relatively isolated arid zone embedded in the center of North America's subtropical latitudes. This arid zone covers most of north-central Mexico with a tongue extending northward into west Texas and soutern New Mexico. Until recently, very little substantive information existed concerning this arid zone. The vague and inconsistent boundaries delineating the Chihuahuan Desert reflect the general lack of systematic and scientific investigation in this region. In addition to the traditional problem of defining the term "desert", the lack of studies and data bases which extend across the international boundary between the United States and Mexico further complicate the process of placing the Chihuahuan Desert into a regional framework.

To arrive at something more definitive than the previous vague renderings of the Chihuahuan Desert, Schmidt (1) obtained mean annual temperatures and precipitation values for nearly 800 weather stations in the states of Arizona, New Mexico, Texas, Sonora, Chihuahua, Coahuila, Durango, Zacatecas, San Luis Potosi, Nuevo Leon and Tamaulipas. This data was classified according to the de Martonne Index of Aridity (2). An aridity index of <10 was used to delineate the Chihuahuan Desert (Figure 1). This isoaridity is based upon recorded weather observations, and the extrapolation of these data to areas having similar altitude and latitude. Approximately 115 stations are actually located in this arid zone. The decision to select the de Martonne Index of Aridity over other possible methods of regionalization, and establishing the boundary at <10 was based upon the advantages offered by the classification; and the close parallel between the indices and the visual appearances of the natural environment (for additional discussion see (1)).

The Chihuahuan Desert spans more than 11° latitude, and 355,000 $km^2$, or 1.5% of North America. Nearly three-fourths of this arid zone is in Mexico where it accounts for 13% of the national territory. About one-third of the

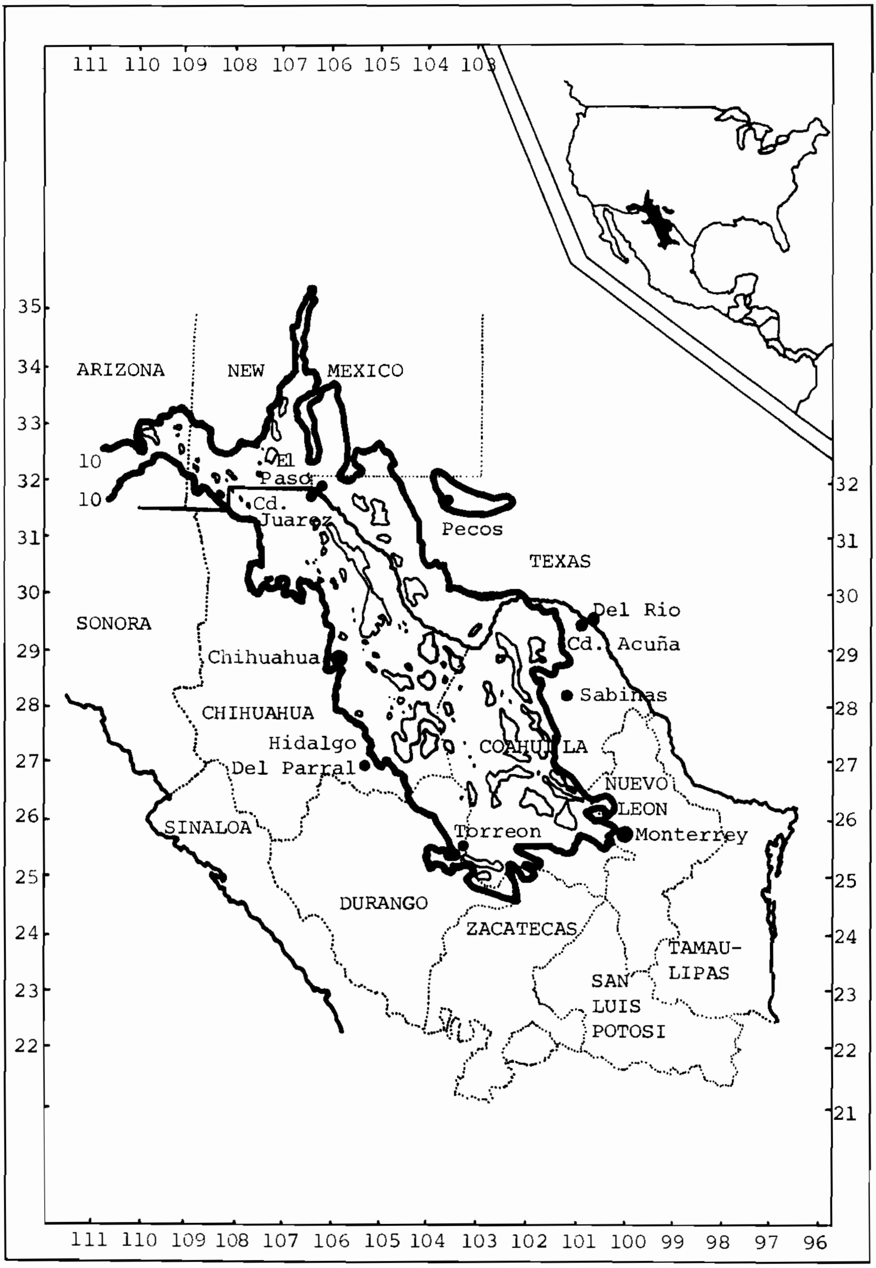



FIGURE 1. The Chihuahuan Desert: delineation by Schmidt (after de Martonne (2)). Also shown are mountain masses which are too high and hence too cool and moist to classify as desert.

Desert is in the state of Chihuahua from which this arid zone derives its name.

The mean average of the indices for the Chihuahuan Desert is 7.9 (median = 8.3) with values ranging from 4.7 to 10. The lowest aridity indices occur in the southern portion of the Chihuahuan Desert in Coahuila, and along the lower Rio Grande (Rio Bravo del Norte).

Twelve conceptualizations of the Chihuahuan Desert were mapped at the same scale to identify similarities and differences, and to provide a finer basis for establishing the boundaries (Figures 2-13). The interpretation of the Chihuahuan Desert presented here, based upon the de Martonne Index of Aridity, coincides most closely with the Thornthwaite map (Figure 6, 1931). The Mexican portion of the aridity index map is also very similar to the Koppen-Garcia delineation constructed by the Instituto de Geografia, UNAM (Figure 3, 1970)(3).

Maps showing the distribution of natural vegetation do little to clarify the location of arid zones in North America. A major problem results from the lack of data pertaining to plant communities in the Chihuahuan Desert. As stated by Barbour et al. (in 4), this type of data "does not exist to the same degree of detail or volume as data for the other two warm deserts". Phytogeographers generally regard a continuous cover of creosote bush (*Larrea tridentata*) as the common denominator in determining the continent's southern deserts (5,6). Vegetation maps, such as Shantz and Zon (7), Shreve (5) (Figure 4, 1942), Kuchler (1970), Flores et al. (8) (Figure 7, 1973) and Hunziker et al. (Figure 13 in (4)), suggest the location of the southern deserts, but there is little agreement concerning the distribution and dominance of the creosote bush or other plants. Barbour et al. (in 4) points out that the "density of *Larrea* is much greater in Chihuahuan sites than in the other two warm deserts", but there is no reference to the boundaries between these arid zones (Figure 13). The significance of the creosote bush as the common denominator of North America's warm desert is also questionable considering the recent plant invasions into arid and semi-arid grasslands (9,10).

A composite of all the Chihuahuan Desert maps used in this study indicates that the core area, or the area every delineation considers to be part of this region, coincides fairly close to the representation arrived at using the de Martonne Aridity Index (Figure 1). Other than relatively minor deviations, where an interpreter chose to include or exclude mountain masses located near the exterior boundary, there are three areas in the desert where major differences exist in the delineations. The southern boundary is the area of greatest discrepancy. Generally, the vegetation maps show the desert extending as far south as southern San Luis Potosi, whereas most of the climatic delineations show the southern boundary more

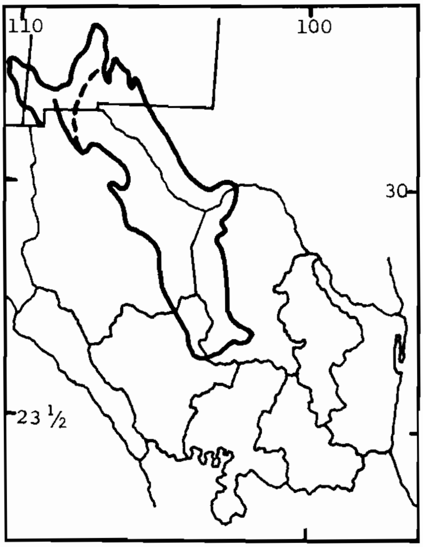



FIGURE 2. The core area of the Chihuahuan Desert based upon a composite of the source maps used in this study. The dashed line represents Shreve's western boundary (5)

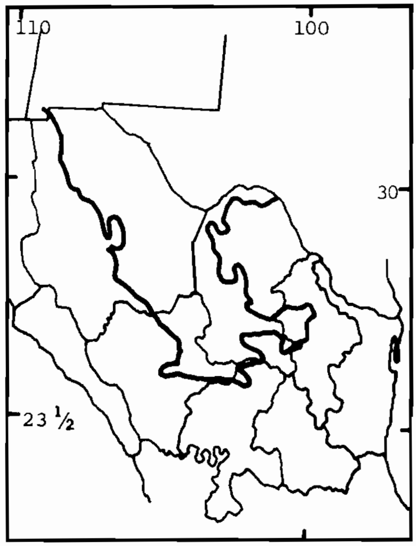



FIGURE 3. The Chihuahuan Desert: delineation by Instituto de Geografía using the Köppen-Garcia classification (3)

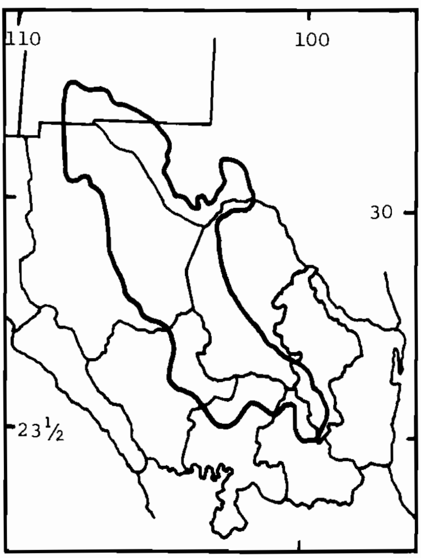



FIGURE 4. The Chihuahuan Desert: delineation by Shreve (5)

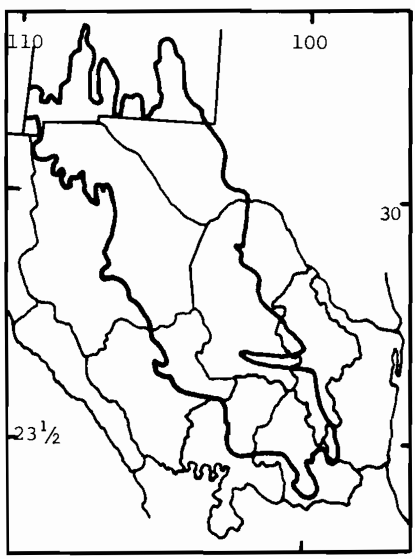



FIGURE 5. The Chihuahuan Desert: delineation by Johnston (11) and Henrickson et al. (12)

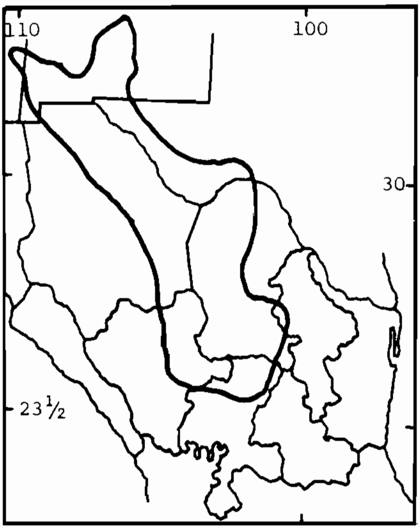



FIGURE 6. The Chihuahuan Desert: delineation by Thornthwaite (13). His 1948 map, which includes only the U.S. portion of the arid zones, shows a connection between the Sonoran and Chihuahuan Deserts, and includes an arid corridor up the Pecos River Valley

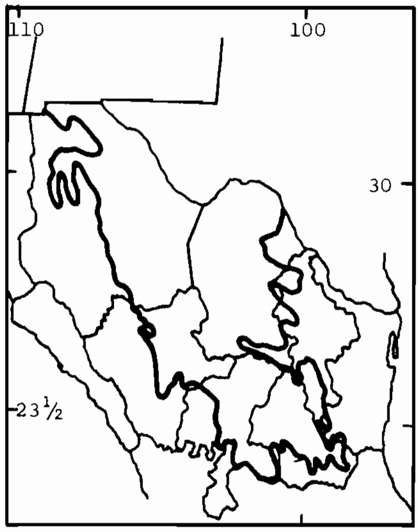



FIGURE 7. The Chihuahuan Desert: delineation by Flores Mata et al. (8)

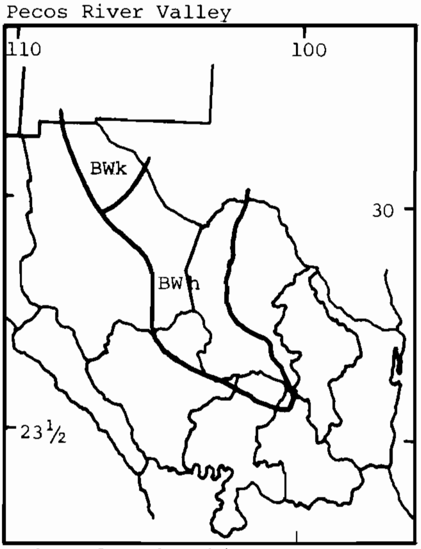



FIGURE 8. The Chihuahuan Desert: delineation by Vivo Escoto (14) using the Köppen classification

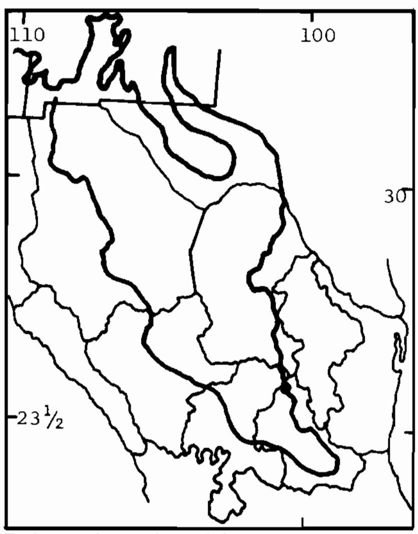



FIGURE 9. The Chihuahuan Desert: Mexico delineation by Leopold (15); U.S. delineation by Russell (16) using a modified Köppen classification

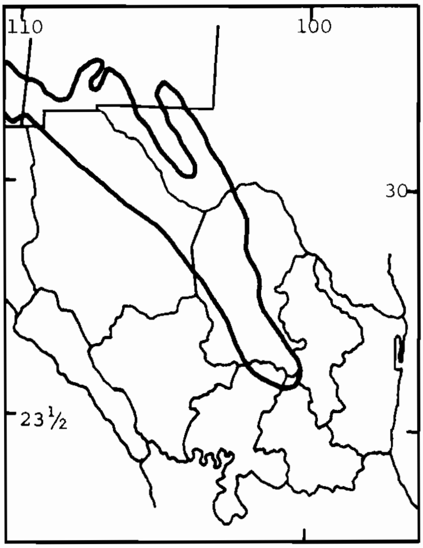



FIGURE 10. The Chihuahuan Desert: delineation by Ackerman (17) using the Köppen-Geiger classification

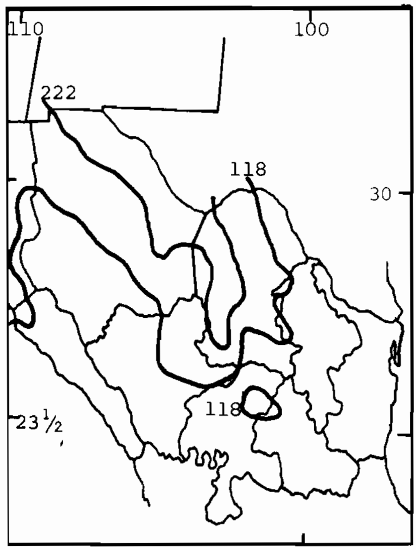



FIGURE 11. The Chihuahuan Desert: delineation based upon the Emberger classification (1932) modified by Stretta-Mosino (1963). Map published in Soto & Juaregui (18)

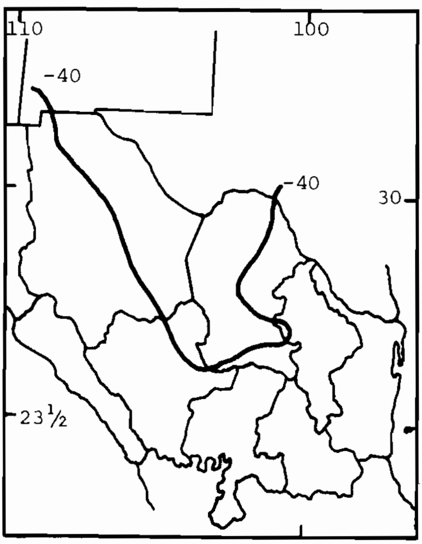



FIGURE 12. The Chihuahuan Desert: delineation by Contreras Arias (19) using the Thornthwaite classification

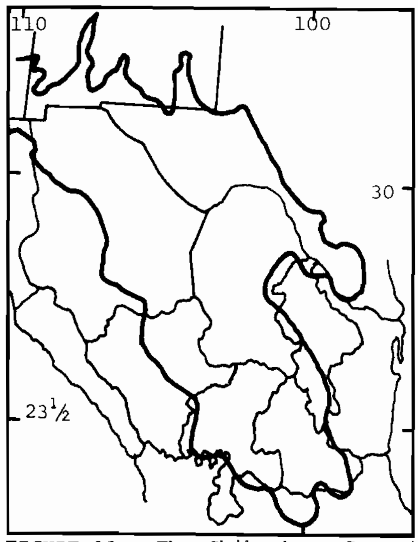



FIGURE 13. The Chihuahuan Desert: delineation by Hunziker et al. (in 4). Based upon the distribution of the creosote bush

or less corresponding with the Coahuila-San Luis Potosi border. It should be noted that the definitive appearing map of the Chihuahuan Desert used by Johnston and Henrickson (the original map is overlain by the geographic grid system and the boundaries show considerable detail) includes a larger area than would be anticipated for a final delineation (Figure 5). This map's intended use is to insure complete coverage for collecting desert plants (11, 12,20).

Another problem area is found in the Pecos River valley of Texas. Only a small "pocket" area of this river basin falls within the parameter to qualify climatically as desert (Figure 1). Climatic data do not support the inclusion of an arm of the desert extending northward from the Rio Grande, across the Stockton Plateau, and up the Pecos River as shown in Figures 4,5,9,10 and 13.

The physical environment of the Chihuahuan Desert is relatively homogeneous, although this statement should not be interpreted to mean that local differences do not exist. The general uniformity found in this arid zone results from the following features:

1. The desert is generally surrounded by mountain masses which have nearly uniform heights and, hence, similar orographic effects.
2. Most of this arid zone lies more or less an equal distance from the sources of moisture - the Gulf of California, Pacific Ocean, and the Gulf of Mexico.
3. The desert's position on the continent, with its relatively low latitudinal location and surrounding mountain masses, results in little moisture being derived from frontal activity; as a result, this arid zone is characterized by a very high percentage of its precipitation falling in the form of rain during the summer months.
4. There are very few through-flowing rivers, hence there are few areas of erosional lowland. As a result nearly all of this arid zone, which is characterized by basin and range topography has a base level of approximately 1200 m.

More detailed climatic data were obtained from the 115 weather stations found in this arid zone. Analysis of this information makes it possible to identify the spatial and temporal variations of weather and climate which characterize this region. It was found that climatic conditions for the Chihuahuan Desert are not extremely severe, and are relatively homogeneous, particularly when compared to other arid zones. A comparison between the mean and median indicates that annual temperatures are statistically near stabilization, and annual precipitation totals are not.

However, because of the constraints on time, funding, and a lack of complete data sets for all stations found in and around the Chihuahuan Desert, these conclusions (which are discussed further below) must be considered preliminary.

## TEMPERATURE CONDITIONS

The average annual temperature for the Chihuahuan Desert is 18.6°C (median = 18.6°C) with station averages ranging from about 14°C to 23°C. Nearly half of the mean annual temperatures are within 2°C of the average. Only a few stations have recorded extreme temperatures higher than 50°C, or lower than -15°C. Although temperatures are fairly similar throughout this arid zone, the highest annual and monthly temperatures and the longest frost-free seasons occur in the lower altitudinal and latitudinal locations. Almost 90% of the Chihuahuan Desert lies at an altitude between 1100 m and 1500 m. The average altitude of the climatic stations is 1235 m. Only in the southern most portion of the Chihuahuan Desert does this arid zone extend above 1500 m. At comparable altitudinal locations, the average annual temperatures in the northern part of the Chihuahuan Desert are about 3° to 14°C cooler than those in the south.

The average hottest monthly temperatures are very similar throughout the Chihuahuan Desert. It is largely the colder winter months in the north that account for the cooler average annual temperatures. The passage of the more well developed portion of cold fronts in the northern Chihuahuan Desert, although seldom severe, do create more variable and cooler weather in the winter. The increased influence of frontal activity in the north is exemplified by the larger annual temperature range of approximately 22°C, compared to a range of 18° to 20°C in the south. July is normally the warmest month and January the coolest Diurnal temperatures usually range from about 18°C to 20°C

## PRECIPITATION CONDITIONS

The mean annual precipitation for the Chihuahuan Desert is 234 mm (median = 242 mm) with a range of approximately 150 to 400 mm. Nearly two-thirds of the stations have annual totals between 225 and 275 mm. No portion of this arid zone has experienced a year without recording precipitation, although only 5.5 mm were recorded at Maclovio Herrera, Chihuahua in 1965. Aridity in this desert zone stems from a combination of orographic barriers, domination by a subtropical high pressure cell, and continentality. The effect of orographic lifting and the resulting arid interior of the continent are clearly illustrated by the profiles showing the relation between precipitation totals and topography (Figures 14 and 15). Nearly all of the Chihuahuan Desert is 400 to 700 km from the nearest source of precipitable water - the eastern-north Pacific Ocean and the Gulf of Mexico. The effects of continentality are not as important as the effect of orographic barriers. The Laguna area near Torreon is one of the driest regions within the Chihuahuan Desert, but it is also an area which is closest to a source of moisture. Investigations by Mosino (21,22) indicate that the high interior of Mexico is an elevated heat source, especially during the warmer months, that triggers instability and lifts the moist air up the slopes of the mountain ranges lying on the east and west of the Chihuahuan Desert Thus, air currents release most of their moisture by forced lifting on the seaward slopes of the mountains.

In the Chihuahuan Desert most of the precipitation falls during the summer in the form of rain from the thundershowers. Hail-producing thunderstorms also occur, but they seem to be less frequent and of lower intensity than those found on the Great Plains. The northern portion of this arid zone usually receives some snowfall during the cooler half of the year. An average of about two snow storms can be expected each year, although seldom does snow remain on the ground for more than a day or two. Snow is more common in the Sierra Madre's above 2200 m, but even here accumulation is relatively small. The Chihuahuan Desert is not nearly as dry as many other arid zones in North America. For example, the mean annual precipitation for the entire Baja Peninsula is 153 mm (6), which compares with the lowest annual rainfall totals for the interior desert.

Nearly all locations in the Chihuahuan Desert receive more than 70% of their annual precipitation during the warmest half of the year (May through October), with maximum rainfall occurring in July and August. No station has a winter maximum precipitation, but several months without appreciable moisture are not uncommon. During the summer, precipitation coincides with the large-scale monsoonal-like circulation that causes moist, tropical air to be carried northward as the oceanic subtropical anticyclones expand and migrate. The much smaller quantities of precipitation received in the winter is the result of frontal activity associated with moist air from the Pacific Ocean. Because most of the Chihuahuan Desert is in the lee of the Sierra Madre Occidental and other mountain ranges to the west and north, and is located more equatorward on the continent, this arid zone does not have a winter rainy season like that of northern Sonora and the Arizona Uplands. The seasonality of precipitation is the major distinction between the warm deserts of North America.

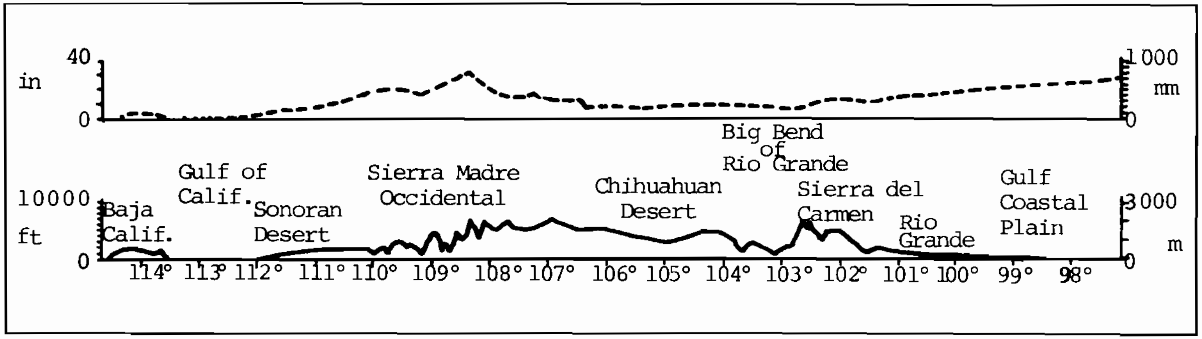



FIGURE 14. The relation of average annual precipitation and topography along latitude 29° N. Based upon precipitation data from the Carta de Climas (3) and Schmidt (23). Vertical exaggeration: approximately 35.

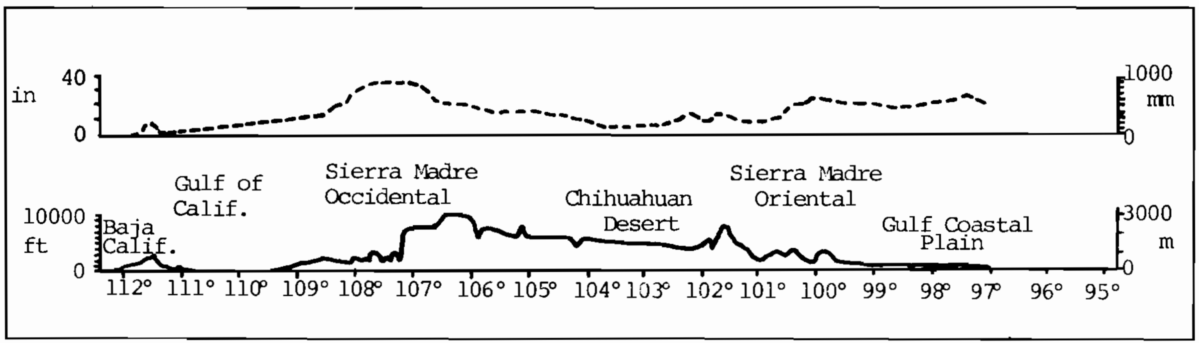



FIGURE 15. The relation of average annual precipitation and topography along latitude 26° N. Based upon the Carta de Climas (3). Vertical exaggeration: approximately 35.

The northwest boundary of the Chihuahuan Desert, which extends across the Continental Divide (c. 1400 m) of southern New Mexico into eastern Arizona, comprises a broad transition zone. The name proposed for this narrow corridor connecting the Chihuahuan Desert with the Sonoran Desert is "Son-Chih". For statistical purposes the 109°W meridian, which corresponds to the New Mexico-Arizona border, may be suitable as the division between these two deserts. Shreve's map (5) is the only interpretation which shows the Chihuahuan Desert as an isolated entity. The establishment of a precise boundary between the Sonoran and Chihuahuan deserts is complicated by the fact that the Sonoran Desert proper lies between sea level and about 900 m (6), and most of the Chihuahuan Desert is over 1200m. Aside from higher temperatures and a longer growing season associated with the lower altitudes found in the Sonoran Desert, the most significant environmental feature is the double maxima of precipitation, which provides plants with moisture over a larger portion of the year, and accounts for the relatively dense and "lush" vegetation found in this arid zone. Although the exact percentage of precipitation received during the winter half of the year and the effect of warmer temperatures with lower altitudes which equate to "typical" Sonoran Desert vegetation is undetermined, the westernmost boundary of the Chihuahuan Desert, proposed by this author, corresponds to the 55-60% isolines depicting the mean percent of annual precipitation falling during the six summer months (May-October) (24). The area west of the dashed line on Figure 1 receives less than 55-60% of its mean precipitation in the summer six months, and the area east of the boundary receives a larger percentage during the high sun period. The explanation for the presence of so-called anomalies, such as "a large island of Chihuahuan Desert flora (which) occurs along the San Pedro Valley of Arizona,... and well away from the main body of the parent desert" (6), appears to result mainly from the seasonal distribution of precipitation. The area in southeastern Arizona receiving more than two-thirds of its moisture during the summer months, as depicted on McDonald's map (24) showing the summer mean precipitation amounts expressed as a percentage of total annual mean precipitation, closely corresponds to the island of Chihuahuan Desert flora.

## Summer Moisture

For nearly two-thirds of the year the zonal flow over the Chihuahuan Desert is from the west. About mid-July the circulation pattern shifts to a more easterly flow, and continues into early fall. During this time, circulation around a warm upper-level high-pressure cell centered over Texas and New Mexico produces a southeasterly flow aloft bringing moist, tropical air from the Gulf of Mexico over northern Mexico and the southwest United States. More recently Rasmusson (25) and Hales (26-28) placed into proper perspective the sources of precipitable water for the Sonoran Desert. Their work, complemented by Tubbs (29) and Brennan (30) demonstrated that the Gulf of California is a major source of summer moisture for northwest Mexico and the adjoining southwest United States dispelling the previous notion that moist air west of the Continental Divide was almost entirely derived from the Gulf of Mexico.

The proportion and significance of tropical revolving storms as a source of moist air for the interior desert has not been completely solved. It seems reasonable to accept, in general, that water vapor in the atmosphere over the Chihuahuan Desert during the summer comes from the Gulf of Mexico. But, it is proposed here that much of the significant or deluge-type rain that falls in the Chihuahuan Desert is the result of tropical storms in the eastern-north Pacific Ocean.

Tropical revolving storms, sometimes reaching the intensity of tropical cyclones and occasionally hurricane force (called Chubascos in the eastern tropical Pacific) are responsible for most of the heaviest and most widespread rains occurring in the Chihuahuan Desert. These powerful storms are also responsible for most of the large deviations in precipitation totals from year to year, especially those deviations occurring during the warm season (Figures 16-20).

The relatively recent increase in the number of spacecraft, and improvements in sensor components now provide us with valuable and very useful tools to observe temporal environmental conditions, especially in more remote areas. Sadler's (31) pioneering work in the use of satellite imagery to detect the presence of tropical cyclones in the eastern-north Pacific found that approximately three-fourths of these storms are not detected by conventional observations. He found that about 30 tropical storms occur annually, of which 40% reach hurricane intensity. This frequency ranks the eastern-north Pacific second to the western Pacific in the development of tropical storms and hurricanes.

Film rolls (35 mm) of satellite imagery were obtained for most of the July-September months of 1971 to 1979 from the U.S. National Environmental Satellite Service, and used in conjunction with the U.S. Daily Weather Maps. Very preliminary analysis indicates that tropical revolving storms, from both the Gulf of Mexico and the eastern-north Pacific, are frequently of sufficient size and intensity to supply the atmosphere of the interior desert zone with relatively large quantities of water vapor. Using prolonged or significant daily rainfall for El Paso, Texas during the summer months as a criteria, satellite imagery was used to determine the source of the moisture. Deleting isolated thunderstorms, which were unrelated to

FIGURES 16-18. Precipitation deviations from the mean for El Paso, Texas

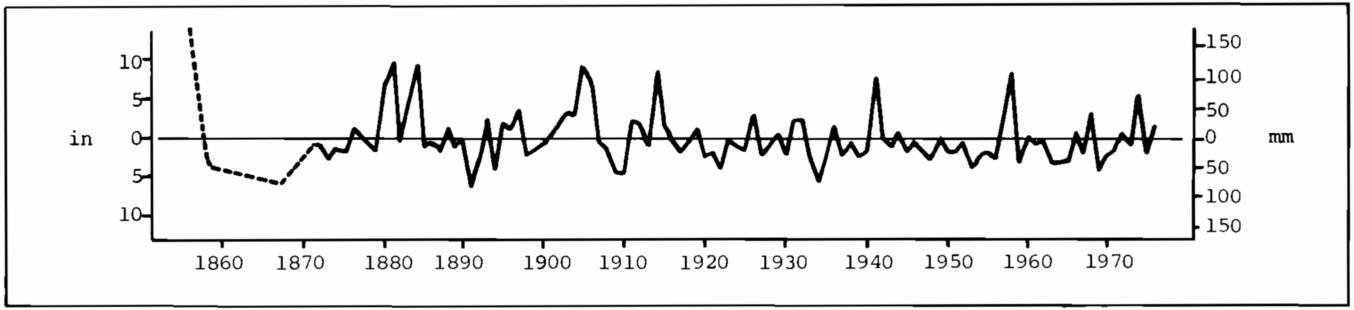



FIGURE 16. Annual precipitation (214 mm or 8.42 inches)

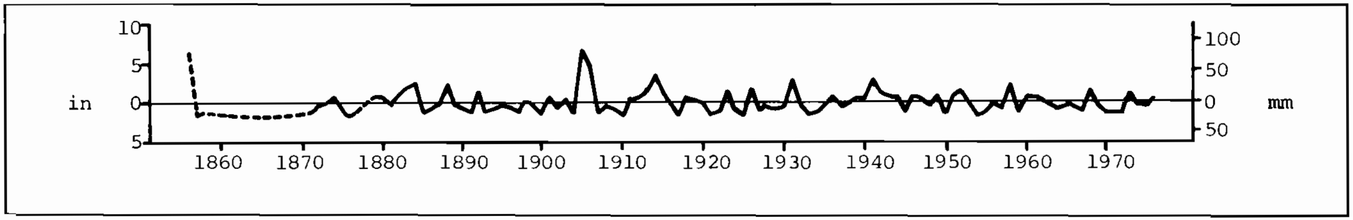



FIGURE 17. Cool season precipitation (Nov. - April, 59 mm or 2.32 inches)

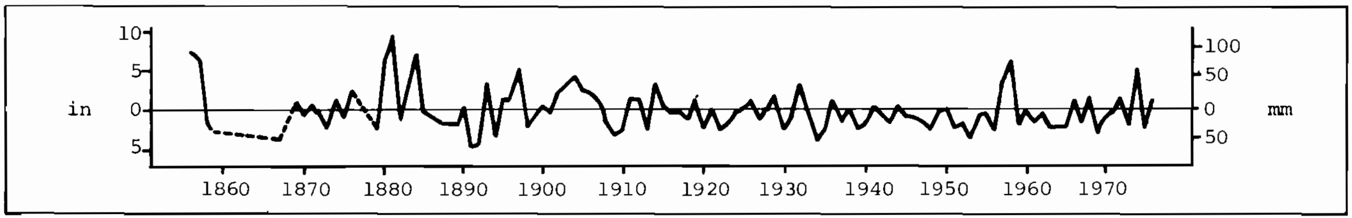



FIGURE 18. Warm season precipitation (May - October, 155 mm or 6.13 inches)

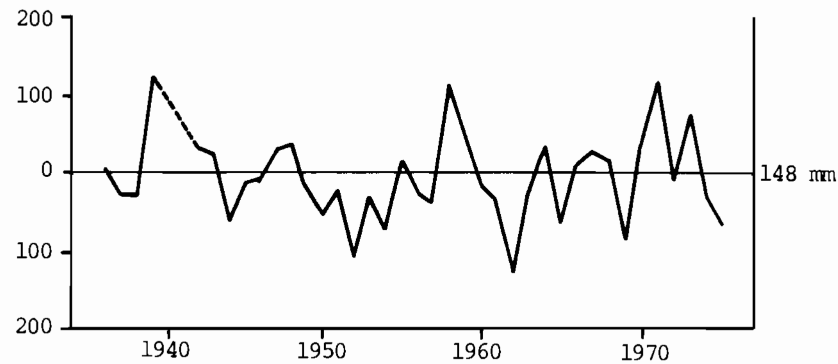



FIGURE 19. Warm season (May-Oct.)

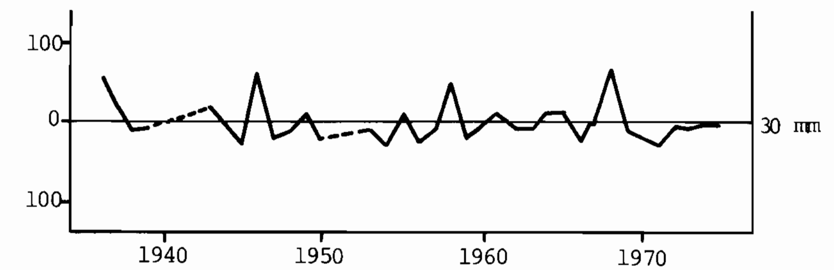



FIGURE 20. Cold season (Nov.-April)

FIGURES 19 & 20. Precipitation deviations from the mean for Presa Cuije, Coahuila

tropical revolving storms, it was found that approximately 45 percent of the precipitated moisture was derived from the eastern-north Pacific and 55 percent from the Gulf of Mexico. The proportion of the source of annual rainfall from tropical storms varied from 40 to almost 65 percent on the Pacific side and from 43 to 60 percent on the Gulf of Mexico side. When these storms move near the east and west coast of Mexico and establish strong cyclonic circulation, it normally takes 2 or more days for the moisture to reach deep into the interior desert. The large quantity of moisture placed in the atmosphere by tropical revolving storms usually results in continuous cloud cover, and light rains. Although based upon casual observations of cause and effect for El Paso, it appears that much of the heavier rainfall during these more humid periods is the result of frontal activity. In 1974 and 1975, 85 and 79 percent of the annual precipitation in El Paso was attributable to tropical revolving storms. Data and maps pertaining to deluge rainfall in Mexico published by the Secretaria de Recursos Hidraulicos (now SARH) for the period 1953 to 1968 indicate that the greatest deluges of rainfall occur on the southerly margins of the interior desert.

Comparing newspaper accounts with daily rainfall data for the past 100 years in El Paso, Carson (32) found that at least 50 mm of rainfall occurring within a period of 1 or 2 days are required to cause damage and disruption to residence of the Pass.

The intent of this study is to identify and characterize the ingredients of weather and climate for the interior desert, and to provide a much better regional map of the Chihuahuan Desert, based upon a consistent, uniform and comprehensive system, than has been available in the past. It is recognized that the boundaries of the Chihuahuan Desert cannot be delineated to the satisfaction of all of the sciences concerned with this region, but deserts are basically climatic regions, and hence the elements of weather and climate represent the most significant and unifying factor in identifying arid zones.

## REFERENCES


1. Schmidt, R.H. Jr., A Climatic Delineation of the 'Real" Chihuahuan Desert, Journal of Arid Environments, 2 (3):243-250, (1979).
2. de Martonne, E., Areisme et Indice de'Aridite,Comptes Rendus de L'Academie des Sciences de Paris, 182:1395-1398, (1926); in English, Regions of Interior Basin Drainage, Geographical Review 17:397-414, (1927).
3. Instituto de Geografia, Carta de Climas de la Republica, Univ. Autonoma de Mexico, Comision de Estudios del Territorio Nacional, Scale 1:500,000, (1970).
4. Mabry, T.J., Hunziker, J.H. and Feo, D.R.D. Jr., Creosote Bush: Biology and Chemistry of 'Larrea' in New World Deserts, Stroudsbury, Penn: Dowden, Hutchinson and Ross, Inc., U.S./International Biological Program Synthesis Series, 6, (1977).
5. Shreve, F., The Desert Vegetation of North America, Botanical Review 7:195-246, (1942).
6. Hastings, J.R. and Turner, R.M., The Changing Mile, University of Arizona Press, Tucson, (1965).
7. Shantz, H.L. and Zon, R., Natural Vegetation, Dept. of Agriculture, Atlas of American Agriculture, Washington, D.C., (1924).

8. Flores Mata, G. et al., Mapa y Descripcion de los Tipos de Vegetacion de la Republica Mexicana, Secretaria de Recursos Hidraulicos, Mexico, (1973).
9. Branscomb, B.L., Shrub Invasion of a Southern New Mexico Desert Grassland Range, Journal of Range Management 11:129-132, (1958).
10. Harris, D.R., Recent Plant Invasions in the Arid and Semi-Arid Southwest of the United States, Annals, Association of American Geographers 45:408-422, (1966)
11. Johnston, M. Personal communication, (1975).
12. Henrickson, J. and Garcia, J., Maps of the Chihuahuan Desert Region, Los Angeles State University, California, (1976).
13. Thornthwaite, C.W., Climates of North America, Geographical Review, 21 (4) pl. III, (1931).
14. Vivo, E. and Jorge, A., Weather and Climate of Mexico and Central America, in West, R.C. and Wauchope, R. (eds.), Natural Environment and Early Cultures, Vol.1 pp.185-215, Handbook of Middle American Indians, University of Texas Press, Austin, (1964).
15. Leopold, A.S., Vegetation Zones of Mexico, Ecology Vol. 31, No. 4:507-518, (1950).
16. Russell, R.J., Dry Climates of the United States, University of California Press Publications in Geography, 5:1-41, (1931).
17. Ackerman, E.A., The Köppen Classification of Climates in North America, Geographical Review, 31:105-111, (1941).
18. Soto Mora, C. and Jauregui, O.E., Isotermas Extremes e Indice de Aridez en la Republica Mexicana, Talleres de Edimex, Univ. Nac. Autonoma de Mexico, Instituto de Geografia, (1965).
19. Contreras, A.A., Definicion de las Zonas Aridas y su Delimitacion en la Republica Mexicana, in Betran, E. (ed.), Problemas de las Zonas Aridas de Mexico, Instituto Mexicano de Recursos Naturales Renovables, A.C., (1955).
20. Henrickson, J. and Straw, R.M., A Gazetteer of the Chihuahuan Desert Region, California State University, Los Angeles, (1976).
21. Mosino Aleman, P.A., Surface Weather and Upper-Air Flow Patterns in Mexico, Geofisica Internacional, Technical Conference on Hurricanes and Tropical Meteorology, 4:117-168, (1964).
22. Mosino Aleman, P.A. and Garcia, E., The Climate of Mexico, in Bryson, R.A. and Hare, F.K. (eds.), Climates of North America, pp.345-404, Vol. II of World Survey of Climatology, Landsberg, H.E. (ed. in chief) Elsevier Publishing Co., Amsterdam, (1974).
23. Schmidt, R.H.Jr., Climate of the Borderlands, U.S.-Mexico Borderlands Sourcebook, Association of Borderlands Scholars, (1978).

24. McDonald, J.E., Variability of Precipitation in an Arid Region: A Survey of Characterists for Arizona, University of Arizona, Tucson, Institute of Atmospheric Physics, Technical Reports on the Meteorology and Climatology of Arid Regions, 1, (1956).
25. Rasmusson, E.M., Atmospheric Water Vapor Transport and the Water Balance of North America: Part 1, Characteristics of the Water Vapor Flux Field, Monthly Weather Review, Vol. 95: 403-426, (1967).
26. Hales, J.E.Jr., Surges of Maritime Tropical Air Northward over the Gulf of California, Monthly Weather Review, Vol. 100, No. 4:298-306, (1972).
27. Hales, J.E.Jr., Southwestern United States Summer Monsoon Source - Gulf of Mexico or Pacific Ocean?, Journals of Applied Meteorology, Vol. 12:331-342, (1974).
28. Hales, J.E.Jr., Southwestern United States Summer Monsoon Source - Gulf of Mexico or Pacific Ocean?, Weatherwise, Vol. 27, No. 4:148-155, (1974).
29. Tubbs, A.M., Summer Thunderstorms over Southern California, Monthly Weather Review, Vol. 100, No. 11, (Nov.): 799-807, (1972).
30. Brenner, I.S., A Surge of Maritime Tropical Air - Gulf of California to the Southwestern United States, Tech. Memo., NOAA, WR88, (1973).
31. Sadler, J.C., Tropical Cyclones of the Eastern North Pacific as Revealed by TIROS Observations, Journal of Applied Meteorology, Vol. 3:347-366, (1964).
32. Carson, J., Environmental Perception of Rain Conditions in the El Paso Area (1937-1976), Unpublished report of University of Texas, El Paso, (1977).

BIBLIOGRAPHY

1. Benson, L. and Darrow, R.A., The Trees and Shrubs of the Southwestern Deserts, University of Arizona Press, Tucson, (1954).
2. Environmental Data Service, Environmental Satellite Imagery: Key to Meteorological Records Documentation No. 5.4, NOAA (various months and years).
3. MacMahon, J.A., North American Deserts: Their Flora and Faunal Components, <u>in</u> Perry, R.A. and Goodall, D.W. (eds.), Arid-Land Ecosystems: Structure, Functioning and Management, Vol. 1:21-82, International Biological Programme 16, Cambridge University Press, (1979).
4. Meigs, P., World Distribution of Arid and Semi-Arid Homoclimates, Reviews of Research on Arid Zone Hydrology, UNESCO, Paris, (1953) and reprinted <u>in</u> McGinnies, W.G., Goldman, B.J. and Paylore, P. (eds.) Deserts of the World, University of Arizona Press, Tucson, (1968).

5. Schmidt, R.H. Jr., The Climate of Chihuahua, Mexico, Technical Reports of the Meteorology and Climatology of Arid Regions, 23:50, University of Arizona, Institute of Atmospheric Physics, Tucson, (1975).
6. Schmidt, R.H. Jr., A Geographical Survey of Sinaloa, Monograph 50:77, University of Texas, Texas Western Press, El Paso, (1976).
7. Schmidt, R.H. Jr., Climatological Data for the State of Sinaloa, Mexico, Mexican Climatology Series, 1: 164, Tempe: Arizona State University, State Laboratory of Climatology, (1978).
8. Schmidt, R.H. Jr., The Climate of Sinaloa, Mexico, Mexican Climatological Series 2:35, Tempe: Arizona State University, State Laboratory of Climatology, (1978).
9. Schmidt, R.H. Jr., Literature and Data Sources for the Study of Weather and Climate in the Arid Zones of Mexico, Proceedings of the 10th Anniversary issue of the Conference of Latin Americanist Geographers, (in press).
10. UNESCO, Map of the World Distribution of Arid Regions and Explanatory Notes, Technical Note 7, Man and the Biosphere, (1979).

# Part II

# Resource Assessment

# 5
# Soils of Semiarid Regions

*H. E. Dregne*

## INTRODUCTION

The semiarid regions of the world, as delineated on the 1977 Unesco map of World Distribution of Arid Regions (Figure 1), occupy about 40 percent of the arid regions. Their major land uses are grazing and rainfed cropping. Wheat, sorghum, millet, and corn are the principal crops. The semiarid tropics, where sorghum and millet are the dominant crops, is defined by the International Crops Research Institute for the Semi-Arid Tropics in Hyderabad, India as including a much larger area than is shown as semiarid on the Unesco map.

## PRINCIPAL SOILS

Two broad groups of soils are found in the uplands in the semiarid regions (1) (Figure 2). Those occurring in northeastern Brazil, in the Sahel area south of the Sahara, in southwestern India and Rajasthan State, and in northern Australia have similar characteristics. They tend to be moderately to strongly acid in the subsoil, generally highly permeable, contain considerable amounts of iron and aluminum oxides and kaolinitic clays, and have low water and nutrient holding capacities. The soils usually are red in color. They are confined almost entirely to the tropical region where most, if not all, of the rain falls in the hot season and where there is a prolonged dry season. The dominant soil order is Alfisols, followed by Entisols.

A second group of soils is representative of the remainder of the semiarid regions. They are the soils that have a neutral or slightly acid pH in the surface and are alkaline in the subsoils, vary widely in permeability and water and nutrient holding capacity, contain clays that are mainly of the montmorillonitic or mixed layer type, are calcareous in the subsoil, and have colors that are

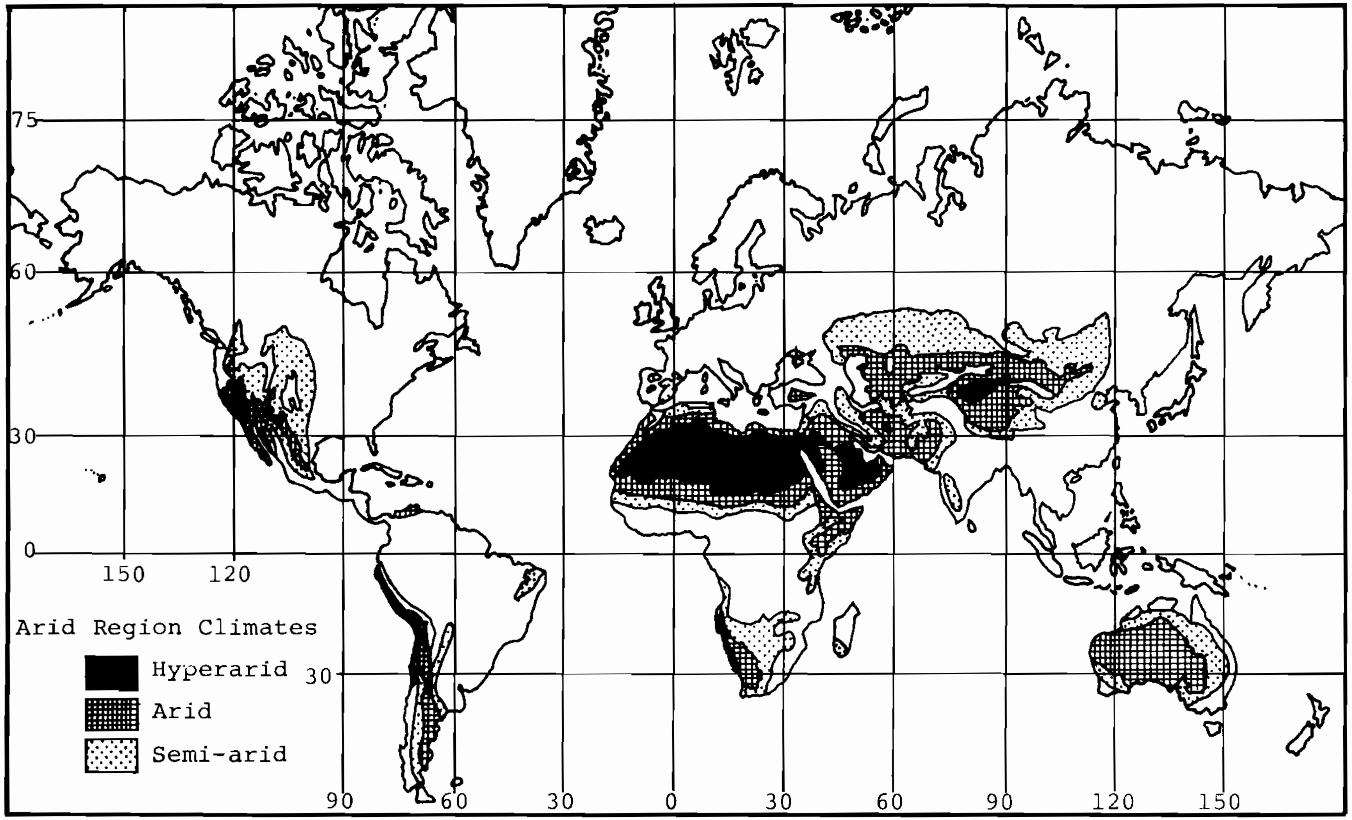



FIGURE 1. Arid regions of the world

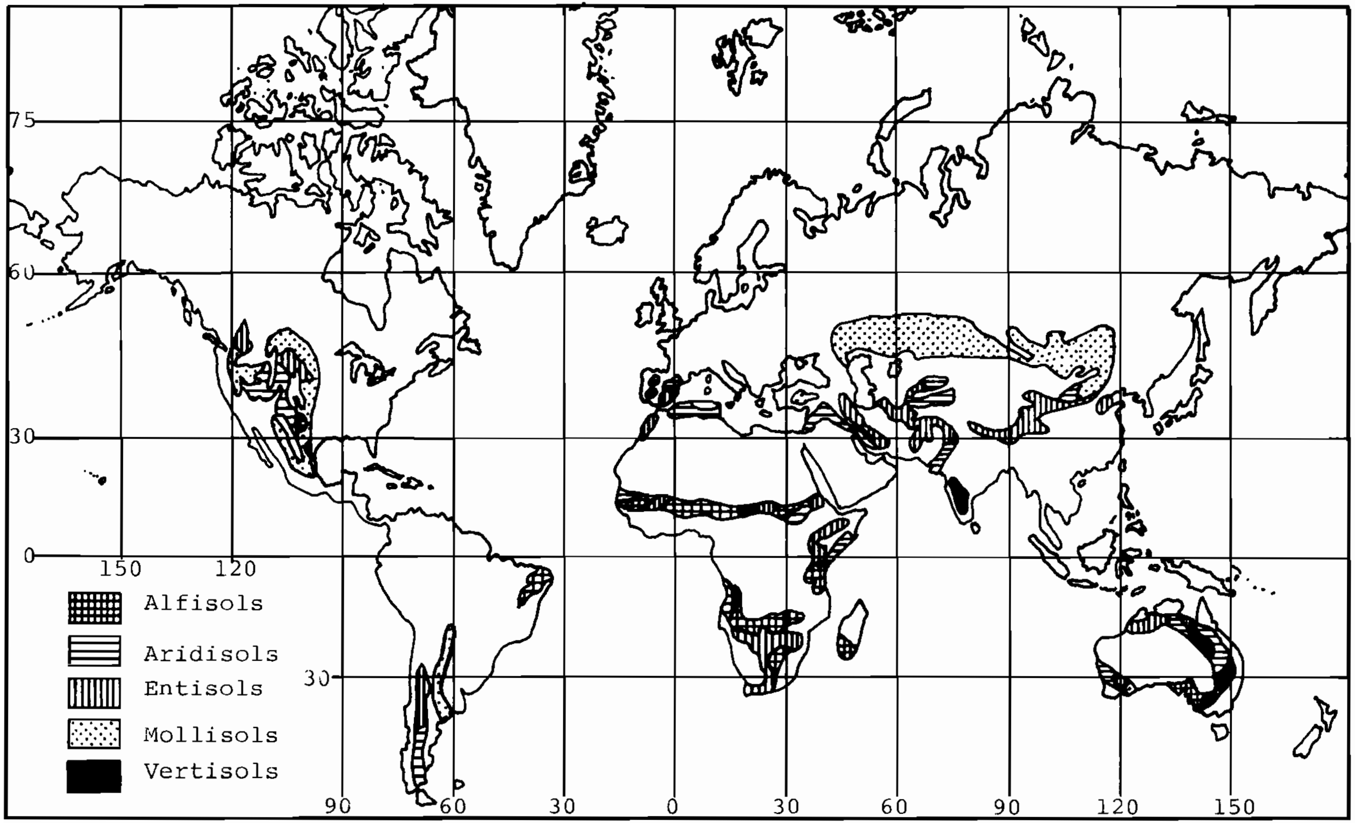



FIGURE 2. Soils of semi-arid regions

mostly gray in the cool regions and brown or red in the warm regions. The climate is Mediterranean (wet winters, dry summers) or continental (cold winters, rain throughout the year). The principal soil orders are Aridisols, Entisols, Mollisols, and Alfisols.

Organic matter levels are low in both groups of soils, commonly running less than 1 percent organic carbon in the surface horizon. Nitrogen content is also low and nitrogen deficiencies are to be expected when the soils are cultivated.

In the closed basins that are typical of arid regions, soils are almost always fine textured clays having low permeability, due to their high content of expanding (montmorillonitic) clay minerals. In the United States and FAO soil classification system, they belong to the Vertisol order.

## SOIL CHARACTERISTICS

Soil development is primarily a function of the age of the land surface, slope of the land, and the climate (2). Old, level to slightly undulating surfaces in a warm and wet climate tend to be more highly developed (have B horizons showing clay accumulation - argillic horizons) than young soils on moderate to steep slopes in a cool dry climate. Of the soil orders occupying large land areas in the arid regions, Entisols and Vertisols are poorly developed soils, Aridisols and Mollisols are moderately developed, and Alfisols are well developed. All Alfisols contain argillic (translocated clay) horizons; some Aridisols and Mollisols have argillic horizons; Entisols and Vertisols do not. The presence of an argillic horizon indicates that there will be a reduction in permeability and a higher water holding capacity in the B horizon and, probably, a reduction in the ease with which roots penetrate that horizon.

In the temperate regions, soils of semiarid climatic zones frequently are calcareous throughout the profile or at all depths below the surface layer. Those soils that are calcareous to the surface are less fertile and more susceptible to wind erosion than the ones that are noncalcareous in the topsoil. High-lime soils tend to be less productive because the calcium carbonate reduces water and nutrient holding capacities, raises the pH, and lowers the availability of phosphorus, iron, and some trace elements.

Tropical Alfisols have rather low water holding and cation exchange capacities in the surface soil, with high capacities in the argillic B horizon. Phosphorus and sulfur availability usually is low and both potassium and trace element deficiencies are common. These soils are rather strongly leached despite the semiarid character of the climate. The entire annual rainfall may come in only three to five months and much of it will move through the permeable profile, carrying soluble matter out of the soil.

Salinity problems in the semiarid regions are confined to a few special places in the landscape. Upland gypsiferous soils are saline in the subsoil and may be saline in the surface. Rainfed croplands may display a salinity condition known as saline seepage, which is due to removing deep rooted vegetation. Saline seeps are widespread in the dryfarm lands of Australia and the northern Great Plains of the United States and Canada. Natural salt accumulations are common in closed basins and in estuaries of rivers. Salinization of irrigated land is much less severe in semiarid regions than in the drier areas.

Profile characteristics of four representative soils of semiarid regions are given in Tables 1, 2, 3 and 4. The Alfisol of Table 1 is typical of the leached acidic soils occurring south of the Sahara, whereas the Alfisol of Table 2 has the properties that are expected in northern hemisphere semiarid regions having a continental climate. The dominant clay minerals of the tropical Alfisol are those of the mixed layer or kaolinitic type; those of the temperate zone Alfisol are mainly mixed layer and montmorillonitic.

Table 3 gives data on a gypsiferous soil of the kind found extensively in the United States and Mexico and in the Middle East. As is the case for most - if not all - gypsiferous soils, this one is also calcareous. The Mollisol of Table 4 is representative of grassland soils in the wetter part of the semiarid zone. The organic matter content of Mollisols is greater than other upland soils of semiarid regions. For this profile, it amounted to 1.1 percent in the upper 41 cm.

## SALINE SEEPAGE

One of the more unusual man-made salinity and wetness problems found in the semiarid regions is that of dryland saline seeps. Recognition that the problem existed and was due to management practices came about 50 years ago, beginning in western Australia. Currently, the largest areas affected are in the wheat regions of Australia and the northern Great Plains of Canada and the United States. It is a problem that is getting worse.

Saline seepage occurs on sloping land underlain by saline strata. It is the result of a reduction in evapotranspiration when deep-rooted plants are replaced by shallow-rooted plants that transpire less water. It also arises when cultivated land is fallowed and when level terraces bring about greater infiltration of water during wet years. If the greater water penetration and reduced evapotranspiration lead to lateral movement of excess water, the water may seep out somewhere on the slide of the

TABLE 1.
Profile Characteristics of a Tropical Alfisol (Psammentic Paleustalf)

| Depth cm | Horizon | Particle Size Sand % | Particle Size Silt % | Particle Size Clay % | Textural Class | pHs | C.E.C.[a] | Base Saturation % |
|---|---|---|---|---|---|---|---|---|
| 0-20 | Ap | 96 | tr | 4 | L | 6.4 | 1.8 | 67 |
| 20-54 | B11 | 85 | 3 | 12 | LS | 5.5 | | - |
| 54-102 | B12 | 82 | 2 | 16 | SL | 5.4 | | - |
| 102+ | B2t | 73 | 5 | 22 | SCL | 5.5 | 13.2 | 47 |

TABLE 2.
Profile Characteristics of a Temperate Zone Alfisol (Aridic Paleustalf)

| Depth cm | Horizon | Particle Size Sand % | Particle Size Silt % | Particle Size Clay % | Textural Class | pH 1:1 | C.E.C.[a] | Base Saturation % |
|---|---|---|---|---|---|---|---|---|
| 0-10 | Ap | 84 | 10 | 6 | LFS | 8.1 | 6.3 | 100 |
| 10-23 | A12 | 66 | 20 | 14 | FSL | 7.7 | 11.0 | 91 |
| 23-35 | B21t | 63 | 18 | 19 | FSL | 7.5 | 12.5 | 85 |
| 35-74 | B22t | 58 | 21 | 21 | SCL | 7.5 | 14.2 | 91 |
| 74-96 | B23t | 49 | 25 | 26 | SCL | 7.6 | 17.3 | 96 |
| 96-150 | B24t ca | 57 | 19 | 24 | FSL | 7.9 | 15.8 | - |

[a]C.E.C. = cation exchange capacity, me/100g.

TABLE 3.
Profile Characteristics of an Aridisol (Typic Gypsiorthid)

| Depth cm | Horizon | Particle Size Sand % | Particle Size Silt % | Particle Size Clay % | Textural Class | pH 1:1 | C.E.C.[a] | Base Saturation % |
|---|---|---|---|---|---|---|---|---|
| 0-0.6 | A11 | 31 | 43 | 26 | L | 7.9 | 20.0 | 100 |
| 0.6-5 | A12 | 28 | 42 | 30 | CL | 7.9 | 21.8 | 100 |
| 5-12 | A13 | 29 | 42 | 29 | CL | 7.9 | 21.6 | 100 |
| 12-33 | B21ca | 25 | 40 | 45 | CL | 7.8 | 21.0 | 100 |
| 33-56 | B22ca | 22 | 40 | 38 | CL | 7.4 | 21.7 | 100 |
| 56-84 | C1cs | 20 | 30 | 50 | C | 7.6 | 6.0 | 100 |
| 84-117 | C2cs | 10 | 50 | 40 | SiCL | 7.7 | 9.6 | 100 |

TABLE 4.
Profile Characteristics of a Mollisol (Aridic Calciustoll)

| Depth cm | Horizon | Particle Size Sand % | Particle Size Silt % | Particle Size Clay % | Textural Class | pH 1:1 | C.E.C.[a] | Base Saturation % |
|---|---|---|---|---|---|---|---|---|
| 0-18 | Ap | 62 | 19 | 19 | FSL | 8.0 | 17.9 | 100 |
| 18-41 | A12 | 43 | 26 | 31 | CL | 7.9 | 20.3 | 100 |
| 41-68 | B21 | 36 | 33 | 31 | CL | 8.0 | 18.6 | 100 |
| 68-96 | B22 | 32 | 26 | 42 | C | 8.1 | 18.1 | 100 |
| 96-137 | C1ca | 29 | 26 | 45 | C | 8.1 | 11.4 | 100 |
| 137-183 | C2ca | 25 | 31 | 44 | C | 8.3 | 13.6 | 100 |

[a]C.E.C. = cation exchange capacity, me/100g.

sloping land or accumulate in low-lying areas. Seepage water will be saline if there are saline strata in the subsoil or non-saline if such strata are not present. Both conditions exist.

The usual situation for saline seepage to develop is where deep-rooted trees are removed and wheat is grown. Seepage also occurs when native grasses are replaced by a wheat-fallow cropping sequence. In the latter case, seepage is increased during the fallow period when evapotranspiration is low.

In places where salinity is not a problem, the increased seepage due to replacement of deep-rooted vegetation by grasses can be beneficial. This is one of the advantages of brush control in semiarid regions. Stream and spring flow commonly is reduced when deep-rooted brush such as mesquite (*Prosopis* spp.) invades grasslands. Replacing the brush with grasses tends to restore ground water flow and stream flow.

## USE AND MANAGEMENT

### Plant Nutrients

Plant nutrient deficiencies that are likely to occur when crop production is attempted on semiarid region soils center on nitrogen and phosphorus. Nitrogen deficiencies can be expected nearly everywhere after a few years of cultivation. Phosphorus deficiencies are less marked on the gray soils of temperate zones but are pronounced on red, well-drained soils such as the tropical Alfisols. Nitrogen and phosphorus deficiencies are less likely to be severe on the high organic matter Mollisols of grasslands. Potassium deficiencies are found in soils of the wetter parts of the semiarid zone but are rare in the drier sections. Sulfur deficiencies can occur in crops grown on tropical Alfisols, and zinc and iron deficiencies are common in highly calcareous soils. In Australia, where trace element deficiencies seem to be accentuated, crop response to copper, molybdenum, and manganese, in addition to zinc and iron, have been noted in dryland cereals.

### Water Conservation

Water conservation is the primary need for agricultural production in the semiarid regions. Conservation is accomplished by preventing runoff, collecting runoff water, providing storage reservoirs, reducing evaporation, and utilizing management practices such as fallowing land between crops. Terracing is the most common way to prevent or reduce runoff and is widely used in dryland farming. Runoff farming using water harvesting techniques has been practiced for millenia in subsistence agriculture (3) but has not yet been adapted successfully to commercial agriculture. The potential for water harvesting appears to be considerable if materials and techniques can be found that are economic to use and are suitable for mechanized operations.

Reducing evaporation from soil and plant surfaces is technically feasible now but the cost exceeds the returns in many cases. Various ionic and non-ionic products have been developed to coat soil and plants with impermeable covers that prevent evaporation. To date, the high cost of application limits their use to high acre-value crops. Fallowing to reduce evaporation and conserve moisture in crop land is effective in some places but not in others. It is not useful where temperatures are high and dry seasons are lengthy. The benefit of fallowing often is in the soil nitrogen mineralization that occurs rather than in moisture conservation (4). Minimum tillage is another management method that helps to conserve moisture.

## Erosion

Although wind erosion is more dramatic in its effect on the human population, water erosion causes considerably greater damage to land resources in semiarid regions. This greater damage is done despite the fact that water erosion control measures are easier to apply than wind erosion control measures. The difference is that water erosion can occur on any sloping land, whereas the major threat of wind erosion is on sandy lands.

Water erosion can be controlled by terracing, strip cropping, contour cultivation, minimum tillage, and the planting of trees and grasses. Terraces can be constructed in wet or dry regions and are not dependent upon favorable rainfall. Wind erosion, on the other hand, requires some kind of vegetative cover for long-term control. In the drier part of the semiarid zone, the impact of droughts frequently leads to a severe reduction of plant cover and a corresponding increase in susceptibility to wind damage. In fact, the increase in the wind erosion hazard that accompanies a drought comes just when the vegetative protection of the soil is at a minimum.

On a worldwide basis, both wind and water erosion are being accelerated in the developing countries by the expansion of cultivation from the wetter parts of the semiarid regions into the drier parts. Good rangelands are being sacrificed to the ever-greater need for food crops, and with it goes an increasing risk of erosion as lands become more and more marginal for dryland cropping.

Erosion control is practiced poorly in most of the semiarid regions despite the availability of knowledge about the principles involved. There are many reasons for the poor performance record in erosion control. The most important probably are the absence of good research information, the lack of an effective extension service to advise farmers, the inability of poverty-stricken farmers to install needed control measures, and the uncertainty about the short-term benefits of conservation practices. Among other reasons is the lack of political will by governments to assign a high priority to a problem that seldom is dramatic and wreaks its damage slowly.

## SUMMARY

Soils of semiarid regions belong to two major categories: 1) acidic leached soils of the tropics and subtropics and 2) neutral to alkaline calcareous soils of the temperate zone. The former are dominantly Alfisols and Entisols whereas the latter are mostly Aridisols, Entisols, and Mollisols. Soils in closed depressions are Vertisols having similar characteristics irrespective of the climatic zone in which they occur.

Nitrogen and phosphorus are likely to be deficient for crop production everywhere in the semiarid regions. Deficiencies of sulfur, potassium, zinc, and iron are related to particular kinds of soils.

Management practices for crop production are primarily oriented toward water conservation and wind erosion control. Techniques for doing so are, in general, already known but much remains to be done in applying them.

## REFERENCES

1. Dregne, H.E., Soils of Arid Regions, Elsevier Scientific Publishing Company, Amsterdam, The Netherlands, (1976).
2. Jenny, Hans, Factors of Soil Formation, McGraw-Hill Book Company Inc., New York, (1941).
3. Evenari, M., Nessler, U., Rogel, A. and Schenk, O., Fields and Pastures in Deserts, Eduard Roether, Buchdruckerei und Verlag, Darmstadt, Germany, (1975).
4. Sims, H.J., Cultivation and fallowing practices, In Russell, J.S. and Greacen, E.L. (editors), Soil Factors in Crop Production in a Semi-arid Environment, University of Queensland Press, St. Lucia, Queensland, Australia, (1977).

6

# Remote Sensing to Detect Desertification Processes

*K. J. Dalsted*
*V. I. Myers*

## INTRODUCTION

Nearly one-third of the earth's surface, excluding polar regions, has been defined as arid lands according to soil groups (1), vegetation (2), and climate (3). In numerous instances, reduction in the productivity of these lands has resulted in serious consequences not only for the environment but for local populations. Reduction in productivity or degradation of arid-lands environments had been termed desertification (4) or, in a somewhat more restricted sense, desertization (5). Causes, controls and impacts of desertification have been outlined in great detail elsewhere (6,7).

The major causes of desertification are thought to be overgrazing, lack of erosion control, and improper water management (5,8,9). In some areas cutting of trees for fuel, crusting of the soil surface, and burning of rangeland (10) have also been cited as causes of desertification. All of the above practices imply man's mismanagement, but events of nature, such as the distribution of precipitation, also can exacerbate the degradation process. Disturbance or removal of surface cover can lead to severe erosion, water erosion during intense rains or wind erosion in dry, windy cycles.

In the Sahel region of Africa, for example, the frequency distribution of rainfall is more likely to be below the mean than above it, and the overall distribution has a large coefficient of variation (11). Coupled with the skewed precipitation distribution is the tendency of local inhabitants to adopt practices which are designed for wet years. Improved animal health programs and other livestock improvements in the Sahel (12) and growing populations with their demands for food and fiber place even more pressure on the environment.

Remote sensing has been acknowledged as a valuable tool in recognizing several so-called indicators of desertification (9,13,14). However, knowledge of a particular region's resources is incumbent to any program(s) of systematically identifying indicators of desertification. Considering the vast area of arid lands and time required for detailed mapping of resources, reconnaissance surveys appear to be the best alternative for gathering the data. Landsat imagery has been used as a low-cost, efficient base for completing reconnaissance-level surveys around the world. The Veracruz region of Mexico (15), the Sudd region of Sudan (16,17), and the Middle Luni Basin of India (18) are but a few regions where Landsat data have been employed in resource mapping projects.

The objectives of this paper are twofold: 1) to detail the use of Landsat data in completing region-wide resource information, and 2) to illustrate uses of Landsat and other information to define levels of susceptibility to desertification. Examples are presented from Sudan, Mauritania and Senegal, and India.

## METHODS AND MATERIALS

Utilization of Landsat imagery and concomitant data provides an efficient, multistage approach to resource mapping. Acquisition of available Landsat imagery from the EROS Data Center or from a regional data receiving center for the area is the first step. Cyclic precipitation distribution, viz. wet season and dry season, must be considered in the selection of Landsat data to provide maximum information.

The multispectral bands of Landsat may be used individually or, collectively, in a false color representation. Soils, geology, surficial hydrology, land use, and vegetation are common themes in a Landsat-based reconnaissance survey. Scales that are commonly used are 1: 1,000,000 or 1:500,000. For certain themes that require larger scales, e.g. location of irrigated lands, surface water or other spectrally contrasting themes, scales such as 1:250,000 or 1:200,000 can be used. The area of minimum delineations increases dramatically with larger scales and therefore can require greater intensity of ground observations.

Preliminary delineations based on available resource information and interpretation of Landsat are made on overlays on the imagery. These delineations provide a basis for field investigation and characterization of mapping units. If aerial photographs are available they can be used to further verify and update mapping units. Prior to on-ground characterization, the preliminary delineations are checked (i.e. lines are adjusted, eliminated, and/or added) from low level aircraft over-flights transecting initial mapping unit delineations. Composition and properties of the various mapping units are next completed in the field by a team of resource experts. For example, soil profile descriptions and sampling of soil horizons provide both taxonomic information of the mapping unit and chemical and physical characterizations for use in determining agricultural potential. When available, aerial photography can also be used in representative block mapping exercises (i.e. semi-detailed scales) to further define soil mapping unit composition. Management and land use practices are also recorded as they affect the status and utilization of the resources. Interpretations from the survey are based on field investigations and sampling. A good foundation of resource information is established for use as baseline data in time-progressive programs or evaluations.

Indicators of environmental degradation vary in magnitude, distribution and extent. The usefulness of Landsat imagery is, therefore, restricted to those indicators that can be consistantly located with respect to Landsat's small scale view. Collection of data such as cropping systems, range stocking rates, distribution of watering holes, etc. are important to the overall understanding of mechanisms of desertification. The causes of desertification must be ascertained in a region in order to determine what the indicators are and what their significance is.

The Landsat resource survey and its interpretations provide a means of stratifying regions according to susceptibility to desertification (e.g. wind erodibility, suitability for various agricultural crops). Ground observations can then be concentrated in those regions where susceptibility to desertification is greatest.

## RESULTS AND DISCUSSION

Desertification is a world-wide problem, but its manifestations are multiform in nature and appearance. Consequently, approaches must acknowledge the inherent peculiarities of a region's resources, climate, land use practices and population. The manifold nature of desertification and its many and interlaced components or causes dictate that region-by-region analyses take place.

This paper discusses application of Landsat data and other information in three regions: Sudan, Mauritania-Senegal, and India.

### Sudan Example

The following section is based on technical reports presented by Ali (19) and Mohamed and Idris (20). Central Sudan is a zone of transition from a semi-desert to a semi-arid environment (north to south). This area is covered by 14 Landsat scenes, has recently experienced a lowered carrying capacity for livestock and a reduction in crop production due to the combined pressure of man and adverse climate.

All of the causes of desertification previously outlined were found in this region of Sudan. The authors incorporated Landsat data with other resource data and determined patterns, limitations, and potentials of land use, vegetation and soils. Soil resources were mapped for the region, and soil interpretations were completed, e.g. suitability for indigenous crops and susceptibility of soil to deflation.

Aeolian features and areas of bare dunes were key landforms used in the Landsat analysis. Source areas for sand and channels of strong turbulence were located and analyzed using Landsat imagery (Figure 1). Marrs et al. (21) utilized a similar approach to define source areas and wind channels for sand dunes in Wyoming, U.S.A. Landsat data revealed patterns and channels from source to deposition areas. Definition of areas highly susceptible to wind erosion was thereby accomplished with minimal expenditures in ground observation, cost, and time.

Wind erosion is a significant problem due to overgrazing, low precipitation, sandy soils, and strong winds during the dry season. The soil characteristics which are influential in wind erosion were extracted from survey characterizations (Figure 2). The soil properties which were considered in this theme extraction were wetness, texture, slope, and percent plant residue cover.

The characteristics of Landsat data were found to be applicable to region-wide resource studies in Sudan. Limitations and suitability of soils were interpreted from the reconnaissance-level soil survey. The results have utility in defining the mechanisms of desertification in Central Sudan. Management alternatives can be formulated from this baseline data, and appropriate strategies and/or more detailed observations can be concentrated in critical zones.

## Mauritania-Senegal Example

The Sahel region of Africa encompasses a large band of arid lands south of the Sahara. This region experienced a recent drought from 1968 to 1973; the results were devastating in terms of lives lost and reduction in livestock herds. This in part prompted disaster agencies such as United States Aid for International Development (USAID) to seek a means of quantifying the effects of desertification (22).

Parts of ten Landsat scenes were examined to investigate the application of Landsat data to desertification. This region (Figure 3) is located in an area of low precipitation (100 to 300 mm) and coarse-textured soils. Agriculture is concentrated near and in the Senegal River Valley. This is significant in terms of crop production for the countries involved but especially so for Mauritania due to its paucity of rainfall and good soils.

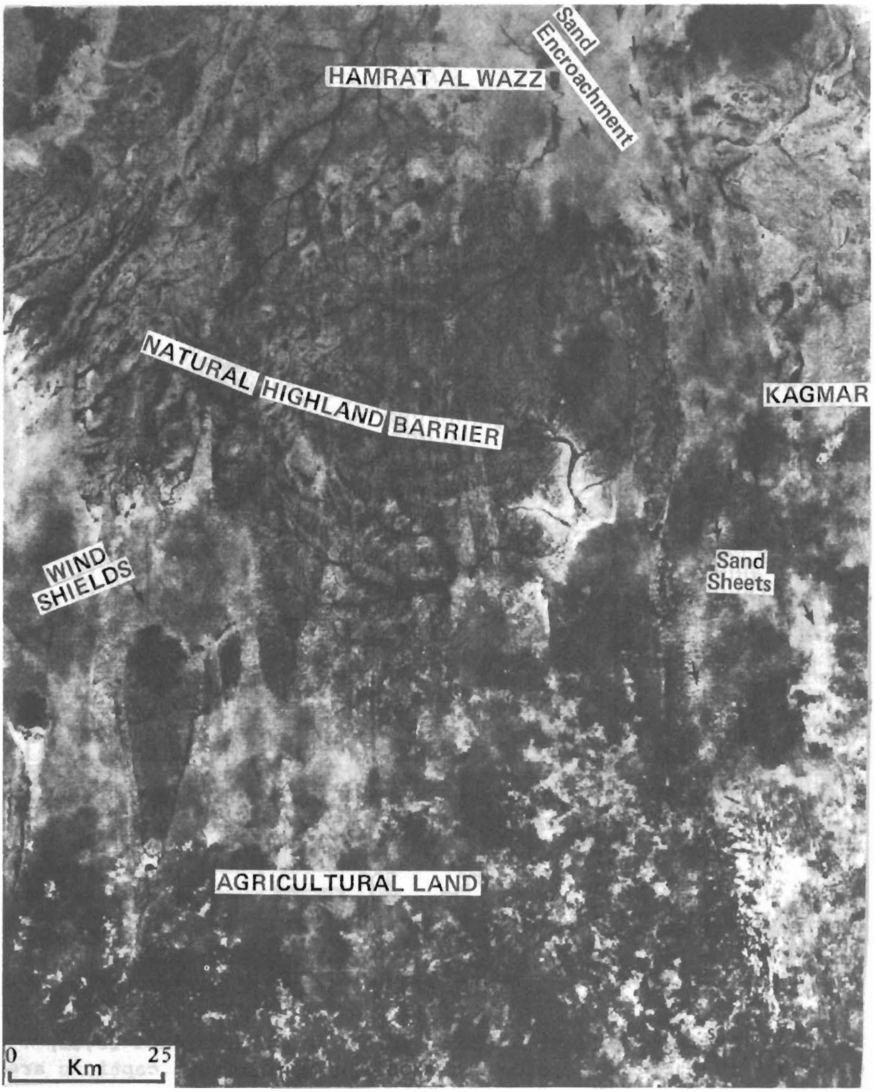



FIGURE 1. Black and white print of Landsat color composite showing a natural barrier and wind corridors in Central Sudan. Sand sheets, wind directions and corridors, and areas protected from sand are easily discernable. Conservation practices should be implemented in the areas upwind from agricultural lands (after Ali, 19).

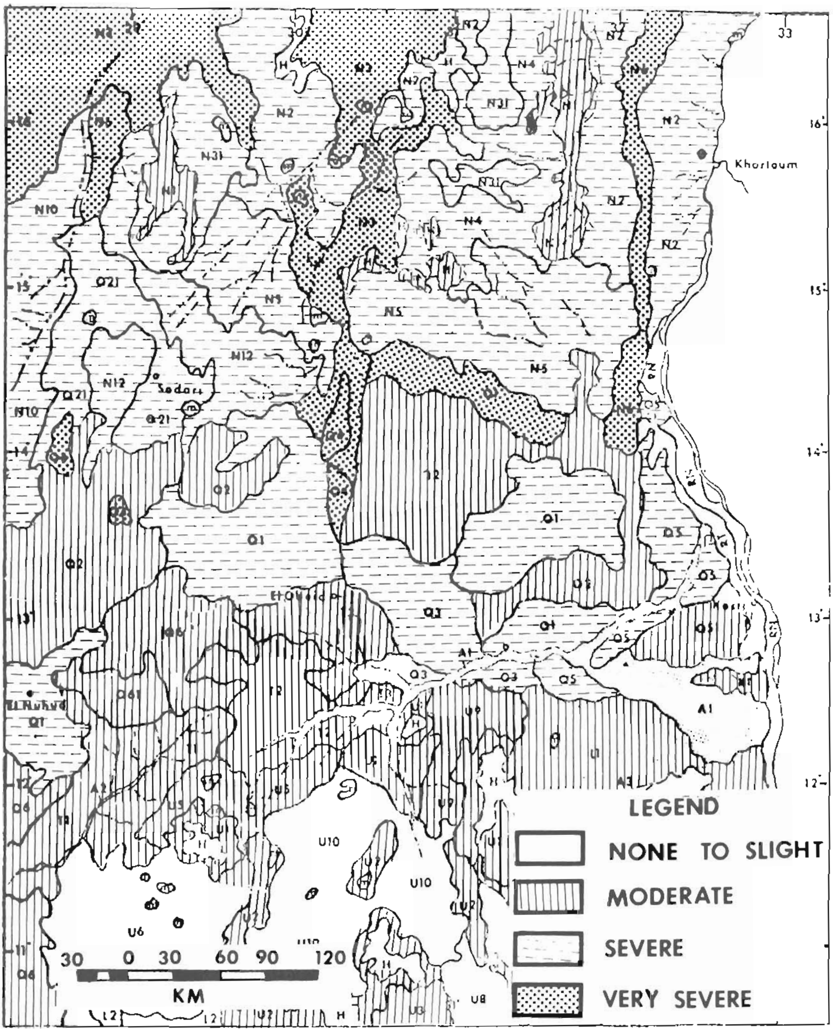



FIGURE 2. Thematic extraction from Landsat (reconnaissance-level) resource survey is shown in Central Sudan. Alphanumeric captions are physiographic units: N1 - Northern Plateaus and Pediplains; Q - Sandy Qoz Lands; T - Deflation Area; N - Nuba Uplands; L - Flat Clay Plains; A1 - Seasonal Water Course, alluvial; R - Floodplains and Terraces of White Nile; and A - Mountains and Hills. The susceptibility of areas to wind erosion is very useful in determining where conservation practices should be concentrated. Planning efforts benefit from knowing the location and extent of this problem (after Mohamed and Idris, 20).

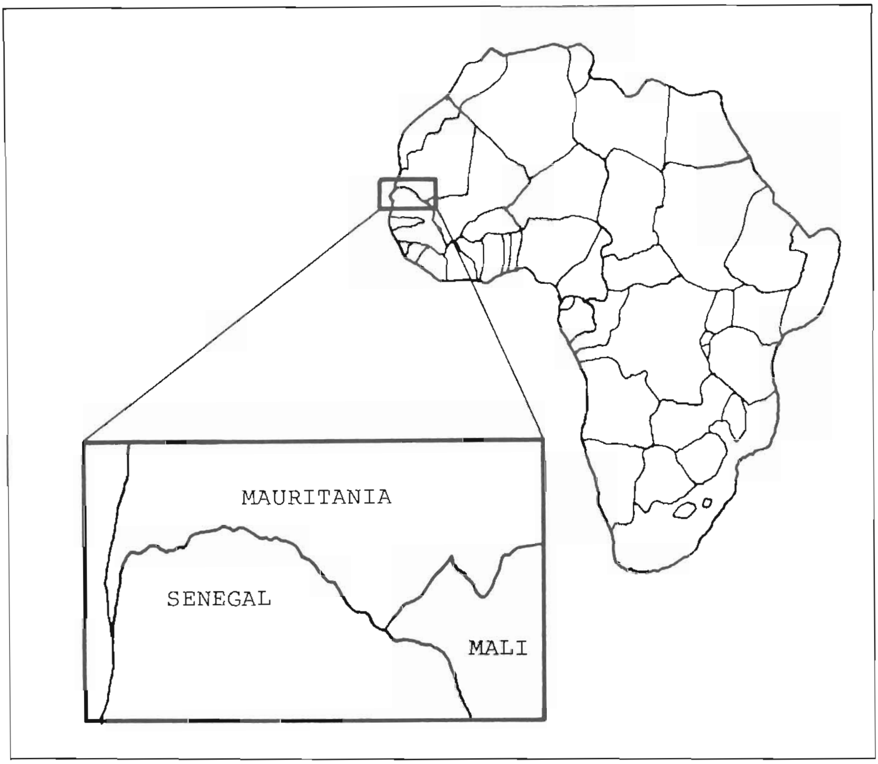



FIGURE 3. Location of study area for desertification investigation in Mauritania-Senegal (16)

The multistage approach to the resource survey provides a quick and inexpensive means of surveying and characterizing mapping units. Availability of Return Beam Vidicon (RBV) imagery from Landsat 3 and medium-level air photography add further dimensions to survey techniques (Figures 4, 5 and 6). While the physiographic and soil delineations are based on Landsat data, climate records, and available soils information, air-photo interpretations provided a secondary means of verification. Ground authentication would be needed before finalization of mapping units. Digital, computer-enhanced Landsat imagery as well as digital transformations of Landsat data for vegetation, soils, and other (23,24) have potential for supplementing interpretations made from the standard Landsat products.

Based on the physiography, an arid region can often be stratified into units of varying susceptibility to the various components of desertification, e.g. wind erosion (Figure 7). Further refinement of detail can be accomplished utilizing current air photos (Figure 8). Landform analysis provides numerous clues to the identification

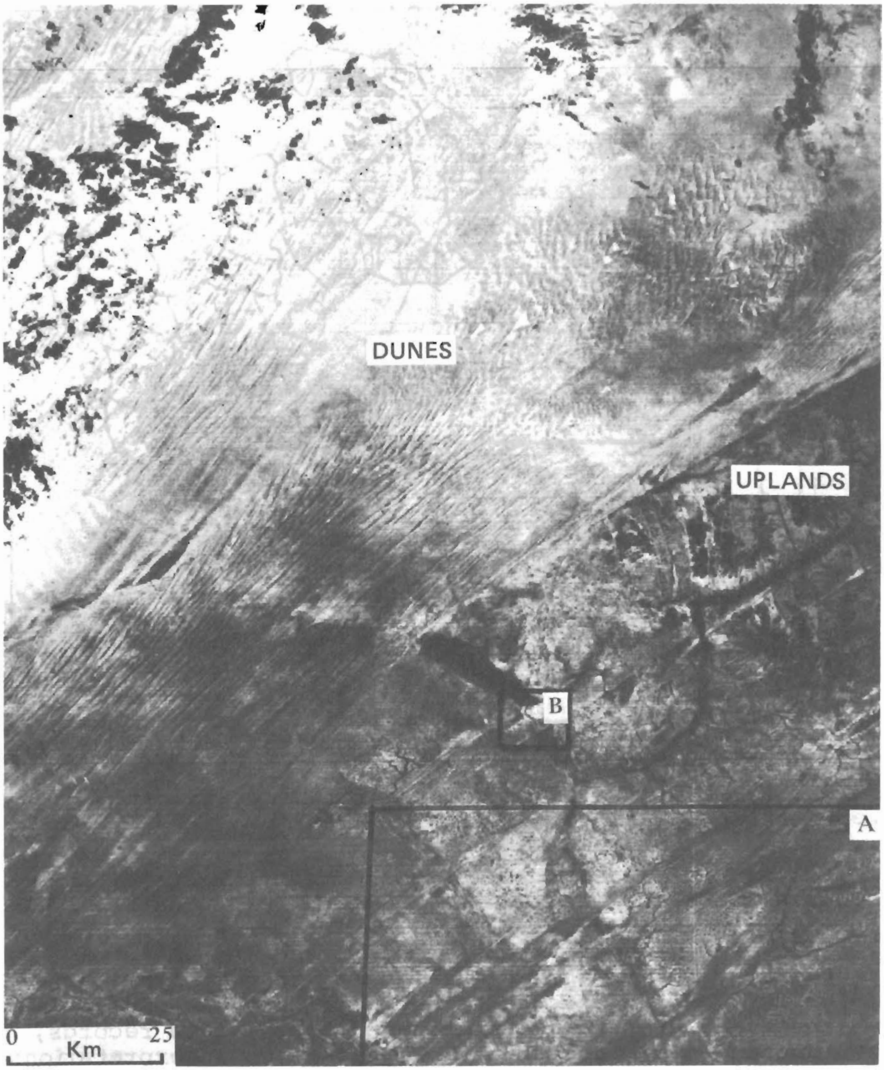



FIGURE 4. Black and white print of Landsat color composite of Mauritania showing the interface of dune and upland physiography. Sand stringers in the uplands are apparent. Clouds and cloud shadows are concentrated in the northwest one-quarter of this scene. Dune types are easily divided into longitudinal and transverse; this is strongly influenced by wind direction and velocity. A - Area of Landsat scene which is partially covered by the Return Beam Vidicon (RBV) image shown in Figure 5. B - Area of air photo in Figure 6.

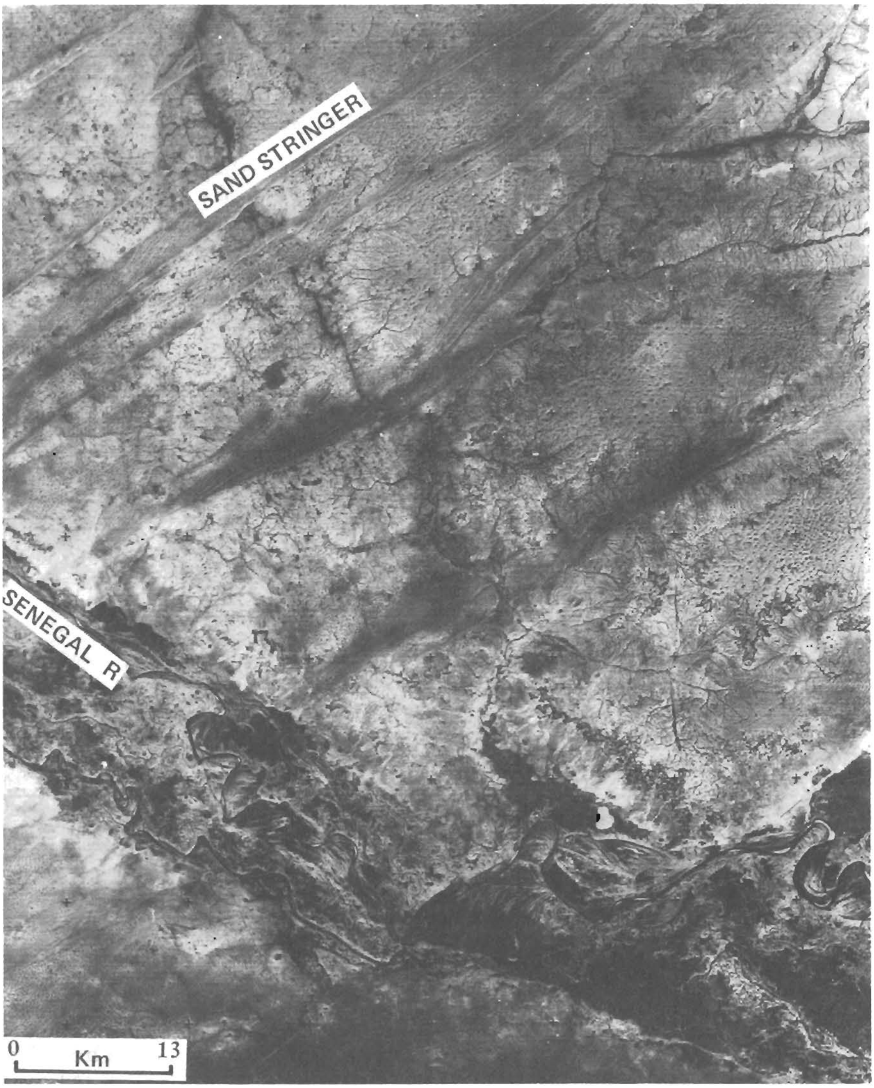



FIGURE 5. A RBV image, a subscene of the Landsat Multispectral Scanner (MSS) (see Figure 4) is shown. Details of landform, land use, surficial drainage are superior to Landsat MSS imagery, but RBV is spectrally inferior to Landsat MSS.

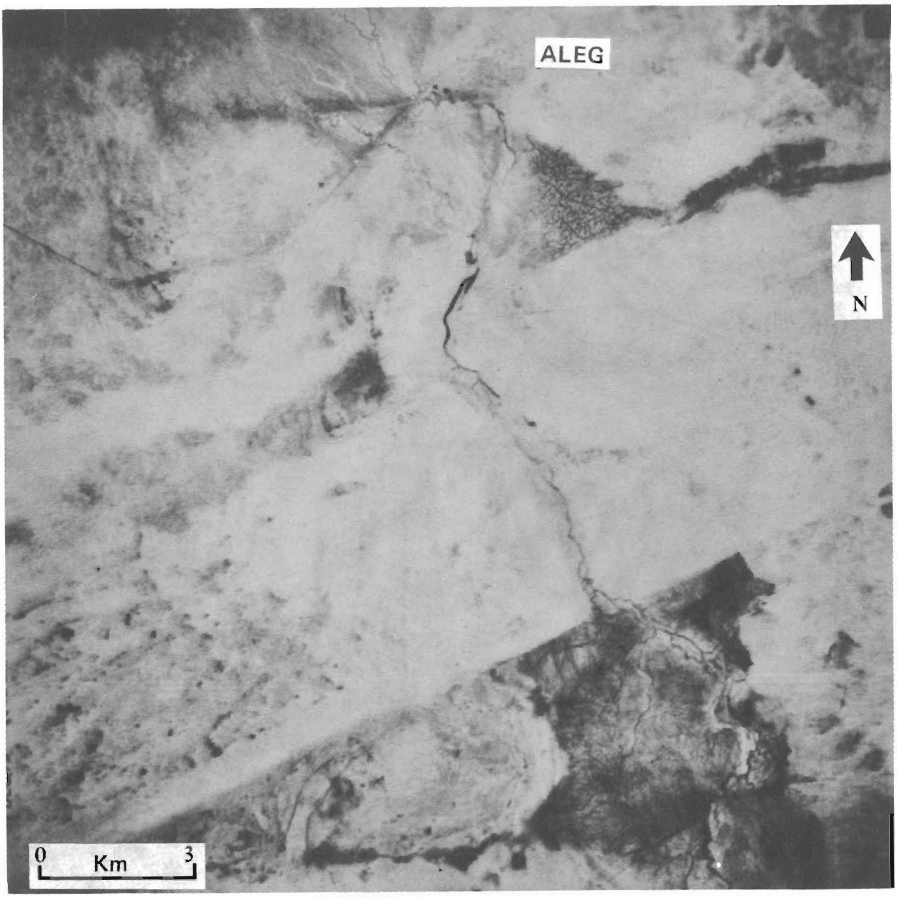
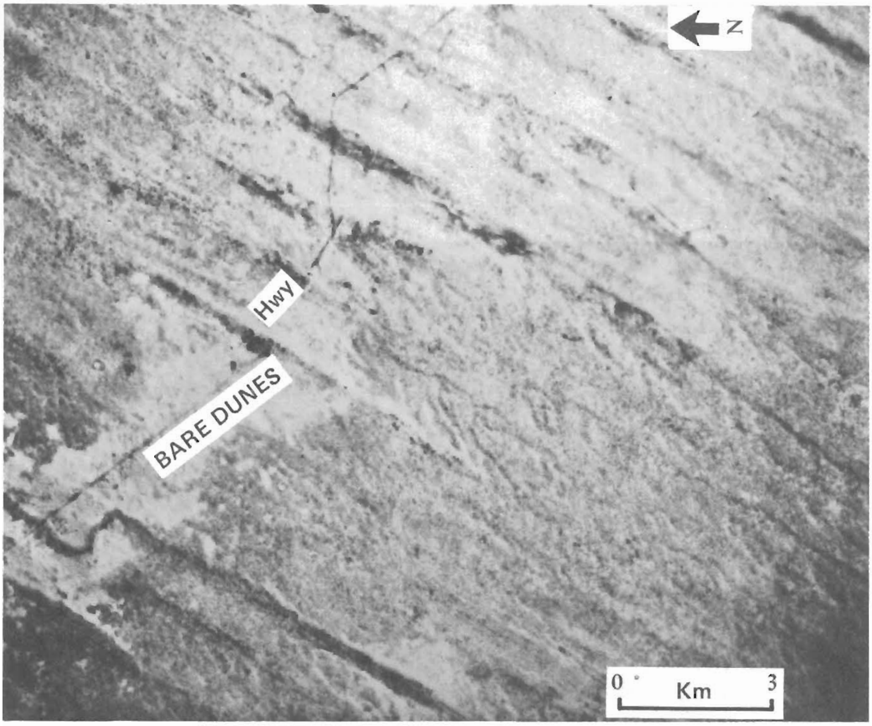



FIGURE 6. A color infrared aerial photograph of the Aleg area is reproduced in black and white. Original scale was 1:50,000. Comparison to Landsat imagery reveals both the detail recorded by Landsat and the number of photographs that would be needed to cover one Landsat scene. Aerial photography is very useful in the multistage approach to mapping of resources and their current use, i.e. soils, vegetation, land use, surficial hydrology, geology. (Air photo was obtained under USAID Contract AID/afr-C-1619, Mauritania Renewable Resource Management).


FIGURE 7. A black and white reproduction of a Landsat color composite reveals the varying degrees of vegetation in dune and inter-dune areas of southwest Mauritania. Dark tones indicate a vegetation cover or a wet surface. Lighter tones are less dense coverage of vegetation or, in some cases, salinity. The highway from Rosso to Nouakchott is well defined by barren dunes.



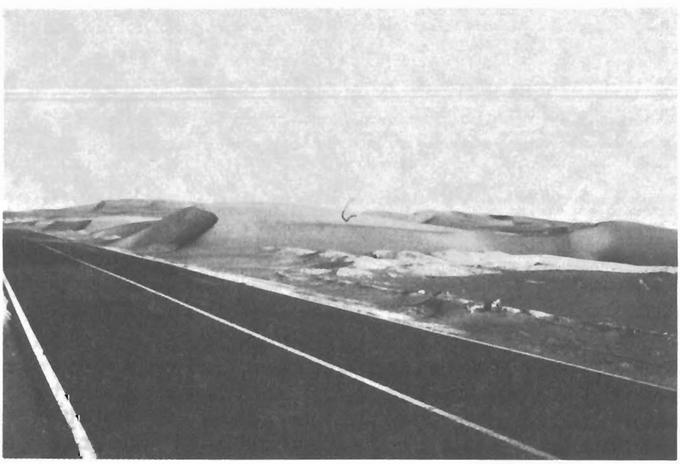



FIGURE 8. A black and white print of a color infrared aerial photograph corroborates the interpretation of barren dunes around the Nouakchott highway. A ground photograph from the highway gives perspective to the size of the dunes. (Aerial photograph is from USAID Contract AID/afr-C-1619, Mauritania Renewable Resource Management).

of resources and their potentials, e.g. shallow ground water (Figure 9). Further potentials and suitabilities can be completed upon finalization and characterization of the respective mapping units and their descriptions. Consequently, beyond the primary resource maps several thematic interpretations are possible.

Where regions of homogeneity have been delineated and ground checked, resistance to desertification can be quantified relative to the scale and detail of the survey. Specific indications within those regions can next be located to determine the present status of the environment. Numerous indicators are visible on Landsat imagery but air photos and ground checks are needed for full authentication. The following illustrative examples of desertification indicators are presented without complete ground observation.

Bare sand dunes within areas of stabilized dunes are often easily located (Figure 4). Burn patterns are another easily recognized feature on multidate Landsat imagery (Figure 10). Annual flooding of the Senegal River provides a recharge of moisture for flood recession agriculture. Since sedentary agriculture is concentrated along the Senegal River, the annual flooding is an important indicator of the potential success of crop production. Drought years are apparent when viewing multidate Landsat imagery (Figure 11).

Deforestation (Figure 12) is a critical indicator of potential desertification. Unless proper replanting programs or natural reforestation are pursued or allowed, a future supply of fuel will not be available. Additionally, the favorable edaphic environment created by trees (e.g. soil stability, shade, organic matter) will be degraded.

## Information Data Base - India Example

Shankarnarayan and Singh (18) reported that an evaluation of Landsat data revealed no advance of the desert in the Rajasthan Region of India. They did, however, ascertain that severe wind and water erosion and salinization were affecting large areas in the Indian arid zone. They determined that remote sensing techniques were of great value in the monitoring of this aspect of desertification.

Resource maps and thematic interpretations are extremely useful, but over large regions and with updates over time these data become unwieldy. Computerized data processing systems are available and they provide a multidimensional tool for storage and manipulation of resource data (25).

A computer output product for an earlier feasibility study around Jodhpur, India is shown (Figure 13). The data presented were entered into the system at a 4 $km^2$ cell size; this size is variable and dependent upon the size and shape characteristics of the mapping units, i.e. soils,

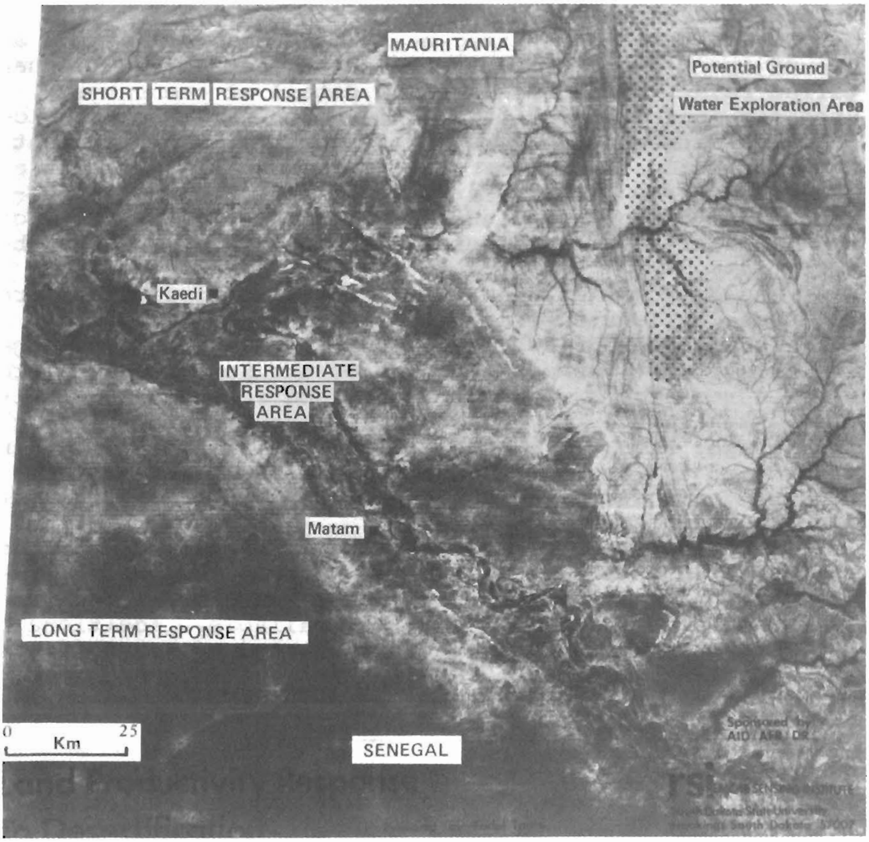
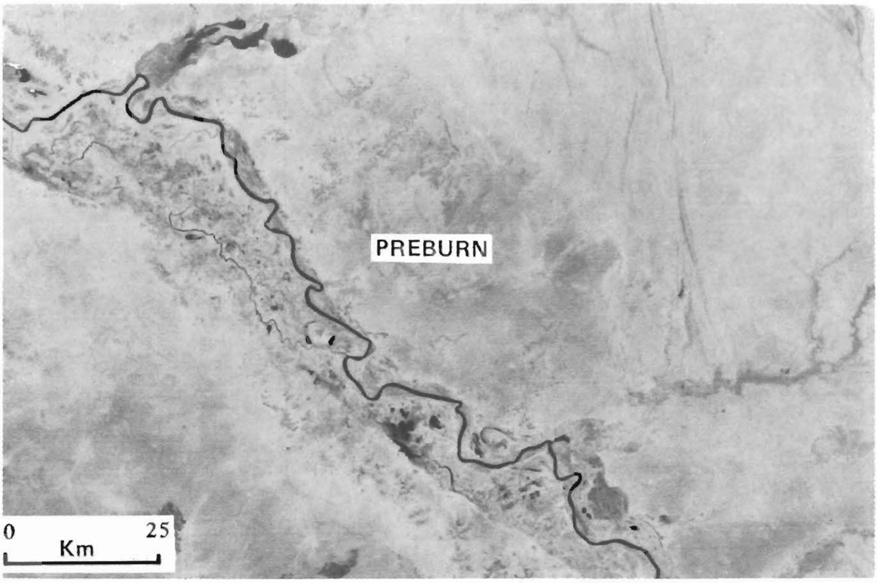



FIGURE 9. A black and white print of a Landsat color composite was used to locate a potential source of ground water in Mauritania. Geologic structures and drainage patterns were useful in determining this exploration area. A preliminary indication of susceptibility to desertification is also shown. The response areas are based upon photo-interpretation and available data. The ability of each area to resist desertification processes determines whether it is short, intermediate or long term.



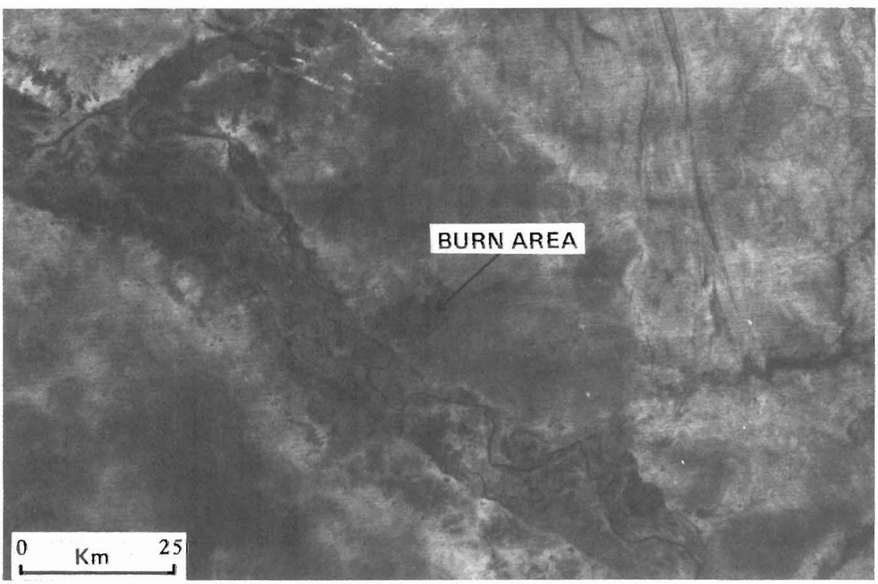
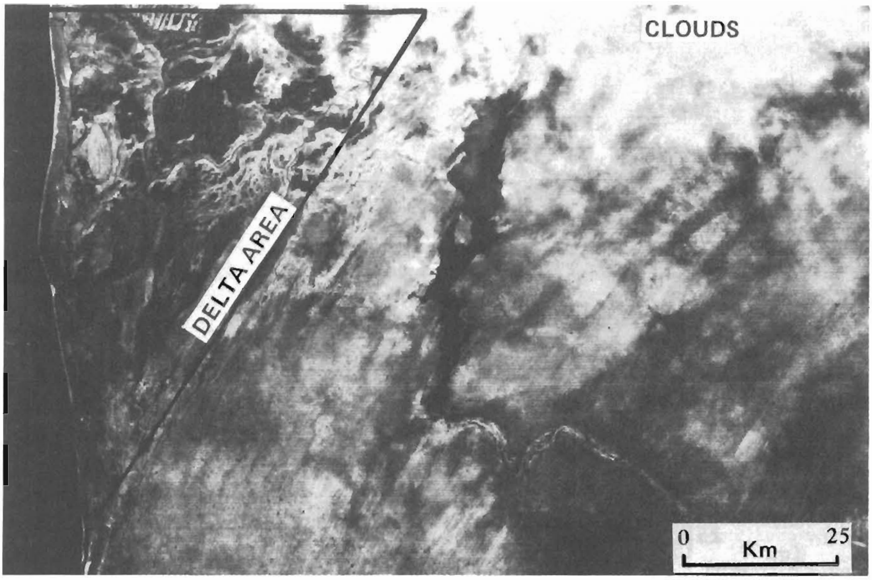




FIGURE 10. Landsat scene showing the Gorgol region of Mauritania before and after a burn. False color composite image is reproduced in black and white.



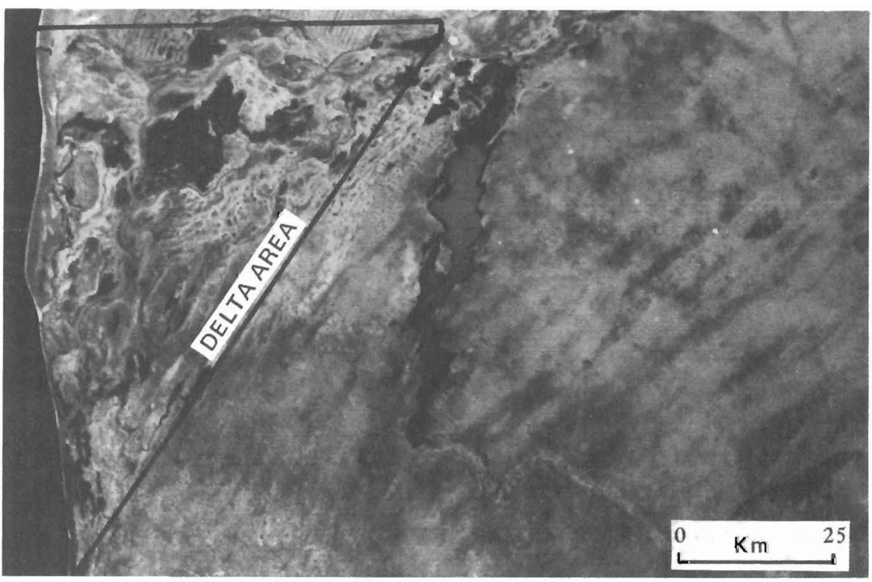
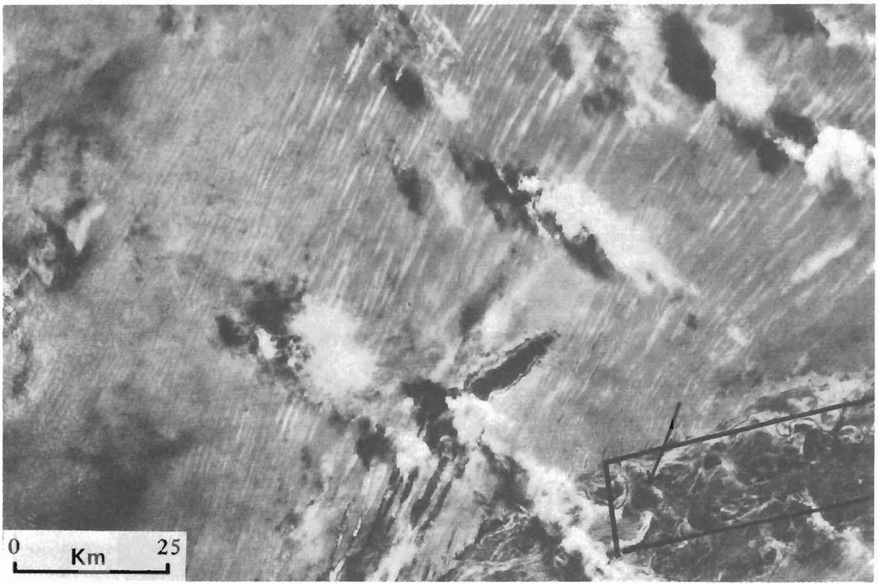




FIGURE 11. Extent of seasonal flooding at the Senegal River Delta. The 1972 Landsat scene shows more flooding than the 1977 scene. Dark tones are vegetation, wet soils, or standing water.



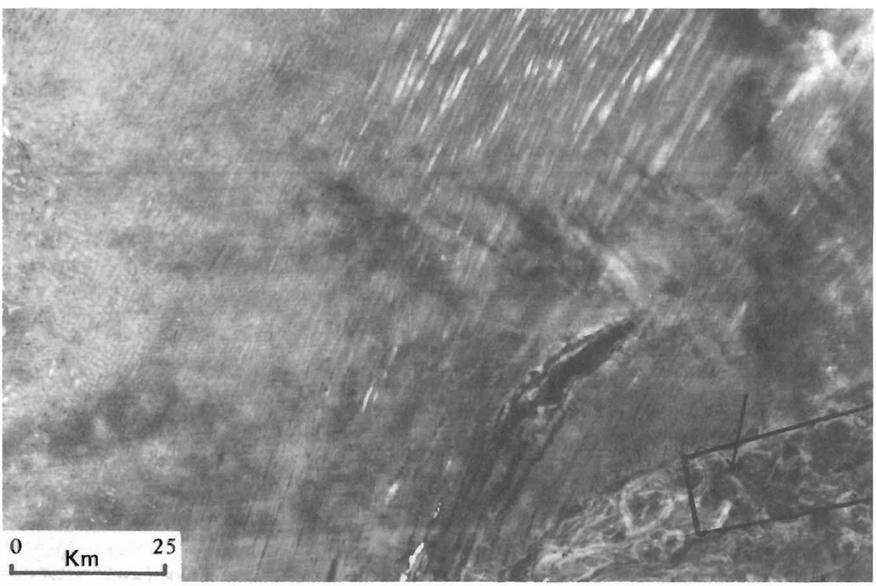
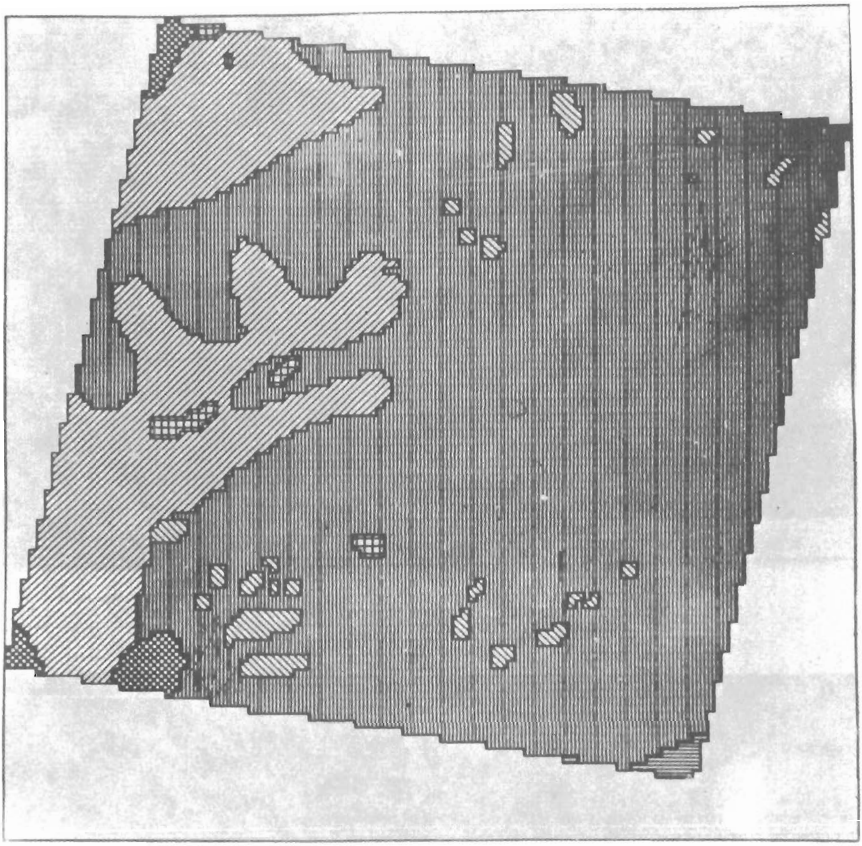




FIGURE 12. Comparison of forest areas near Rosso, Mauritania indicates a reduction in forest area from 1972 to 1977



Desert soils: 6636 km$^2$

Lithosols and regosols of hills: 792 km$^2$

Red desertic soils: 24684 km$^2$

Red and yellow soils of foothills: 132 km$^2$

Sand Dunes: 460 km$^2$

Saline soils of depressions: 220 km$^2$

Outside Landsat frame: 16360 km$^2$

FIGURE 13. Physiography of the State of Rajasthan, India is displayed as a computer product. The boundaries were originally interpreted from Landsat imagery and entered into the computerized system as 4 km$^2$ cells (9).

geology, vegetation, etc. Numerous options are available to display various thematic maps or tabulations of the units. An application example of this system to desertification monitoring would be a display or plot of changing land use over time, e.g. conversion of rangeland to cropland, by soil capability classification of the region. This type of multidate information would indicate where and to what extent marginal lands were being put into crop production.

The data base approach to a monitoring program offers a dynamic system capable of being updated, enlarged, or changed with minimal input effort once baseline data are entered. Changes in critical desertifying areas are important for the implementation of proper management actions or when assessing the success of intervention projects. The reliability of a data base is directly influenced by the quality of resource data which is entered; consequently, great care must be exercised in the resource survey to insure accuracy.

Berry and Ford (26) recommended a variety of techniques be combined for minitoring desertification indicators on a global scale, e.g. on-ground data collection by locals, use of satellites and other global data gatherers, etc. They proposed that five global indicators of desertification should be monitored; i.e. albedo, dust storms, rainfall, soil erosion and sedimentation, and salinization. Irrespective of whether remote sensing techniques can provide data on all these indicators or that the list of indicators to be monitored is inclusive, a system is needed to store, display, and provide access to data of this type on a continuous basis.

## SUMMARY AND CONCLUSIONS

The ultimate effect of desertification or desertization is a reduction of potential productivity of arid lands. Increasing demands for food and fiber in arid zones and the inevitable dry years can combine to start or accelerate the regression of environment.

Utilization of Landsat to locate wind channels provided a means of recognizing the major avenues and sources for sand movement. Wind erodibility was displayed as an interpretation from the soil properties coupled with climatic data. Landsat imagery provides multidate, multispectral information for use in mapping resources at reconnaissance levels. Aerial photographs provide another stage of investigation. These data when characterized and ground checked furnish the necessary resource interpretations upon which management plans can be devised to halt land decimation.

Multidate indicators of desertification were shown on Landsat imagery for regions of Mauritania and Senegal.

A Landsat-based system together with other remote sensing data and ground observation has potential use in an effective desertification monitoring system. Collation of the resource data and their interpretations can be accomplished using a computerized data base. Multiple year, multi-theme data can be plotted to various scales or simply tabulated. A global system of desertification monitoring must start with baseline data and then proceed to updates of the variable components within the system. To accomplish these goals a system is needed that is simple to operate, yet can provide sophisticated display and tabular products.

Remote sensing data and techniques are available for application to mapping of resources and locating indicators of desertification. Formulation of management and conservation efforts in arresting desertification must be based upon physical resource data in concert with climate, population, and land use pattern data.

## ACKNOWLEDGMENTS

The major funding for the Sudan and Mauritania-Senegal examples presented in this paper was by USAID. Mr. Bill Pearson, AID/AFR/SFWA, and Mr. Touré Fadel of Mauritania provided valuable contributions to several of the Landsat interpretations.

The data base illustration of India was originally reproduced as part of a desertification feasibility study for the U.N. Environment Program, Nairobi, Kenya.

The authors wish to extend their deep appreciation to Dr. Don Moore, Dr. Janet Gritzner, and Ms. Mary DeVries for their valuable criticisms and suggestions for this paper. Dr. Moore also supplied the ground photo of the Nouakchott highway. Mrs. Donna Rue and Mr. Jan Griesenbrock provided invaluable assistance in preparation of the manuscript and production of the figures, respectively.

## REFERENCES

1. Dregne, H.E., Soils of Arid Regions, Elsevier Scientific Publishing Company, New York, (1976).
2. Shantz, H.L., History and Problems of Arid Lands Development, in White, G.F. (ed.), The Future of Arid Lands, Am. Assoc. for the Adv. Sci., Publication No. 43:3-25, (1956).
3. Meigs, P., World Distribution of Arid and Semi-Arid Holoclimates, in UNESIO Reviews of Research on Arid Zone Hydrology, Arid Zone Research, I:203-210, (1953).
4. Reining, Priscilla, Handbook on Desertification Indicators, Am. Assoc. for the Adv. of Sci., Washington, D.C., (1978).

5. Le Houérou, H.N., The Nature and Causes of Desertification, in Glantz, Michael H. (ed.), Desertification: Environmental Degradation in and around Arid Lands, Westview Press, Boulder, Colorado, (1977).
6. Office of Science and Technology, Desert Encroachment on Arable Lands: Significance, Causes and Control, TA/OST/72-10, Agency for International Development, Washington, D.C., (1972).
7. U.N. Conference on Desertification, A/Conf, 74/1-36, Nairobi, Kenya, (1977).
8. Dregne, H.E., Desertification: Man's Abuse of the Land, Journ. Soil and Water Cons., 33:11-14, (1978).
9. Myers, Victor I., Mann, H.S., Moore, Donald, Devries, Mary, Hady, Abdel M., Remote Sensing for Monitoring Resources for Development and Conservation of Desert and Semi-Desert Areas, Proceedings, International Symposium on Arid and Semi-Arid Lands, Jodhpur, India, (1978).
10. Huss, Donald L., Range Management Must Move Center Stage in the Desertification Show, Rangeman's J., Vol. 5(3):78-81, (1978).
11. Katz, Richard W. and Glantz, Michael H., Rainfall Statistics, Droughts and Desertification in the Sahel, in Glantz, Michael H. (ed.), Desertification: Environmental Degradation in and around Arid Lands, Westview Press, Boulder, Colorado, (1977).
12. Van Voorthuizen, E.G., Global Desertification and Range Management: An Appraisal, J. Range. Management, 31(5):378-380, (1978).
13. Bale, J.B., Conte, D., Goehring, D. and Simonett, D.S. Remote Sensing Applications to Resource Management Problems in the Sahel, Earth Satellite Corporation, Washington, D.C., (1974).
14. Dalsted, K.J. and Worcester, B.K., Remote Sensing for Interpretations of Soil-Plant Interactions as Indicators of Desertification in Western Africa, in Goodin, J.R. and Northington, David K. (eds.), Arid Land Plant Resources, ICASALS, Texas Tech. Univ., Lubbock, (1979).
15. Myers, Victor I., Crops and Soils, in Reeves, Robert G. (ed.), Manual of Remote Sensing, American Society of Photogrammetry, Falls Church, Va., (1975).
16. Worcester, B.K., Dalsted, K.J. and Moore, D.G., Sahel-Sudano Desertification Study, SDSU-RSI-78-07, Remote Sensing Institute, South Dakota State University, Brookings, Final report submitted to U.S. Agency for International Development, Contract P10/T No. 625-907-3-6786453, (1978).
17. Worcester, B.K., Klingebiel, A.A., Younes, Hussein, Hamad, H.M., Khalil, Khalio and Bushara, Yahia, Soil Resources and Potential for Agricultural Development in the Bahr El Hebel ir Southern Sudan., SDSU-RSI-78-11, Remote Sensing Inst., South Dakota State University, Brookings, (1978).

18. Shankarnarayan, K.A. and Singh, S., Application of Landsat Data for Natural Resource Inventory and Monitoring of Desertification, SDSU-RSI-VISP-79-17, Remote Sensing Inst., South Dakota State University, Brookings, (1979).
19. Ali, Abbas Doka M., Remote Sensing for Monitoring Soil Resources and Areas Affected by Desertification in Central Sudan, in Andrawis, A.S. and Khidir, M.O., (eds.), Proceedings of Sudan Symposium and Workshop on Remote Sensing, SDSU-RSI-VISP-80-08, Remote Sensing Institute, South Dakota State U.,Brookings, (1980).
20. Mohamed, Y.Yagoub and M. Fadl Elmoula Idris, Application of Landsat for Determination of Land Resources and Desertification Monitoring, in Andrawis, A.S. and Khidir, M.O. (eds.), Proceedings of Sudan Symposium and Workshop on Remote Sensing, SDSU-RSI-VISP-80-08, Remote Sensing Inst., South Dakota State University, Brookings, (1980).
21. Marrs, R.W., Kolm, K.E.,Gaylord, D.R., Marwitz, J. and Dawson, P., Locating Areas of High Wind-Energy Potential, Tech. Report RLO/2343-77-1, Remote Sensing Lab., Univ. of Wyoming, Laramie, (1977).
22. Paul, Charles, Internationalization of Remote Sensing Technology, Photogrammetric Engineering and Remote Sensing, Vol. 44(5):625-632, (1978).
23. Kauth, R.J. and Thomas, G.S., The Tasselled Cap - A Graphic Description of the Spectral Temporal Development of Agricultural Crops as Seen by Landsat, Proceedings Symposium Machine Processing of Remote Sensing Data, 4B:41-51, LARS, Purdue Univ., West Lafayette, Indiana, (1976).
24. Richardson, A.J. and Wiegand, C.L., Distinguishing Vegetation from Soil Background Information, Photogrammetric Engineering and Remote Sensing, Vol.43(12) 1541-1552, (1977).
25. Wehde, M.E., Dalsted, K.J. and Worcester, B.K., Resource Applications of Computerized Data Processing: The AREAS Example, J. Soil and Water Cons. 35(1): 36-40, (1980).
26. Berry, Leonard and Ford, Richard B., Recommendations for a System to Monitor Critical Indicators in Areas Prone to Desertification, Report to USAID, U.S. Task Force on Desertification, Clark University, Worcester, Massachusetts, (1977).

# 7
# System of Classification and Physiographic Survey*

*E. Quiñones-Garza*

## 1.0 FUNDAMENTAL CONCEPTS

In the System of Classification and Physiographic Survey which is being outlined here, we will make use of some fundamental concepts that will be developed and defined in this section. These are: topographic element, topoform and the concept of macroclimatic alteration through continental morphology.

### 1.1 Topographic Element

The various forms of the surfaces of the continents (and islands) may be described and analyzed based on fundamental types of surfaces of homogeneous topographies. The curvatures that are characteristic of each one of these fundamental types have a vertical and horizontal component in relation to which their contours can be concave, flat or convex.

It is out of such considerations that the term topographic element was created and adopted in this System with the following definition: Terrestrial surface of homogeneous topography, whose limits are indicated through changes in the type of superficial curvature (i.e. concave, flat and convex) in vertical, horizontal or both directions, or through abrupt changes of slope.

The topographic elements that are applied in this System are the following:

Element 1 is flat and horizontal, lacking a vertical component, relief and slope (Figure 1).

Element 2 is flat but has relief and slope. It is slanted with respect to the horizontal (Figure 2).

Element 3 is convex in the horizontal and vertical directions, and with positive relief (+) as it is elevated in relation to an ideal flat surface. It could be called a "positive domed element" (Figure 3). This element in its ideal form is uniform, i.e. does not present changes in the degree of its convexity with distance.

*Translated from Spanish

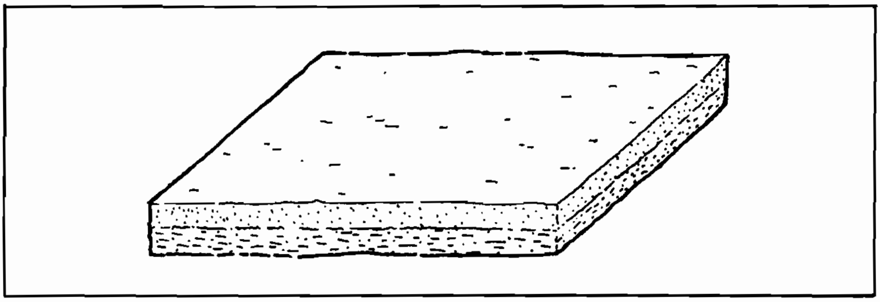


FIGURE 1.

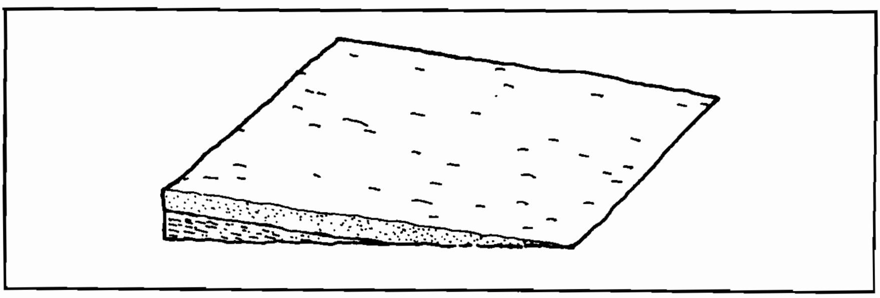


FIGURE 2.

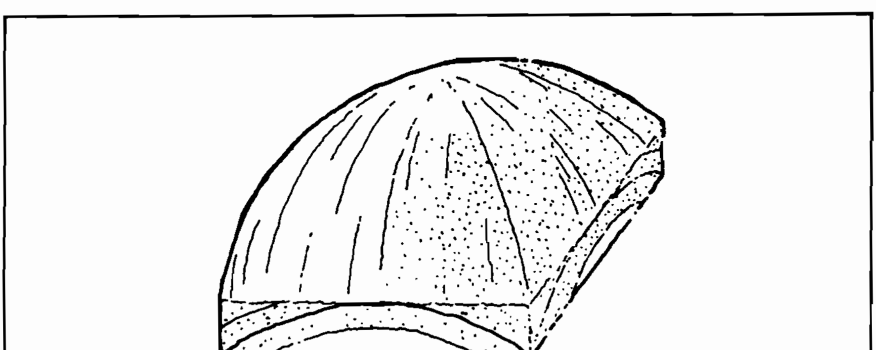


FIGURE 3.

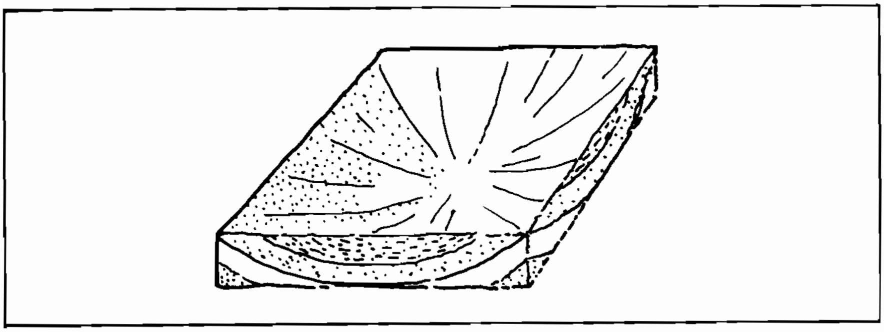


FIGURE 4.

Element 4 is concave in the horizontal and vertical directions and of negative relief (-) as it dips downward centripetally in relation to an ideal flat surface. It could be called a "negative domed element" (Figure 4). This element in its ideal form is uniform, i.e. does not present changes in its degree of concavity with distance.

The other elements which are included in this System are the nine basic slope geometries presented in the text by R.V. Ruhe (1) and reproduced in Figure 5. They are classified by Ruhe according to their straight (S), convex (V) or concave (C) characteristics in the vertical or horizontal directions. He divides them into three categories according to their complexity:

1. The simplest form which is straight in both vertical and horizontal directions (SS) and coincides with Element 2 of this System (Figure 5-1);
2. Those that combine vertical and horizontal straightness with convexity or concavity in one or the other direction:

   Element 5 (SV) is straight in the vertical direction and convex in the horizontal direction (Figure 5-2a);

   Element 6 (SC) is straight in the vertical direction and concave in the horizontal direction (Figure 5-2b);

   Element 7 (VS) is convex in the vertical direction and straight in the horizontal direction (Figure 5-2c);

   Element 8 (CS) is concave in the vertical direction and straight in the horizontal direction (Figure 5-2d).

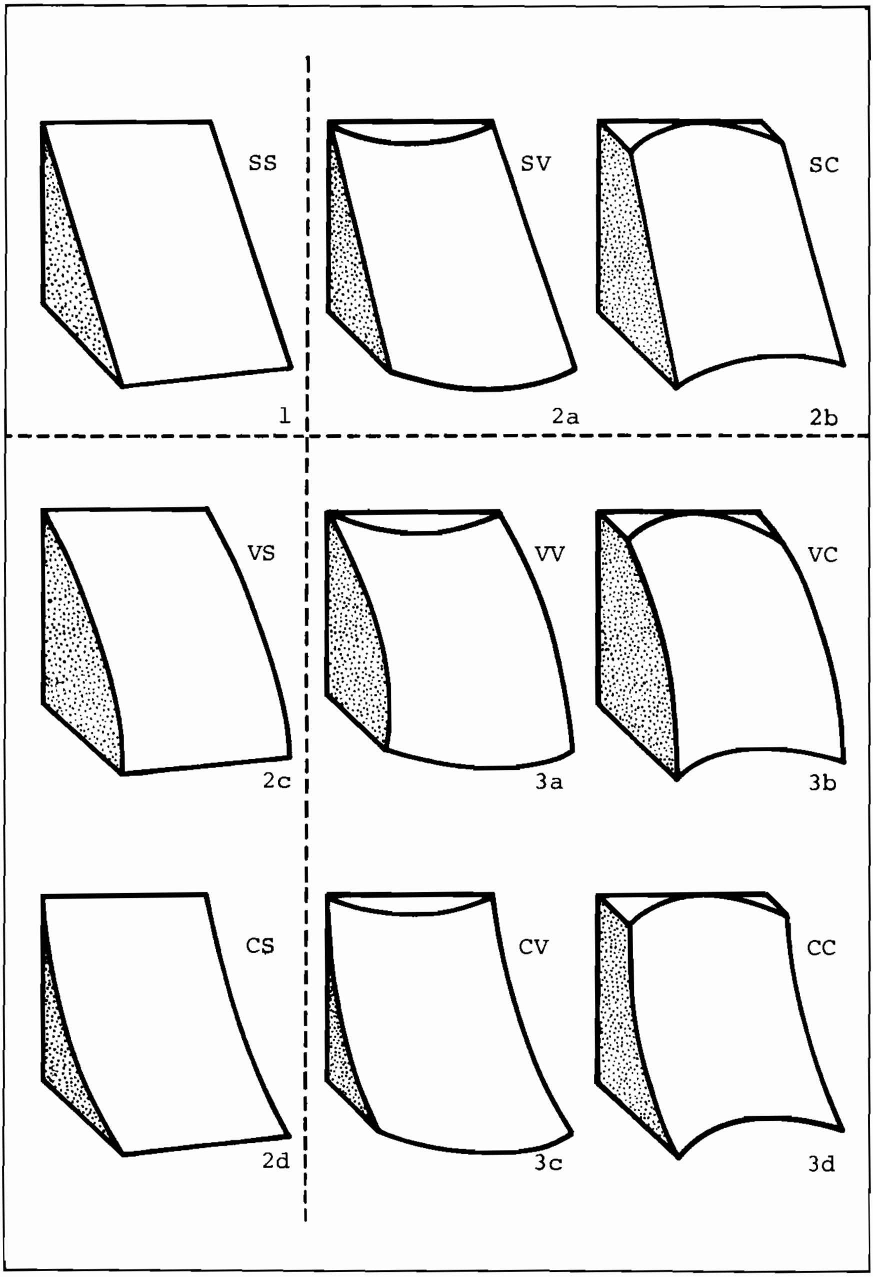



FIGURE 5.

3. Those that combine horizontal and vertical convexity and concavity:

   Element 9 (VV) is vertically and horizontally convex (Figure 5-3a);

   Element 10 (VC) is vertically convex and horizontally concave (Figure 5-3b);

   Element 11 (CV) is vertically concave and horizontally convex (Figure 5-3c);

   Element 12 (CC) is vertically and horizontally concave (Figure 5-3d).

The definitions of topographic elements which have been presented here are of a qualitative character, since they do not take into account quantified areas and slopes nor changes in the degrees of convexity and concavity. Their usefulness lies precisely in physiographic surveys and studies in which the different types of surfaces represent one of the most significant aspects. As indicated by Ruhe, the basic slope geometries adopted as topographic elements for this System correspond to the surfaces that determine the various modalities of the flow of runoff waters. The System also determines the patterns of hydric distribution and, together with data on basal material, determines patterns of infiltration and erosion. From this point of view, the precision of the elements that comprise a particular geoform, for instance a cineritic cone, is of greater direct physiographic interest than the definition of it according to its genesis: "conic elevation formed by accumulation of volcanic ashes or similar scoria material around an escape" (definition approved by the Mexican Geological Institute).

This does not mean that genetic, lithological or climatic considerations are eliminated from this System. Different geological geneses may produce, in some cases, topoforms of convergent morphologies. A domic hill (Figure 6) for instance could be a small eroded volcano, a carstic (chalky) "cockpit" hill, a lacelithe hill or a periclinal fold, always presenting the same essential elements. Therefore, the catalogue of topoforms that will be elaborated will follow a classification based on processes.

The quantitative aspect is also of great relevance for the physiographic surveys, especially in the characterization of Topoform Systems (see Section 2.4). In due time, the usefulness of applying some of the available models for geomorphic analysis will be considered.

## 1.2 Topoforms

In geomorphology the term "geoform" is frequently used when referring to any type of accident of the relief. The term is very broad and therefore ambiguous, since it

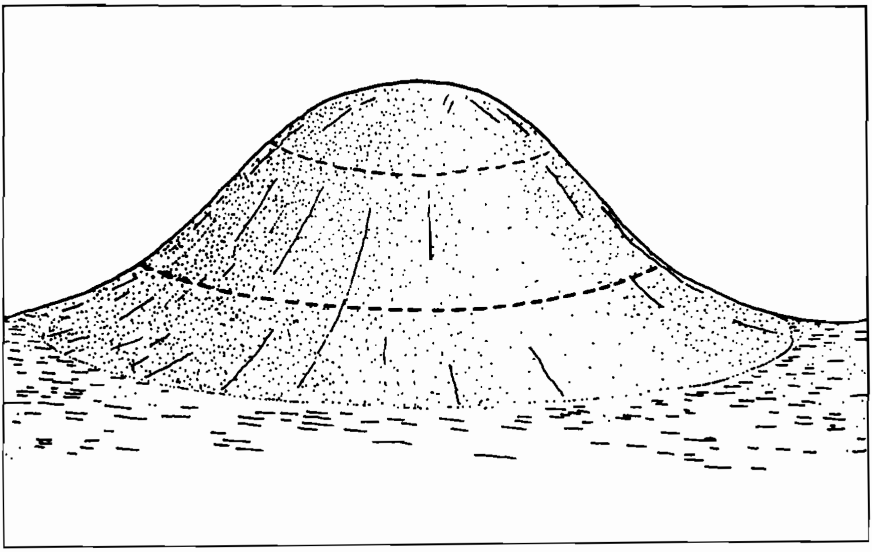


FIGURE 6.

can be applied correctly to a continent, a mountain range, a hill or to a topographic element as it has been defined in this study. We lack a term that refers specifically to those continental geoforms (and islands) with their own characteristic and universal morphologies, such as cineritic cones, alluvial fans, dolinas, etc. Many of the geoforms that could fit into this category can be identified by sight from the ground or by interpretation of aerial photographs at more or less large scales (1: 250,000 and over).

Considering the above observations, in the present Physiographic System all those geoforms that under similar genetic conditions and at any site of any continent (or island), always present the same essential topographic elements, will be called topoforms (from topos - place: "the form of the place").

1.2.1. The Characterization of Topoforms by their Essential Topographic Elements. Almost all conceivable geoforms can be reduced to a small number of topographic elements from among the twelve defined above. The very few exceptions (arches, natural bridges, "bristles", entrances to caves, etc.) are rare cases which do not fall within Topoform Systems (see Section 2.4) but which, at any rate, could be denoted or characterized by means of the introduction of new elements of the negative sign.

The characterization of topoforms based on elements of which they are composed is done in ideal terms. It can be stated, for instance, that the "ideal" cineritic cone is composed of such-and-such essential topographic elements. This permits, in spite of the numerous deviations and alterations with respect to the "perfect model" which nature presents (e.g. displaced, twinned, repeated, terraced, forked, branched elements or even entire twin or fused topoforms), analysis of a form of relief, identification of the essential elements, and characterization of the topoform.

Some examples of characterizations of topoforms through their component topographic elements are presented below:

1. Non-inclining plane (Various routes of origin) - Element 1;
2. Slope (Formed by hydric erosion on edges of inclined strata in which the hard and soft materials alternate - Element 2;
3. Granitic Dome (Dome of naked rock, sometimes exfoliated, frequently tending to conic) - Element 3;
4. Negative Periclinal Fold (Depression in folded rocks) - Element 4;

The following examples involve topoforms with associated elements:

5. Domed Hill (Figure 6) (Various routes of origen). This is composed of three elements: Element 3 on top, Element 9 (VV) in the middle and Element 11 (CV) at the base. Within the nomenclature of this system it would be said that - given its circularity in the horizontal direction - Elements 9 and 11 close up in this topoform.
6. Cineritic Cone (Figure 7) (Formed through accumulation of ashes and other tephrites around an escape opening during cineritic eruption). Height always low. It is composed of two elements: Element 4 on top (the crater) and Element 6 (SV) closed up, constituting its foothills.
7. Inselberg (Island Mountain) (Figure 8) (Considered to be a relic of erosion). This is composed of three elements: Element 1 on top (at the "crest"), Element 6 (SV, the "escarpment") closed up, and with an abrupt change of slope and Element 6 at the base ("embankment of debris") also closed up.
8. Alluvial Fan (Figure 9) (Accumulation of alluvia deposited by a river which loses energy and velocity when passing from pronounced slopes to flat land.) The alluvial fan consists of one single element, Element 6 (SV), which will be described as "cut" since it is interrupted from one side to

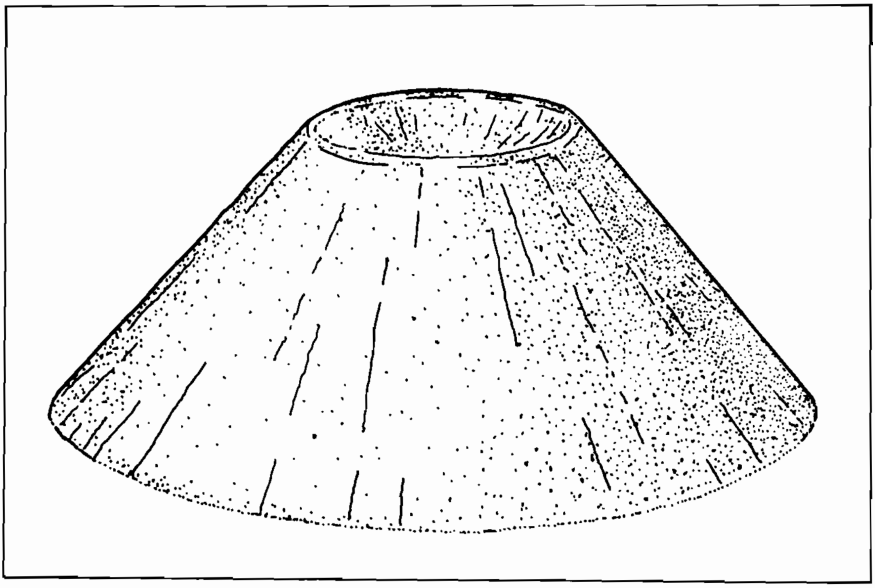


FIGURE 7.

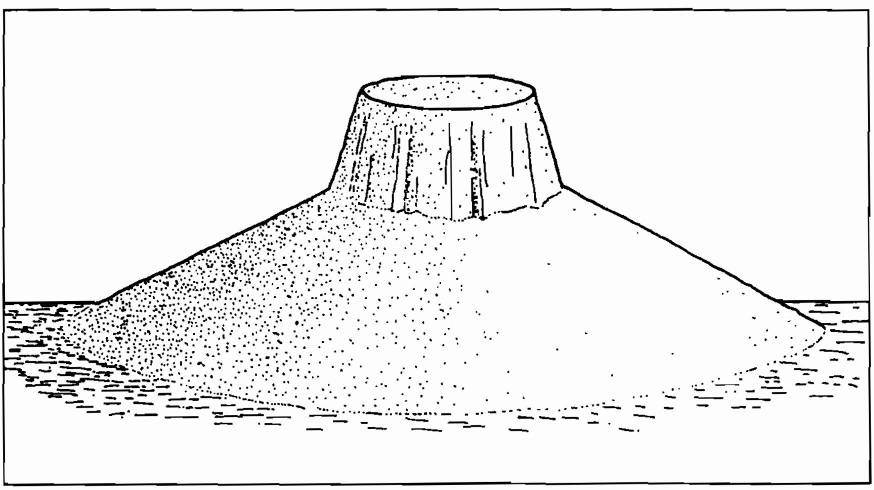


FIGURE 8.

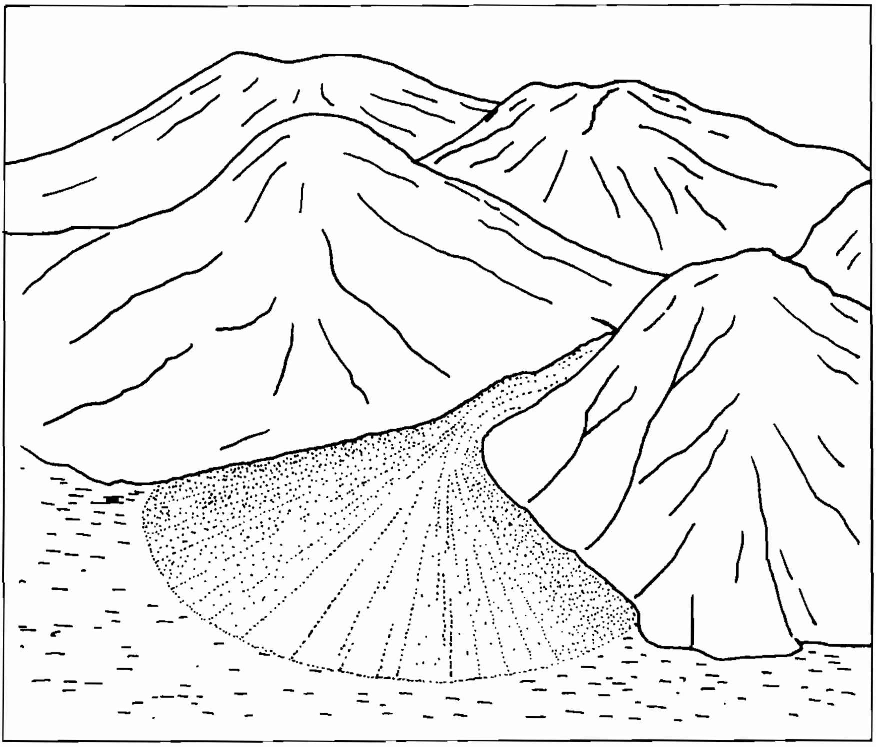


FIGURE 9.

the other by contiguous geoform elements. When a sequence of geoforms like this or any other one, all of the same type, is cut successfully, it is said that they are <u>intersected</u>.

9. <u>Dolina</u> (Figure 10) (Formed by dissolution and/or underground landslide of the soluble rocks of a chalky formation. The "ideal" dolina (whose form approximates the famous sacred underground water reservoir of Chichen Itza) consists of two elements: Element 1 at the bottom and Element 6 (-SC) or Element 12 (-CC) closed up, forming its sides. The majority of the dolinas are circular or oval but they may also be - but less frequently - irregular or even branched. It is because of their common genesis by dissolution in carstic conditions that they may be grouped into the same fundamental topoform type.

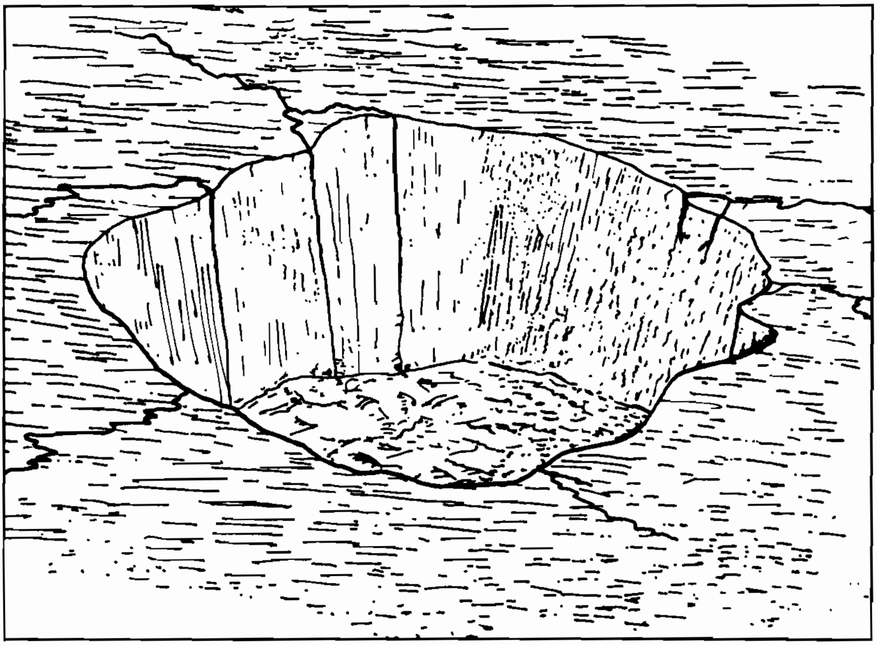


FIGURE 10.

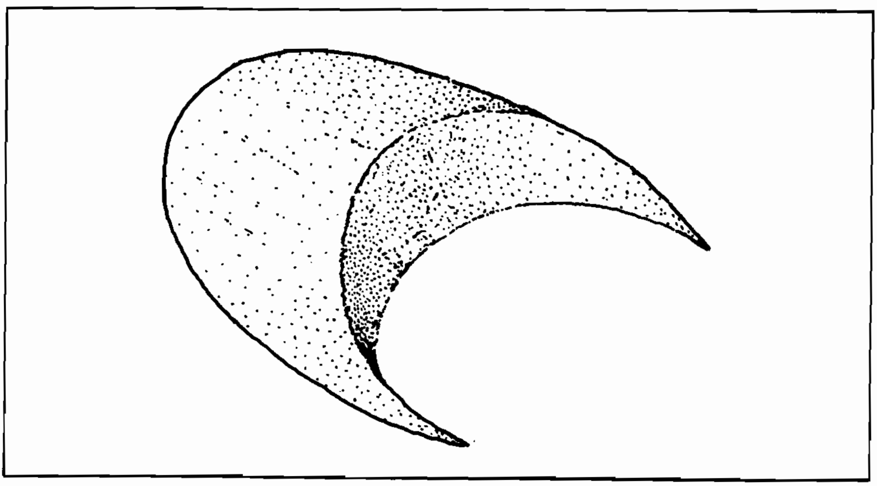


FIGURE 11.

10. Barchan Dune (Figure 11) (Half-moon shaped flat dune, formed by Aeolian accumulation of sand). The Barchan is composed of two elements which cut one another: Element 9 (VV) on the windward side of the topoform, cut by Element 12 (CC) on the leeward side in such a way that the lower part of Element 9 is more spread out at its base than at its top, resulting in the typical half-moon flat form.

### 1.3 Concept of the Macro-Climatic Alteration Due to Continental Morphology

A concept of macro-climatic alteration through continental morphology will be applied in the present System. This concept is derived from Pedro Mosiño's scheme (2); he gives the determinant climatic factors of a given zone the following order of importance: 1) the latitude; 2) orography; 3) distribution of lands and oceans; 4) maritime currents and 5) storms and their trajectories. In his work in 1974 (3) Mosiño describes the effects of each of these factors within the national territory.

In this System, the concept of macro-climatic alteration through continental morphology is applied in the following sense: The great morphological entities that comprise a continent, among which are extensive mountainous masses, can alter the latitudinal patterns of the belts of high and low atmospheric pressures, the wind girdles, and the thermal circulation to such a degree that together they produce different climates from those that would result only from their latitudinal and altitudinal position.

## 2.0 THE CLASSIFICATION LEVELS OF THE PHYSIOGRAPHIC SURVEY SYSTEM

The definitions given in the Section 1 facilitate the elaboration of the Physiographic Survey System, whose classification levels are as follows:

1. Physiographic province
2a. Physiographic sub-province
2b. Physiographic discontinuity
3. System of Topoforms
4. Topoform
5. Element

### 2.1 Physiographic Provinces

The large structural entities which comprise a continent define, generally clearly, superficial morphological units of distinctive characteristics. Such large units of a particular origin and morphology are the physiographic provinces of the continental surfaces, and they are the first and widest divisions that can possibly be defined.

A region is considered a physiographic province when it fulfills the following requisites:

a. Unitary geological origin over the greater part of its area;
b. Characteristic and distinctive morphology;
c. Sufficient extension in order to be an essential structural component of the continental system of macro-climatic alteration;
d. Distinctive lithology due to:
   i) one single lithological pattern over the entire extension;
   ii) a complex lithological mosaic resulting, however, from the unitary origin of the province.

2.2.1. Physiographic Sub-Province. This is a large area resulting from the first sub-division that can be made from a physiographic province when the following requirements are fulfilled:

a. As an integral part of the physiographic province it fulfills the requirements specified in Section 2.1;
b. i) The geoforms which comprise it are typical of that province, but their frequency, size and morphological variation are appreciably different from those present in the rest of the province; or
   ii) It presents predominantly the typical geoforms of the province in general, but associated with other different ones, and these distinguish it by the fact that they do not appear to a considerable degree in the rest of the same province.

2.2.2. Physiographic Discontinuity. This is an enclosed area within a physiographic province whose origen and morphology differ from those of the province, and that fulfills the requirements specified under Sections 2.1a, b and d, and constitutes in itself a separate physiographic province, but cannot be considered as such as it does not fulfill the requisite 2.1c; i.e. it lacks sufficient size to form a significant part of the continental system of macro-climatic alteration.

2.2.3. Site of the Islands in the Second Level of Subdivision. The majority of the islands that form part of the national territory exhibit close and recognizable relations of origin, morphology and lithology with the continental geoforms. From the degree of closeness of such relations it can be determined whether an island or group of islands is considered part of a sub-province or physiographical discontinuity of the continent, or whether it in itself constitutes a sub-province or separate island discontinuity.

## 2.3 Systems of Topoforms

The sub-provinces or physiographical discontinuities can themselves be sub-divided into topoform systems which are topoform entities associated among themselves according to some structural and/or degradative pattern(s). These present a higher degree of landscape uniformity than the second level sub-division of which they are a part. There are topoform systems that are products of one single fundamental genetic process. They belong to one of the following types:

a. System of multiple repetition of identical topoforms (e.g. multitude of domic calcareous hills of tropical carstic "cockpit" type formations);
b. Topoforms of the same type scattered over a plain (e.g. inselbergs (island mountains) in a desertic pediment;
c. Systems of contrasting topoforms which are, however, associated through a common origin and historical unity of the system as a whole (e.g. the volcanic complex of the Sierra del Pinacate, Sonora).

2.3.1. Inclusions. Within the sub-provinces and the physiographical discontinuities, topoform systems and even individual topoforms which by origin, morphology and/or lithology are foreign to the entity which they belong to, can be present. These will be called inclusions.

2.3.2. Place of the Islands in the Third Level of Subdivisions. An island, islet or a group of islets can constitute in itself or themselves an individual topoform system, which can be:

a. Part of one of the continental physiographic entities; or
b. Part of a sub-province or physiographic discontinuity of purely insular character.

Small islands or isles far away from the coasts can be independent insular topoforms without any relation to another entity.

## REFERENCES

1. Ruhe, R.V., Geomorphology, Houghton Mifflin Co., (1975).
2. Mosiño, Pedro A., Factores Determinantes del Clima de la Republica Mexicana con Referencia Especial a las Zonas Aridas, Depto. de Prehistoria, Instituto Nacional de Antropologia e Historia, Mexico, (1966).
3. Mosiño, Pedro A., Mexico: Panorama Historico y Cultural - I. El Escenario Geografico, Los Climas de la Republica Mexicana, Depto. de Prehistoria, Instituto Nacional de Antropologia e Historia, Mexico, (1974).

# 8
# Techniques for Vegetation Mapping in Semiarid Regions

*David A. Mouat*
*Charles F. Hutchinson*

## INTRODUCTION

Vegetation mapping begins with the design and development of an appropriate classification system. At global scales, vegetation is often mapped as a correlate of broad climatic regimes. At much larger scales, it may be mapped according to floristics, physiognomy, numerical relations between taxa, or by environmental characteristics. Remote sensing techniques can be used from one scale extreme to the other. Special considerations need to be addressed, though, for mapping vegetation in arid and semiarid regions.

Methodologies involving both conventional and digital techniques must consider the importance of the terrain in the mapping process, as the sparse vegetative cover precludes a significant signature on an image. Both conventional and digital techniques must rely upon correlations between vegetation and interpretable terrain features. Ground sample and verification site selection must be accomplished to present a statistically accurate picture of the variations within the types.

The purpose of this paper is:

1. to discuss briefly the importance of classification of vegetation;
2. to present conventional and state-of-the-art remote sensing techniques used to map vegetation;
3. to discuss problems of mapping the low-density vegetation of arid and semiarid lands.

## CLASSIFICATION OF VEGETATION

Vegetation is mapped for one of two basic reasons: an interest in learning about the plants themselves or an interest in learning about the physical environment in general. The latter relates the response of plant form to the physical elements of environment (1).

The classification of vegetation involves organizing the components into a series of groups having a uniformity in composition, physiognomy, and pattern of interactions among plants and between plants and the environment. The purpose of vegetation classification is to create order out of the seemingly abstract assemblage of vegetation that is distributed over the landscape. An attempt is made to produce groups that have greater homogeneity in composition, physiognomy, etc. than outside the groups.

Classification systems employ either a divisive or an agglomerative approach. A divisive approach begins with the complete set of entities to be classified, and divides them progressively into smaller and smaller groups. An agglomerative approach proceeds from a single entity and groups like entities with it based on some measure of similarity. At some point it may be decided that none of the remaining entities is similar enough to be associated with the group being formed, and a new group is initiated. A classification system may employ elements of both types (2).

Hierarchical classification is preferred over non-hierarchical techniques as it allows for the aggregation of units at smaller scales and dis-aggregation at larger scales of mapping intensity. In an area of pronounced vegetation diversity, a system which allows for both detailed as well as general descriptions is highly desirable (3).

The classification system most used by the Applied Remote Sensing Program (ARSP) follows the system developed by Brown, Lowe, and Pase (4). It is a digitized system for natural vegetation in North America, following a hierarchical format, and is based on climate, ecology, and evolution. It was first developed for use in the arid southwest United States. The ARSP classification has diverged from that of Brown, Lowe and Pase at the fifth or sixth level to account for variability of species found within a type. The basic system is one in which the types are characterized on the basis of their physiognomy at the more generalized levels and on floristic components at the more specific levels. An example of the classification system used by ARSP is illustrated in Figure 1. It represents a portion of the legend developed for a vegetation map of Organ Pipe Cactus National Monument. This is an arid environment receiving approximately 150 mm of precipitation annually. Figure 2 is a description of one of the types mapped in the Organ Pipe Cactus National Monument vegetation mapping project. Vegetation type descriptions should include information on the physiognomy or appearance of the type, on the relative abundance of the principal species and their variation within type and on type distribution. The thoroughness of the association descriptions (which depend upon adequate field sampling) determines the final utility of the vegetation map, and to a large extent is independent of the classification used (3).

150 Desertland formations
 154 Tropical-subtropical desertlands
  154.1 Sonoran Desertscrub
   154.11 Creosote Bush - Bursage (Lower Colorado) series
    154.111 Larrea tridentata associations
     *154.1111 L. tridentata - Ambrosia dumosa association
     *154.1112 L. tridentata - Ambrosia mixed scrub association
     *154.1113 L. tridentata - Ambrosia deltoidea - Fouquiera splendens association
     *154.1114 L. tridentata - Annuals association
     *154.1115R L. tridentata - Prosopis glandulosa floodplain association
   154.12 Paloverde - mixed cacti (Arizona Upland) series

FIGURE 1. A portion of the vegetation classification and legend used for the Organ Pipe Cactus National Monument vegetation mapping project

154.1113

Name: Larrea tridentata - Ambrosia deltoidea - Fouquieria splendens (Creosotebush - Triangle-Bursage - Ocotillo) association

Physiognomy:

An open, uniform stand of microphyll shrubs 2 to 3 feet tall with very few taller trees and some cacti. Diversity is low and cover is from 10 to 20 percent. This type is generally surrounded by the more diverse Paloverde - Bursage association.

Floristics:

| Characteristic Species | | Associated Species | |
|---|---|---|---|
| Larrea tridentata | 4 - 5* | Cercidium microphyllum | 0 - 2 |
| Ambrosia deltoidea | 3 - 4 | Opuntia fulgida | 0 - 2 |
| Fouquieria splendens | 2 - 3 | Krameria grayi | 0 - 2 |

*(These numbers represent relative dominance in the stand. 5, for example, is the dominant species).

Distribution:

On level ridge-tops and interfluves in the upper bajada from 1,400 to 2,000 feet. This type is found on gravelly soil with a silty matrix. Fragments of caliche are commonly scattered abundantly on the soil surface. This association is found at scattered localities in the upper parts of the Sonoyta Valley and Growler Valley. Commonly surrounded by Paloverde - Bursage middle bajada type on adjacent slopes.

FIGURE 2. An example of a vegetation type description

## CONVENTIONAL TECHNIQUES

Remote sensing based procedures for mapping vegetation deviate from more traditional techniques primarily in the method for delineating the types. Remote sensing techniques include conventional aerial photography, multispectral photography, multistage systems, digital imagery and other systems. Analytical techniques range from manual image interpretation to computerized image analysis. Techniques must be modified to take the arid environment into consideration.

The use of black and white aerial photography provides a planar perspective for cover estimation, interpretation of broad types, and delineation of type boundaries on an easily convertible mapping base. The use of stereoscopes, photogrammetric techniques, and other equipment greatly improves the mapping procedure.

Recently, developments in film-filter combinations, sensing systems, sampling techniques, and analytical procedures have added a new dimension in vegetation mapping. Color and color infrared films with the appropriate filter combinations permit a much wider variety of vegetation discrimination than black and white photography. Color infrared photography is particularly well-suited to vegetation discrimination as it is in the near infrared portion of the spectrum that vegetation is most responsive. Color photography is recommended in many situations involving arid regions as natural color accurately reflects the largely barren surface.

The methods used in producing the vegetation map follow a series of standardized steps, each with carefully defined procedures. Figure 3 illustrates the inventory task sequence.

Some steps in the sequence have been discussed earlier. Others, such as identification, evaluation and acquisition of available data sources and the hiring and training of personnel are largely self-explanatory. The procedures by which the photo-interpreter identifies and delineates types, however, needs to be briefly discussed.

The basic strategy for identifying vegetation types involves analyzing image-subject relationships. The appearance of a particular type is often, but not always, unique. Each type differs from others in terms of its image characteristics including color, texture, pattern, size and radiance. This is because different vegetation types have different physical properties and, importantly in arid areas, have different assemblages of terrain features. Thus, many vegetation types may be directly identified on the basis of their unique image characteristics. The successful application of remote sensing technology to vegetation mapping depends on the analyst's ability to accurately associate image characteristics to the parameters of vegetation being mapped. This is true whether conventional or digital techniques are used.

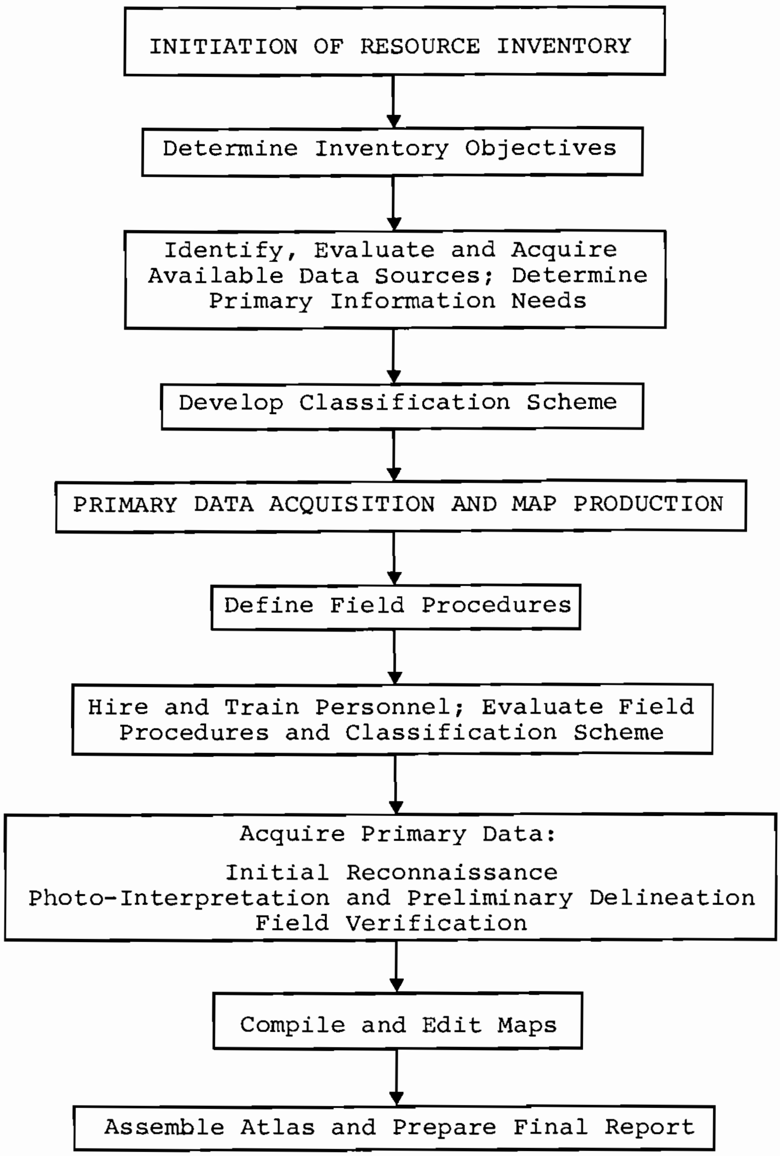



FIGURE 3. Inventory task sequence (after Mouat et al. (5))

Delineation of units, then, can be accomplished on an acetate overlay on the image. Preliminary identifications are often made at this stage and are based on the interpreter's experience and familiarity with the vegetation systems of the area. Subsequent field verification and corrections of the preliminary type maps may require, as necessary, refinement of the classification system. Field verification requires adequate sampling to ensure accuracy and reliability. Detailed field forms are used to ensure a constant quality of work. Finally, careful editing and a cartographic presentation of the final map(s) are required.

## TERRAIN CORRELATION TECHNIQUES

When the scale of imagery is such that plant individuals cannot be discriminated and when vegetative cover drops below the minimum threshold necessary for spectral differentiation of vegetation types (generally less than 30%) new techniques for mapping need to be developed. In arid regions, techniques which involve the discrimination of vegetation through terrain correlation can be effective.

At the simplest level, vegetation mapping through terrain association occurs when small-scale photographic images are interpreted. Color photography is generally preferred over other image types for a number of reasons. Greater exposure and processing latitudes are two advantages of natural color over color infrared. In addition, arid soils have as much if not more spectral differentiation within the visible spectrum than in the photographic infrared. As such, color photography would at the least be as useful as color infrared for differentiating the soil surface. Usually, the image analyst can more reliably correlate terrain factors with natural color photography than with color infrared photography.

Vegetation discrimination from terrain feature analysis presupposes significant correlations between the two. deLaubenfels (1) states that every vegetation type has a certain range of habitat. The forces which actually affect plants are limited in number and nature by the constitution of the plant itself. For example, topography has a profound effect on vegetation largely through microclimate. Aspect and slope angle affects moisture. Landform affects vegetation through its affect on moisture, soil structure, texture pH, and temperature, for example. Numerous studies have been conducted relating vegetation to various terrain features. An important study relating vegetation to terrain was conducted by Kassas and others in Egypt. Kassas' major effort was on habitat-plant community relationships in the Egyptian Desert. He found that vegetation follows rather discrete patterns of landforms and moisture availability. Each of a number of geomorphic divisions in his study area had a specific number of community types of "ecogeomorphic systems" (6-8).

Shreve (9) stated that the upper limit of species was considerably higher on north-facing slopes than on south-facing slopes. He showed that the influence of slope exposure was greater with increasing elevation and felt that the effect of altitude on vegetation was through moisture, temperature, and light factors. Mouat (10 and elsewhere) used stepwise discriminant analysis to analyze vegetation-terrain variable relationships in southern Arizona. He found that vegetation could be differentiated on the basis of a set of interpretable terrain variables.

The importance of being able to quantitatively discriminate vegetation from a given set of terrain variables is considerable. It allows the vegetation inventory specialist to set confidence intervals on mapping units. While surface factors such as elevation, slope, aspect, parent materials, landform, and drainage diversity can be used in these analyses, spectral data relating to the soil surface can also be entered in a digital model. An ideal system combines the two.

## DIGITAL TECHNIQUES

Conventional aerial photography has proven to be an effective tool in the inventory of vegetation and other resources at a variety of scales. However, since 1972 and the launch of the first Landsat satellite, small scale imagery has been available for most regions of the earth in both photographic and digital format. In large part, this new data source complements conventional approaches to vegetation inventory and has brought about the development of a new body of techniques for extracting information from digital imagery (11).

### The Landsat System

In conventional aerial photography, cameras are aimed at the earth and the scene is recorded in one relatively broad portion of the electromagnetic spectrum. In multispectral remote sensing, responses of the earth's surface are recorded in several rather narrow bands of the spectrum (Figure 4).

Landsat images are recorded digitally by a multispectral scanner and transmitted to earth. The area covered by a single Landsat image is an area measuring 185 km by 185 km. Each element of the picture (pixel) represents an area on the ground of 60 m by 80 m. Brightness values from four bands of the visible and near-visible region of the spectrum are recorded for each pixel (Table 1)

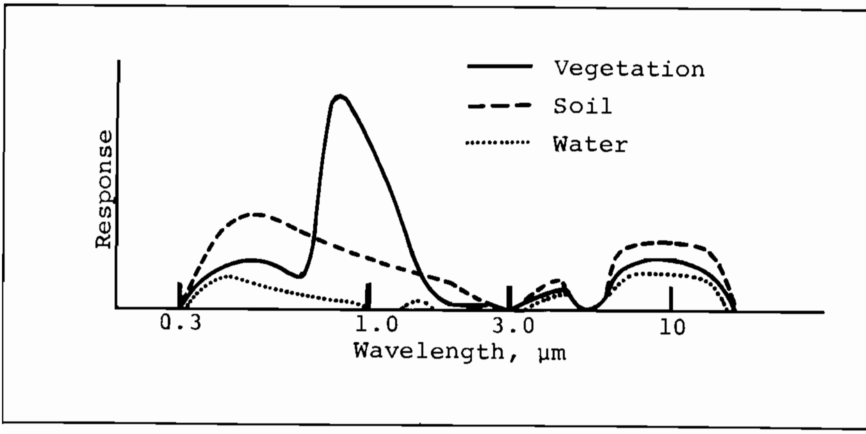



FIGURE 4. Spectral response of some earth features

TABLE 1.
Description of Landsat Data

| Band | Spectral Region | Color | Brightness Levels |
|---|---|---|---|
| 4 | .5 - .6 µm | green | 0 - 127 |
| 5 | .6 - .7 µm | red | 0 - 127 |
| 6 | .7 - .8 µm | infrared | 0 - 127 |
| 7 | .8 - 1.1 µm | infrared | 0 - 63 |

## Techniques for Use of Landsat Data

The digital format of Landsat data allows a wide range of uses. It can be used in a photographic format and interpreted like a conventional aerial photograph. The scale of the photographs that can be produced with reasonable image quality is relatively small; for general applications, a maximum scale of 1:100,000 is used. At such small scales, image-subject relationships are difficult to establish. Thus, the detail of the product that can be consistently produced is relatively low.

Problems of scale, however, do not preclude use of conventional photointerpretation. Because the image is digital, selected portions of the brightness response can be enhanced through the selective increase of contrast or the delineation of edges. Enhancement techniques can be used to increase the general interpretability of the image or may be used to accentuate specific features. Although the enhanced image may be more useful than a raw image, scale is still a problem. The final and most complex way in which digital Landsat data may be used, is digital classification or pattern recognition. In this approach, statistical techniques are used to recognize patterns in the image data that represent classes of phenomena on the ground, including vegetation types.

Digital Classification of Landsat Data. As described above, Landsat records brightness in four bands of the spectrum for each of the 60 m by 80 m pixels that constitute the image. These four observations can be used to define a four dimensional "observation space". In Figure 5, several types of earth features are displayed as they might appear in a two dimensional observation space.

The two tasks that constitute digital classification are:

1. to define/determine the spectral pattern of the features of interest and,
2. to classify pixels into the feature pattern they most resemble.

Task 2, or classification, is the most standardized activity. Generally, a variation of the "maximum likelihood" classification algorithm is used (12). In this technique, the classifier is provided with a statistical characterization of the feature patterns (means and covariances). Pixels within the image are examined and placed in the "most likely" class.

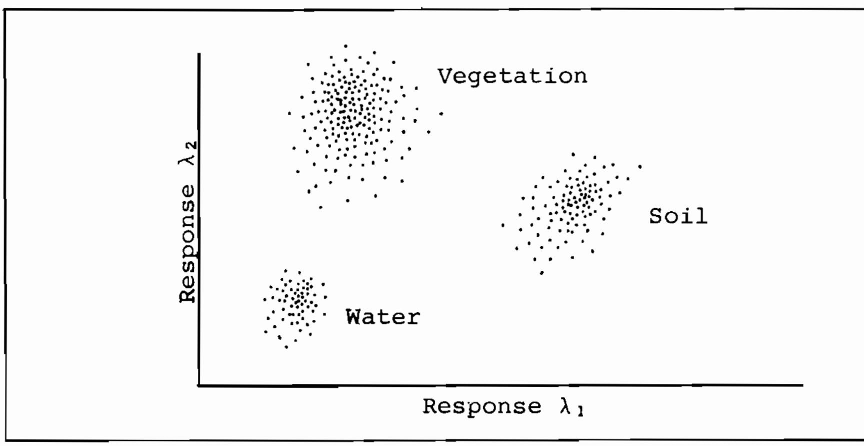



FIGURE 5. Earth features in two-dimensional observation space

There are a number of ways to address task 1, the definition/determination of the patterns of spectral response associated with features of interest. In the past, they have been described by their degree of reliance on a human analyst: supervised, unsupervised and modified unsupervised.

The supervised approach is relatively straightforward. The analyst manually selects sets of training fields within the image which represent the various classes of features in which he is interested. The spectral characteristics of the pixels included in the training fields are passed to the classifier described above. Pixels are grouped into classes. Classes are color coded in an output image and the result resembles a choroplethic map.

The supervised technique was designed for agricultural applications and worked well. However, when applied to vegetation inventories, several problems arise. First, in a vegetation inventory, it is not always possible to know at the outset the number and kinds of classes that ultimately will be recognized. These unanticipated classes cannot be sampled and thus cannot be included in the Landsat classification.

In the unsupervised approach, the patterns of spectral response are "recognized" in the data using cluster analysis. Initially, a random sample of pixels is drawn from the image; clusters are recognized, characterized and passed to the classifier. Following classification, the pixel groups are fitted together in a final map by the analyst. The unsupervised approach is attractive because it can accommodate unexpected variety. Also, it is based on a standard sampling procedure and results can be easily repeated.

There are several problems with unsupervised approaches. First, a relatively large number of clusters must be used to ensure that all potential classes are represented, and computing costs increase as a function of the number of classes. More important, however, is the low frequency bias that is inherent in the random sample; features that are of limited extent are likely to be either missed in the sample or disgarded in the clustering routine due to their small number.

A compromise, the modified unsupervised approach, incorporates desirable features of both techniques. The sample that is drawn is not random: generally, a number of small areas or "blocks" within the image are selected, and merged to form the sample upon which the cluster analysis is performed. In this way, the analyst can include all those regions of the image in which diversity is anticipated but stop short of specifying the number and kind of classes that will be found there. The remainder of the process is performed in the same way as in the unsupervised classification. Thus, an element of analyst control is introduced in the classification process but the potential for feature classes variability is accommodated.

Spectral Properties of Semiarid Vegetation. The sensitivity of sensors and classification routines tends to decrease with cover. The ability to estimate biomass, or distinguish between different types of vegetative cover, appears to decrease significantly in areas with less than 30% crown cover (see, for example, Hutchinson (13)). Thus, in arid regions, it becomes difficult to rely on spectral information to discriminate vegetation types.

Two approaches have been adopted to alleviate the problems of mapping low density vegetation. The first uses ratios, or indices based on ratios, of brightness values from the infrared and visible bands to isolate vegetation response. This approach was recently used in an operational application with good results (14).

The second digital approach for low density vegetation parallels the terrain correlation techniques described previously. This approach involves the combination of terrain features including slope, aspect, elevation and parent material, with spectral data to improve classification (15). Results have been mixed but promising.

Landsat and digital techniques offer promise for inventorying vegetation in large areas. Problems associated with specific techniques and variable spectral response in arid and semiarid lands have been resolved to a large extent. However, Landsat and digital techniques cannot be expected to consistently produce information at a high level of detail.

In large area vegetation inventories, Landsat and digital techniques can best be used either to subdivide a region for a comprehensive survey, or to prioritize regions most worthy of detailed attention in a restricted survey.

## SUMMARY

Efficient and accurate techniques have been developed for mapping vegetation at a variety of scales using remote sensing. The advantages of using conventional aerial photography for large-scale mapping of vegetation are well known. The aerial photograph allows for consistent, accurate delineation of boundaries and interpretation of types. Color infrared photography is well-suited (especially in humid regions) to vegetation discrimination because of high response of plants in the infrared portion of the spectrum.

Landsat offers complementary small-scale imagery in both photographic and digital formats. These data may be either used photographically in a conventional sense, or classified by computer. Of the common approaches to digital Landsat classification, the modified unsupervised approach is preferred for vegetation mapping.

Both conventional and digital techniques of vegetation mapping suffer in arid and semiarid regions where cover is less than 30%. For conventional aerial photographic approaches, natural color photography is recommended because of the importance of soil color.

To deal with inconsistent vegetation interpretation on aerial photography, new techniques have been developed which utilize the correlation between vegetation and terrain variables.

For Landsat, parallel techniques have been developed which combine spectral data with terrain information to improve classification. Another digital approach has been used to isolate the low vegetation response through the use of ratios of the infrared and visible bands.

To achieve best results, all techniques rely equally on ground verification of mapping units.

REFERENCES

1. deLaubenfels, D.J., Mapping the World's Vegetation, Syracuse University Press, Syracuse, New York, (1975).
2. Goodall, D.W., Numerical Classification, p.577-615 in Whittaker, R.H., Ordination and Classification of Communities, Junk, The Hague, (1973). (Tüxen, R. Handbook of Vegetation Science, 5).
3. Mouat, D.A., Mortensen, B.K., Reichhardt, K. and Warren, P., Vegetation Mapping of Grand Canyon National Park: An Analysis of Techniques in Proceedings of the 2nd Conference on Scientific Research in the National Parks, San Francisco, (1979).
4. Brown, D.E., Lowe, C.H. and Pase, C., A Digitized Classification System for the Biotic Communities of North America, with Community and Association Examples for the Southwest, Journal of the Arizona-Nevada Academy of Science, Vol. 14, Supplement 1, (1979).
5. Mouat, D.A., Bale, J.B., Foster, K.E. and Treadwell, B.D., The Use of Remote Sensing for an Integrated Inventory of a Semiarid Area, Jnl of Arid Environments, Vol. 4, 169-179, (1981).
6. Kassas, M., Habitat and Plant Communities in the Egyptian Desert, I. Introduction, Journal of Ecology 40 (2): 342-351, (1952).
7. Certain Aspects of Landform Effects on Plant/Water Resources in Plant/Water Relationships in Arid and Semi-Arid Conditions: A Symposium, Arid Zone Research, UNESCO, Paris, 16:71-78 (1961).
8. Kassas, M. and El-Abyad, M., On the Phytosociology of the Desert Vegetation of Egypt, Annals of the Arid Zone 1:54-83, (1962).
9. Shreve, F., The Vegetation of a Desert Mountain Range as Conditioned Chiefly by Climatic Factors, Carneggie Institute Publication 217, (1915).

10. Mouat, D.A., Relationships between Vegetation and Terrain Variables in Southeastern Arizona, Ph.D. dissertation, Oregon State University, Corvallis, (1974).
11. Mouat, D.A. and Johnson, R.R., An Inventory and Assessment of Wildlife Habitat in Grand Canyon National Park Using Remote Sensing Techniques, p.105-113 in Proceedings of Pecora Symposium 1978, Applications of Remote Sensing Data to Wildlife Management, Sioux Falls, South Dakota, (1978).
12. Swain, P.H. and Davis, S.M. (eds.), Remote Sensing - The Quantitative Approach, McGraw-Hill, New York, (1978).
13. Hutchinson, C.F., The Use of Digital Landsat Data for Integrated Resource Survey: A Study in the Eastern Mojave Desert, California, unpublished Ph.D. dissertation, University of California, Riverside, (1978).
14. Bryant, N.A., McLeod, R.G., Zobrist, A.L. and Johnson, H.B., California Desert Resource Inventory using Multispectral Classification of Digitally Mosaicked Landsat Frames, in Proceedings of 1979 Symposium on Machine Processing of Remotely Sensed Data, Purdue University, (1979), p.69-70.
15. Techniques for Combining Landsat and Ancillary Data for Digital Classification Improvement, submitted to Photogrammetric Engineering and Remote Sensing, September, 1980.

# 9
# Computer Enhancement of Landsat Data for Mapping Renewable Resources in Arid Regions: Special Reference to Guayule in the Chihuahuan Desert

*Merrill D. Ridd*
*Ernesto Neavez-Camacho*

## INTRODUCTION

Renewable resources in any region are dependent upon water supplies. By definition, water in an arid region is scarce. It follows, therefore, that scarce water results in minimal biomass in desert regions.

Minimal biomass, especially sparce vegetation, creates special problems for remote sensing. Inasmuch as vegetation is the major living renewable resource identified and mapped by remote sensors, as vegetation cover diminishes, the difficulty in detecting and mapping the cover increases significantly. Thus, to map, not to mention inventory, a vegetation resource in the desert requires our most innovative effort. The same is true of mapping the water resource itself.

In this paper it will be shown how contrast enhancement and other computer techniques are applied to detect and map Guayule distribution in the Chihuahuan Desert of northeastern Mexico. In addition to Guayule, it will be suggested how contrast enhancement may be used as a preliminary inventory of the water resource. Before discussing the techniques, it is useful to present a brief background on remote sensing, especially from satellite electronic scanners.

## BACKGROUND

Remote sensing, the process of observing and detecting objects from a distance, applies in the case of the earth to any detecting device elevated above the surface of the earth. Traditionally, this has meant aerial photography flown at various altitudes. It still means aerial photography but includes satellite staging as well (Figure 1). Satellite-acquired data is typically less detailed than that from aircraft; however, the coverage of a given "frame" of satellite data is so extensive (185 km

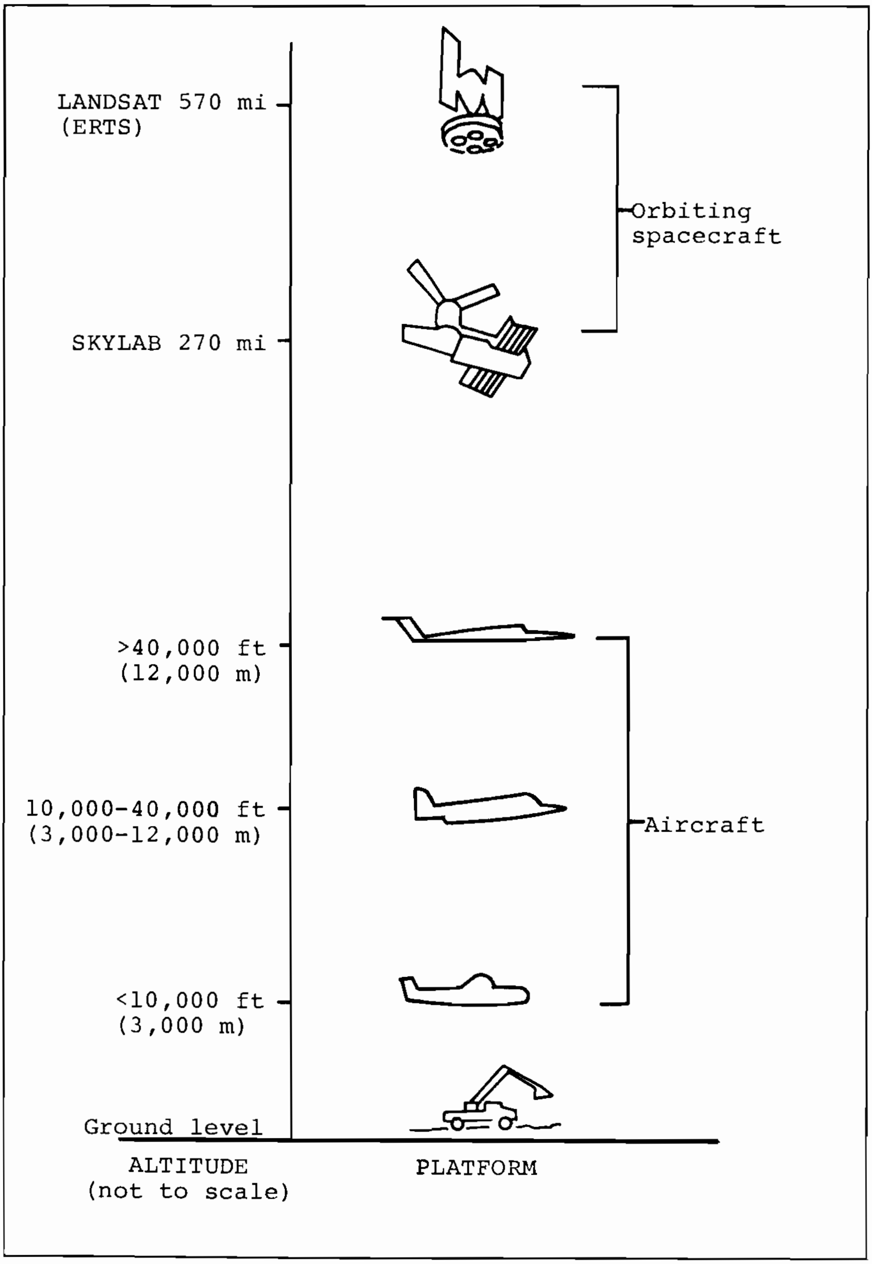



FIGURE 1. Remote sensing may involve staging at any altitude above the surface, and commonly involves two or more levels for a given study

across in the case of Landsat) as to make it very efficient and much less expensive than to use aircraft data (e.g. photographs perhaps 10 km across) for the same area. In fact, it may spell the difference between feasibility and impossibility as a mapping task in a broad region. And yet, unless some innovative mechanism is developed to actually obtain the needed information by the satellite, it may not be possible to obtain the desired information at all.

To understand techniques of computer enhancement and mapping, we must first discuss the digital structure of the satellite sensor data. The Landsat sensor (for Landsats 1, 2 and 3), known as the Multi-Spectral Scanner (MSS), derives digital data from an electronic scanner designed to detect four spectral bands of solar energy, as it is reflected from the earth's surface. The four bands are green and red in the visible spectrum and two bands of near infrared (not thermal) energy. Different surface features reflect different amounts of green, red, and infrared energy. Water, for example, absorbs most solar energy reaching it and reflects little energy in any of the four bands. An alkali or saline flat on the other hand may reflect most of the solar energy in all bands. Between these two extremes are found shrubs, forest, grass, crops, and all other cover types.

As the sensor scans across the scene area it segments the area into spatial units of about 1.15 acres or .5 hectares. Each of these units is called a picture element or pixel. For each pixel a brightness value is measured for each of the four spectral bands. Thus, four brightness values are telemetered to earth for each pixel. These values represent the digital data from which all Landsat products are made.

Basically, this stream of digital data is made available either in photographic form (called images inasmuch as they are not derived directly from camera and film) or in the form of computer magnetic tapes. Photographic products may be made in black and white for a single band, such as in Figure 2 which is made from the red band (band 5), or in "false" color by compositing any three of the bands. Figure 3 shows schematically how this is done with lights, filters, and optics. The digital data tapes may be processed through the computer to produce line printer maps, or to display on a cathode ray tube (CRT) screen, or to use for contrast enhancement, etc.

## WHAT THE SATELLITE "SEES"

With a "resolving power" of only one-half hectare (about 60 by 80 meters), it is evident that the Landsat system has its limitations. Individual Guayule plants simply will not be detected. In fact, whole patches of

FIGURE 2. A Landsat frame covers 185 kilometers on a side or about 34,000 square kilometers, as seen in this band 5 image south of Saltillo, Mexico

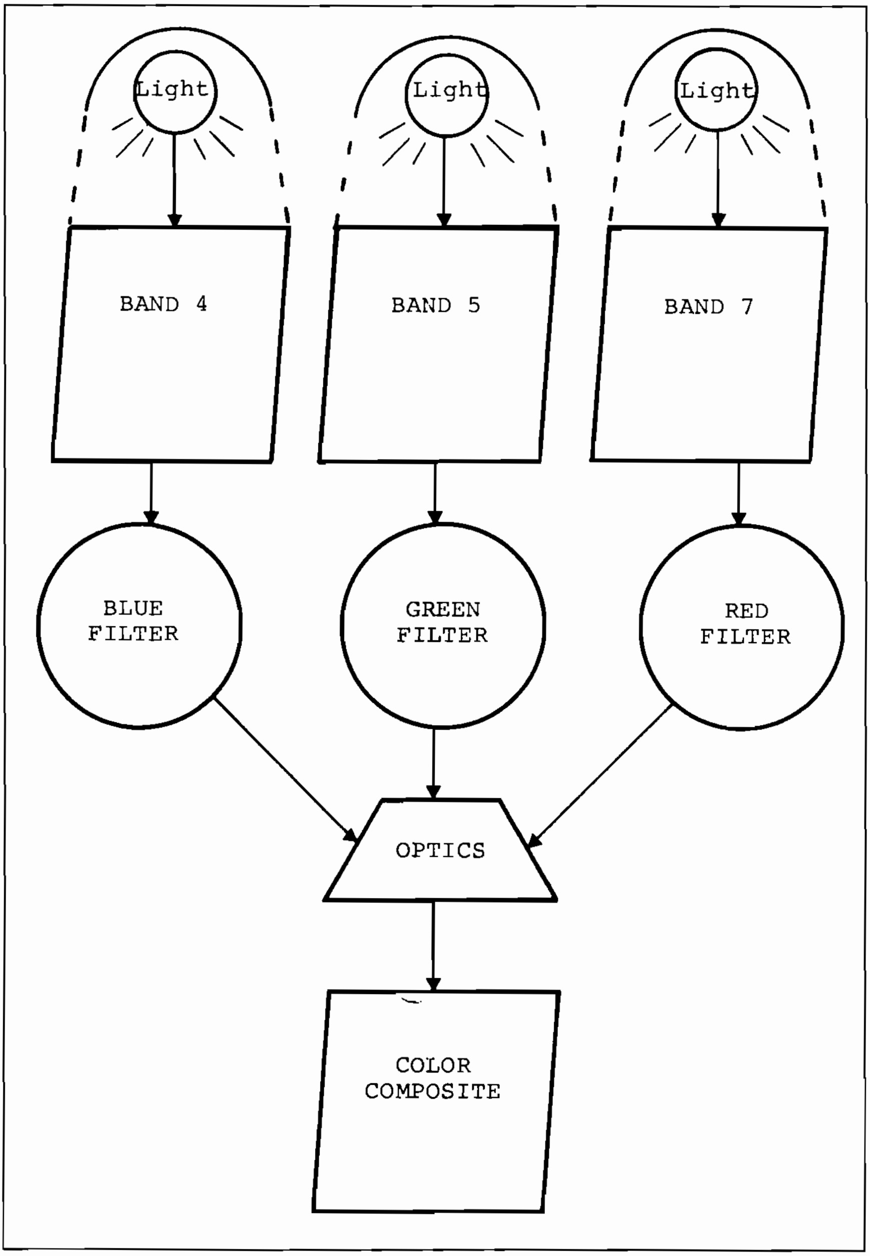



FIGURE 3. False Color Composites (FCC) are created from the images of any three bands, using conventional filters, optics, and film

Guayule may be indistinguishable. The signal received by the sensor is really a composite of all that lies within the pixel - the individual plants, the soil, and all else in the 60 by 80 meter area. This limitation may be quite severe, especially in arid regions where individual plants are typically separated by much bare soil. In sparsely vegetated areas, the soil may dominate the brightness signal detected by the satellite sensor more than the plants do.

Yet, the tool may be very useful if the soil and vegetation co-vary in their spatial distribution. This we might expect to some degree because of the interaction of biophysical systems in nature. To the extent there is substantial spatial correlation between soil, vegetation, topography, and other components of the landscape, the composite of these elements as "seen" by Landsat may be taken as a surrogate for the individual components. And to that extent Landsat may be a significant tool in regional resource applications, where vast areas of resources need to be inventoried quickly and cheaply. This is especially so in areas where relatively little is known of the resources, their ecological associations, and their distributions. Such is the case in many arid regions of the world. And such is the case in the Chihuahuan Desert and the Guayule environment. The remaining question relative to Guayule mapping is, "Do the components of the environment in which Guayule occurs co-vary spatially to the extent that the composite signals received by the satellite sensor reasonably will define the Guayule producing areas?"

## GUAYULE IN THE CHIHUAHUAN DESERT

Preliminary field observation showed that Guayule typically occurs on gentle piedmont slopes, below the mountain front and well above the bolson basin floor (Figure 4). Within this general piedmont area considerable variation occurs in the geologic origin of landforms although relief is minimal. Guayule typically occurs on the gentle rises and is rarely found in abundance in the swales. The rises are in most cases dissected pediments in their geologic origin, or are underlain by thick caliche deposits in coarse texture alluvial aprons. In either case they are very dry sites with poor water penetration and holding capacity.

Much bare and gravelly soil is exposed between individual plants. Total plant cover rarely exceeds 60% and Guayule is rarely the dominant species. In this "Guayule-producing environment" Guayule covers less than 9% of the area, according to 83 field plots.

The piedmont area of Guayule-producing environments is generally visible on the standard NASA/EDC (EROS Data

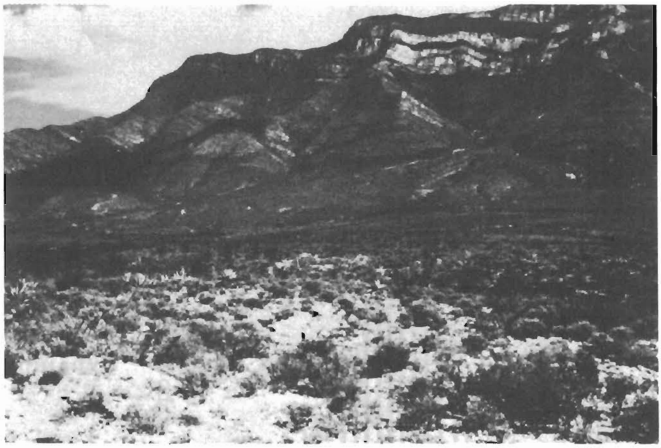


FIGURE 4. Most of the Chihuahuan Desert Guayule is scattered on piedmont slopes, interspersed with other species and much bare, gravelly or rocky soil

Center) photographic product, seen in Figure 2 as a middle to light gray tone. On enlarged color composite prints the piedmont area shows more clearly, but still does not display the variation due to minor relief differences on the piedmont slopes. Thus, the distribution of Guayule can only be crudely approximated. The present research strategy for determining the distribution more accurately involves two computer techniques: 1) contrast enhancement and 2) line printer mapping.

## CONTRAST ENHANCEMENT

Contrast enhancement, otherwise known as contrast stretching, color stretching, image enhancement, etc., has been explored by many investigators in various applications (1-4). It is a computerized process which in the present case utilizes the digital computer tapes from NASA and increases the light and dark contrast pixel-by-pixel within the scene. The result is projected on a precision CRT, in color, and photographed. The photograph may then be used in conventional fashion by tracing the Guayule pattern on a light table and measuring the area.

Briefly, the process is based on the brightness of each pixel as sensed by the satellite in each of the four bands. Most pixels have a brightness in the middle range or slightly lower, as seen in the top illustration in Figure 5. Generally no pixels occupy the extreme light or extreme dark ends of the scale. The full scale, called the dynamic range, for Landsat data runs from 0 to 127

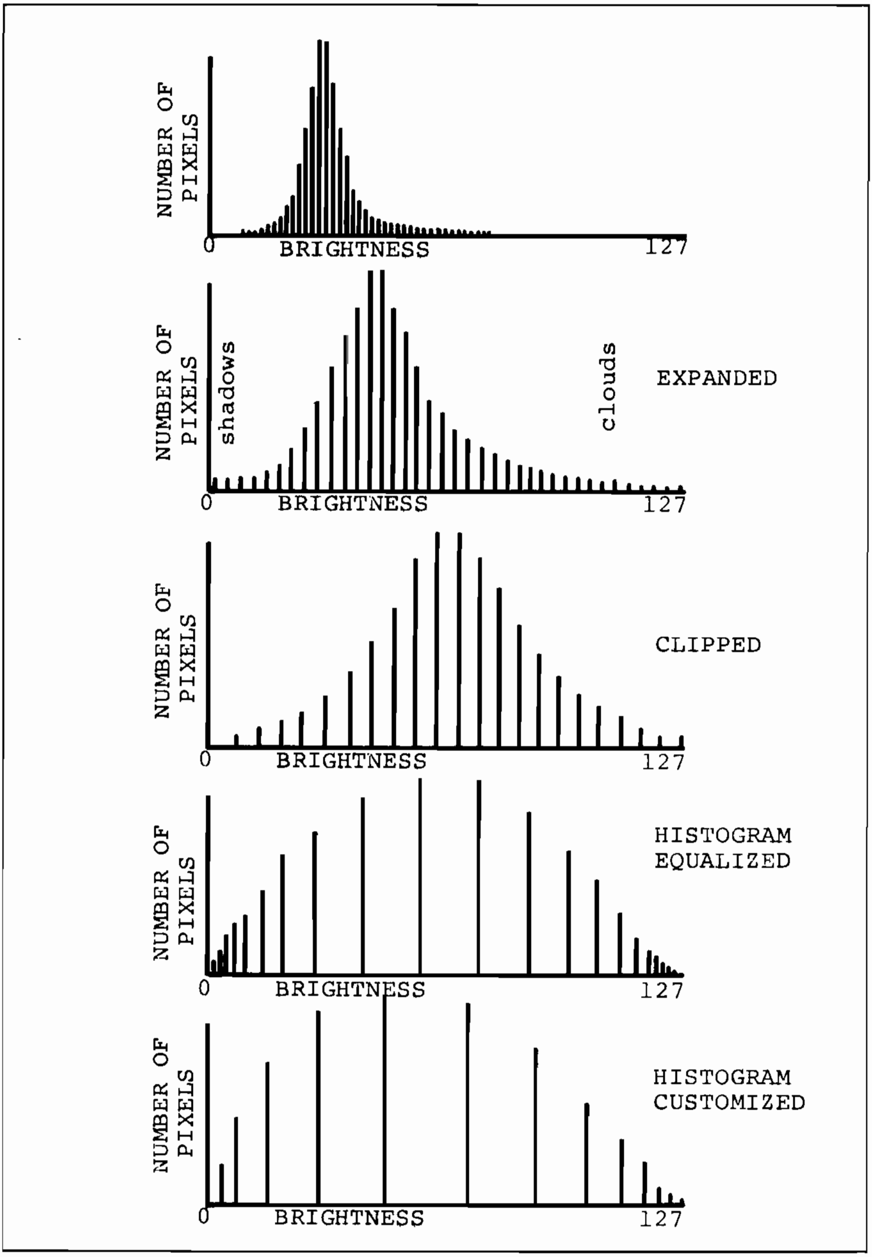



FIGURE 5. Computer contrast enhancement may involve several steps, each increasing the contrast in the Guayule environment

discrete positions. Since the upper and lower extremes of the scale are not being occupied by any pixels, it follows that the actual data set might as well be expanded to utilize the full dynamic range. Without discarding any data at all, contrast is enhanced by expanding the brightness values between neighboring pixels, so to speak (second illustration, Figure 5). Inasmuch as it is simply the matter of contrast of brightness between adjacent pixels that creates the photo image and makes it possible to interpret, it follows that increased contrast creates an increase in diagnostic power within the image.

A second step in contrast sketching might well be to discard the brightest and darkest pixel positions, as they merely represent clouds and shadows or other useless data (with respect to this study). Thus, a "clipping" procedure stretches the brightness still more, without sacrificing any data of value. This process can be continued through "histogram equalizing" to spread even further the contrast in the middle range where most pixels occur.

Now, if it is known wherein the Guayule environment lies along the brightness scale, that zone may be stretched even more to dramatize the contrast within the Guayule-producing environment. (See lower illustration in Figure 5). This has been done to produce the product as shown in Figure 6 (the color photographic product is of course much more effective than this half-tone black and white). Now, the Guayule pattern may be traced on the light table, and the hectare count determined by planimeter. With field ecological sampling, carefully located, it is now possible to determine the standing crop and to estimate sustained yield. Figure 7 shows an enlarged segment of the enhanced image. Other reports demonstrate the integration of contrast enhancement and field data to determine crop and yield estimates (5,6).

## DIGITAL LINE PRINTER MAPPING

A second technique, utilizing computer line printer maps, may refine the contrast enhanced product still further. Earlier it was mentioned that various earth surface features and cover types have distinctive reflection or brightness characteristics among the four spectral bands. These distinctive characteristics have come to be called "signatures". Some such features are represented in Figure 8. Implicit in the illustration is a classification of cover types that has already been processed and sorted-out in the computer. Through experimentation using an unsupervised maximum likelihood classifier, Guayule has been found to have a general signature as indicated. However, there are variations within Guayule cover, depending on its density and the mix of other vegetation and of soil, etc. Furthermore, other cover types are very similar to the Guayule areas.

FIGURE 6. On the contrast enhanced photograph, the Guayule environment may be traced and measured

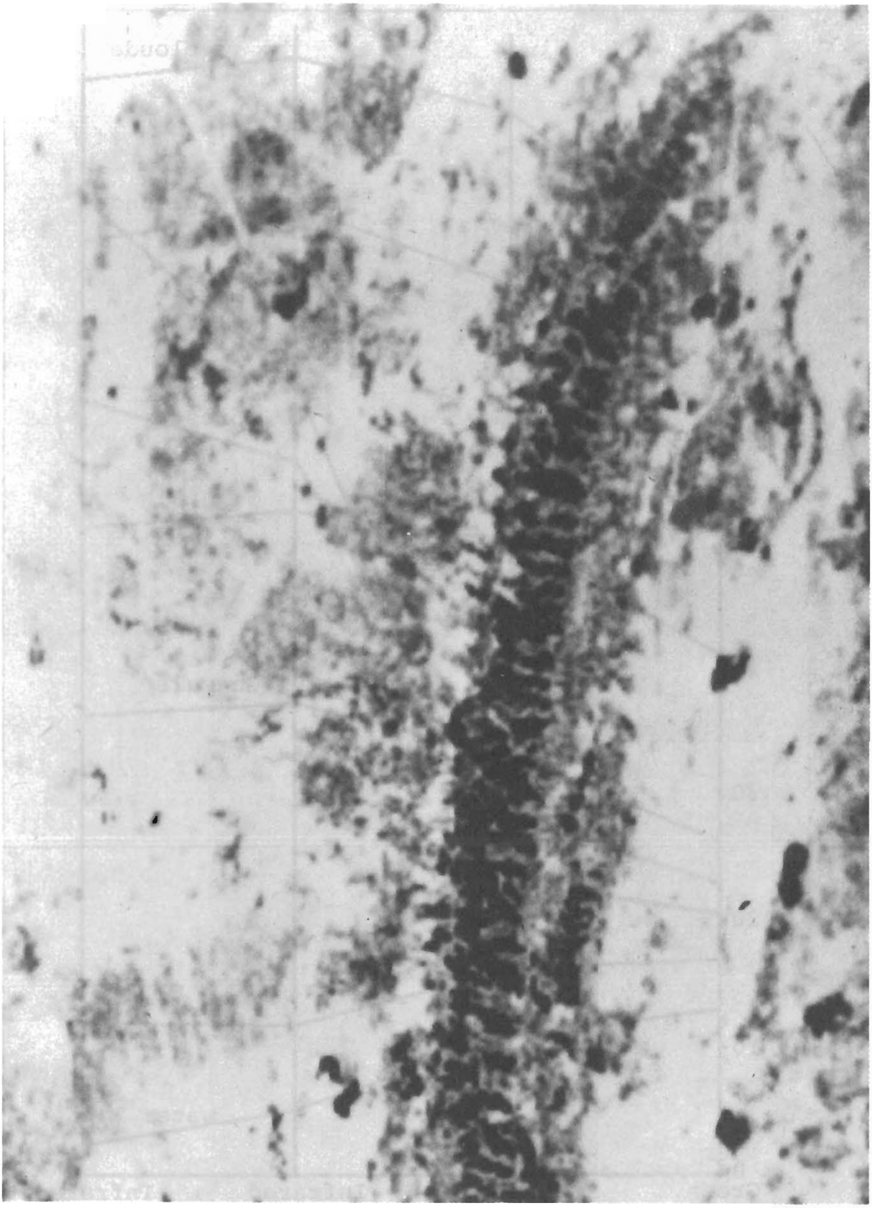


FIGURE 7. This enlarged contrast enhanced product from Figure 6 demonstrates (especially in color) the improved quality for the identification and mapping of Guayule environment along the piedmont in medium gray tones

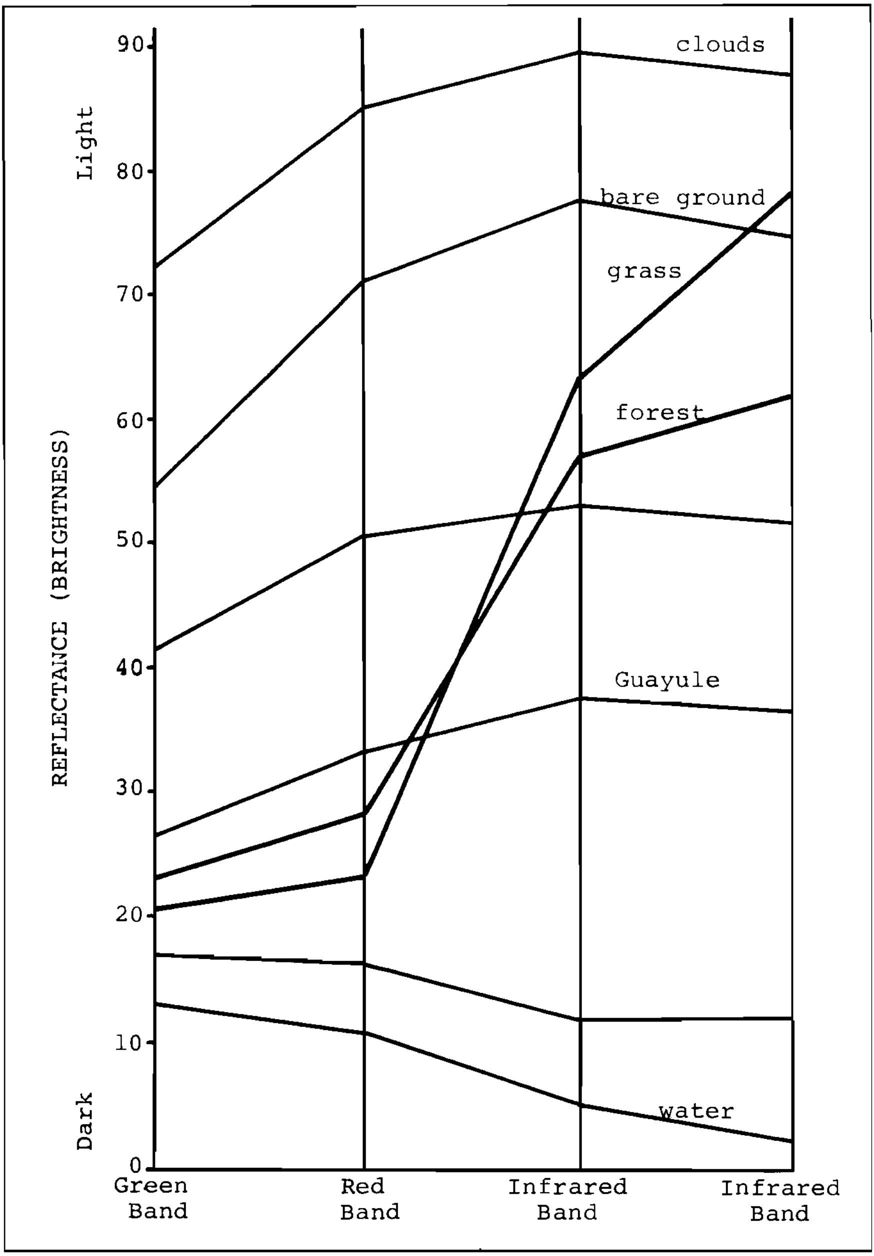



FIGURE 8. Various classes of cover type may be detected by their distinctive "signatures" of brightness among the four spectral bands

Figure 9 shows a contrast enhanced product of part of Sierra Zuloaga (it is much more impressive in color), while Figure 10 shows a first approximation print map of the Guayule-producing environment of the same area with an arbitrary symbol using the letter "L" and an overstrike "/". Field experience demonstrates that, although this pattern is quite good in general, it is slightly too extensive and it obscures some variation within the Guayule area. Thus, a second and third run of the classifier program is focused on the Guayule environment more directly. The result is a more detailed breakdown within the Guayule environment (Figure 11). The letter "D" is generally representative of fair stands of Guayule, the letter "C" is somewhat better, and the letter "B" at this stage of investigation appears to represent the richest stands of Guayule. All other symbols are taken as non-Guayule.

This digital refinement is a substantial improvement over the contrast enhancement product, if subsequent field investigation verifies the ranking of abundance. It is better because the contrast enhanced image alone is still subject to tracing and subjective judgement regarding color and tone variations. The digital symbols on the other hand provide a discrete pixel-by-pixel count of Guayule distribution, subdivided by relative densities. If the results obtained via use of this technique are confirmed

FIGURE 9. A contrast enhanced image of the west end of Sierra Zuloaga exhibits in color the pattern of Guayule distribution around the mountain

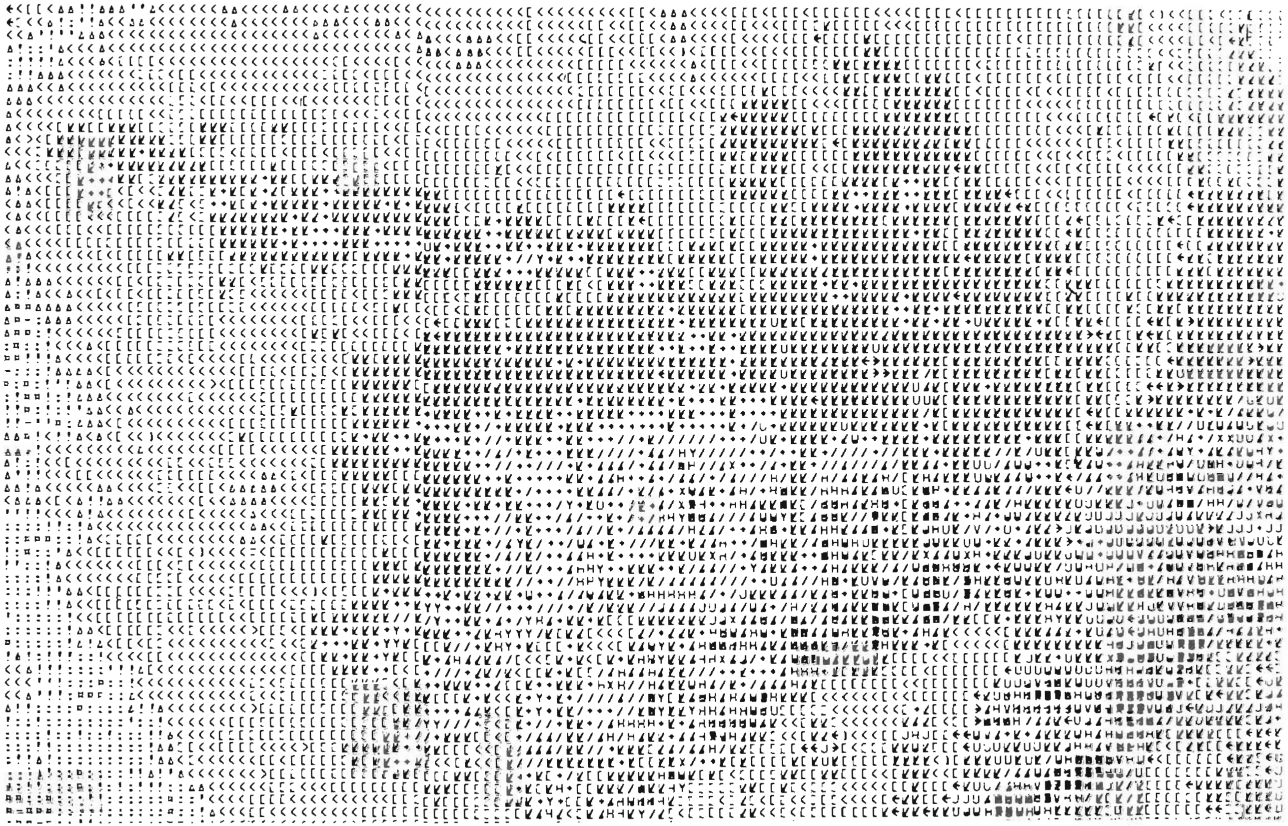


FIGURE 10. A line printer map depicts the general pattern of Guayule in the same location as in Figure 9.

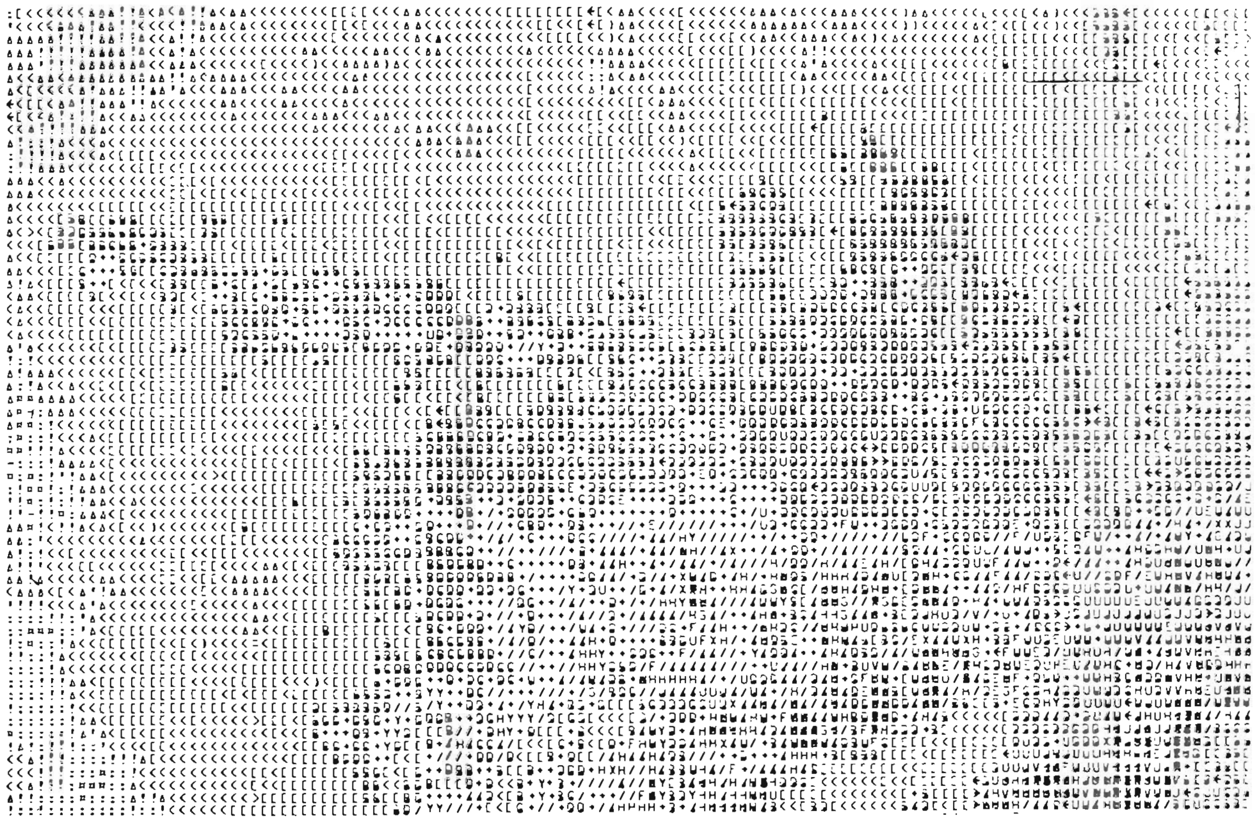


FIGURE 11. A refined line printer product is more detailed, suggesting areas of variable density Guayule

by field investigation, then Landsat, with some special digital manipulation, has proven to be an effective and powerful tool in the mapping of Guayule, its distribution and relative densities.

## WATER RESOURCE

Finally, regarding water resource inventories in arid areas, the same techniques show considerable promise. Figure 12, in color form, vividly displays red spots (seen here only as dark gray) of dense biomass, in contrast to surrounding sparsely vegetated areas. Such spots represent places of anomalous water consumption to produce such heavy biomass. The water may be surface water or near-surface ground water. The vegetation there may be naturally occurring or introduced in the form of irrigated crops or pasture. To distinguish between natural and man-induced vegetation would in most cases be possible through visual association with topography on the image, with natural vegetation typically occurring along channel courses.

In any case, whether the vegetation is natural or man-induced, and whether the water is surface or ground water, an enhanced image provides a reliable tool for detecting accurately the presence of water consuming sites. Computer enlargements of such areas permits a pixel-by-

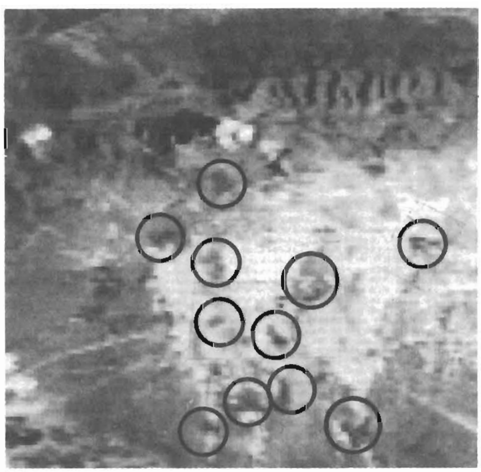


FIGURE 12. In color this enhanced image depicts clearly the sites of significant water consumption by the presence of dense biomass (circled dark gray spots which appear in red on the color original), in contrast to the surroundings

pixel count of the hectares involved in each site, if such information were desired. Large regions of the arid zones could be quickly and inexpensively inventoried and mapped for water consuming sites. Further studies of water application and consumption by crops and natural vegetation could begin to provide water volume data as well.

## SUMMARY

It has been shown that Landsat data can be used effectively to detect and map renewable resources in arid regions, at certain levels of generalization and under certain conditions. One of the conditions is a degree of spatial correlation between the component systems of the natural landscape. In the case of Guayule it is shown that rather accurate maps of its distribution might be made through two digital processing techniques - contrast enhancement and line printer mapping. For general identification of water consuming areas contrast enhancement may be used by distinguishing sites of concentrated biomass. Here again, it is the interrelationship of biophysical systems (in this case including man's intervention) that makes such detection and mapping possible. And this tool is available today as has been shown.

As improved satellite sensors become available, along with evolving computers, peripheral equipment, and software systems, the diagnostic power of detecting and mapping natural resources in arid regions will improve our knowledge and managment of resources in vast regions that are little understood today.

## REFERENCES

1. Andrews, Harry C., Monochrome digital image enhancement, Applied Optics 15: 495-503, (1976).
2. Chavez, Pat S. and Mitchell, William B., Computer enhancement techniques of Landsat MSS digital images for land use/land cover assessments, 6th Annual Remote Sensing of Earth Resources Conference, (1977).
3. Frei, Werner, Image enhancement by histogram hyperbolization, Jour, Computer Graphics and Image Processing 293-301, (1977).
4. Williams, D.L. and Miller, L.D., Monitoring forest canopy alteration around the world with digital analysis of Landsat data, National Aeronautics and Space Administration, Washington, D.C., (1979).
5. Ridd, M.K., Neavez-Camacho, E. and Campos-Lopez, E., Contrast enhancement applied to Guayule distribution in northern Mexico, Paper presented at the Third International Guayule Conference, Pasadena, California, April 27 - May 1, (1980).

6. Ostler, K.W., Alder, G.M. and Garza, R., The community ecology of Guayule (Parthenium argentatum, gray) Paper presented at the Third International Guayule Conference, Pasadena, California, April 27 - May, 1, (1980).

BIBLIOGRAPHY

1. Native Plants, Inc., Ecology and reproduction of Guayule (Parthenium argentatum, gray) in natural stands in Coahuila, Nuevo Leon, and Zacatecas, Mexico Report to Centro de Investigación en Química Aplicada (CIQA), Saltillo, Coahuila, Mexico, (1979).

# Part III

# Development Options

# 10
# Strategies for the Prevention of and Fight Against Desertification*

*Manuel Anaya-Garduño*

## DESERTIFICATION - A PROBLEM OF MANKIND

Desertification is a dynamic process which physically and biological degrades ecosystems, sometimes irreversibly, and causes social, economic and political consequences. It is estimated that in the south of the Saharan Desert, 65 million hectares have been converted to desert in the last fifty years. It has also been estimated that two-thirds of the roughly 150 nations of the world are affected by desertification of varying intensity, and that 14% of the world population, or 628 million people, live in arid zones: 72% of these in semi-arid zones, 27% in arid zones and the remaining 1% in extremely arid zones (1).

### Population and Desertification

Today, a growing world population is endangering the ecosystem's productive capacity as indicated by the relentless spread of desertification. The world's population was 4100 million in 1975, and is projected to exceed 6350 million in the year 2000 (2). In many nations population is growing at a faster rate than food production, and malnutrition is prevalent.

Rural population densities typically vary according to the productivity of the ecosystem; generally they are less than 1 inhabitant/km$^2$ in extremely arid zones, less than 5/km$^2$ in arid zones and less than 10/km$^2$ in semi-arid zones. The ranges are from less than 1 person to 10 people/km$^2$ in arid zones to less than 1 person to 100 people/km$^2$ in developed countries (1). This concentration of people in developing countries promotes the rapid deterioration of ecosystems due to immoderate felling, uncontrolled cutting of firewood, overgrazing, reduction of the vegetation cover and exposure of the superficial soil to aeolian and hydric erosion; thus the productivity of the ecosystem is reduced, ecological deterioration is increased and the abandonment of land is promoted (3).

*Translated from Spanish

## The Advance of Desertification

It is estimated that overgrazing has damaged more than 2400 million hectares of the world's surface area and that these lands exhibit the worst deterioration. In second place, with regard to area covered and damage inflicted, are forests, which have suffered from badly-planned felling, uncontrolled cutting of firewood and fires. In third place is dryland agriculture, which occupies around 1300 million hectares in the world and where aeolian and hydric erosion are prevalent. Finally, irrigated agriculture occupies 200 million hectares of the world's surface and poses dangers of salinity, lack of drainage, marine intrusion, over-exploitation of water resources and accelerated silt build-up in reservoirs. As a result of these processes, the rate of advancement of desertification today is greater than the rate of recuperation of affected areas and represents a danger for the sustained production of food.

The above-mentioned land uses are not the only ones that pose risks of desertification. Desertification problems may also arise from other soil uses, such as national parks, ecological reserves, roads, mineral exploitation and human settlements.

In Table 1, some of the physical and biological processes which cause environmental deterioration are presented, and some of the problems of water, soil and plant management are analyzed (4). The principal desertification processes are: 1) reduction of the vegetation cover, 2) aeolian erosion, 3) hydric erosion, 4) deterioration of the soil structure, 5) reduction of organic matter, 6) salinity, 7) lack of drainage (4,5).

The above facts indicate the need for adequate integral planning for the use of water, soil, flora and fauna resources with the objective of preventing desertification, reducing ecological deterioration and assuring sustained food production. The next section discusses some important considerations in integrated planning of resource use.

# IMPORTANT CONSIDERATIONS IN INTEGRATED PLANNING OF RESOURCE USE

## Water and Land Available for Agricultural Purposes

The correct management of water and soil represents the basic infrastructure to achieve permanent agricultural production systems. The most important limiting factor for the development of arid and semi-arid zones has been, is and will be water. The principal uses of water, in order of importance with regard to volume consumed, are: agricultural, industrial and domestic. Some countries,

TABLE 1.
Physical and Biological Processes which Cause Desertification
(* Natural causes)

| Causes | Problems |
|---|---|
| **Water** | |
| *Scarce precipitation<br>*Erratic and bad distribution of rainfall<br>Bad management of irrigation water<br>Overexploitation of waterways and superficial reservoirs<br>Water losses | Scarcity of water |
| *Erratic and bad distribution of rainfall<br>Deficient drainage systems<br>*Uncontrolled superficial drainage | Bad management of rain water in dryland areas |
| Lack of knowledge re consumption levels<br>Deficient land leveling<br>Inadequate water distribution<br>Inadequate irrigation methods<br>Inadequate parcel distribution | Bad management of irrigation water |
| *Erratic and bad distribution of rainfall | Lack of control over superficial drainage |
| **Soil** | |
| Reduction in vegetation cover<br>*Geological erosion<br>*Uncontrolled drainage<br>Sedimentation and obstruction<br>Degradation of soil structure<br>Inadequate farming<br>Aeolian erosion<br>Diminishing of the soil profile depth<br>Loss of superficial soil fertility<br>Leaching<br>Reduction of moisture holding capacity | Erosion |
| Accumulation of salts<br>Excessive irrigation<br>*Water quality<br>Deficient washing practices<br>Bad management of irrigation water<br>Inadequate drainage systems<br>*Uncontrolled drainage | Salinity and deficient drainage |
| **Plants** | |
| Cut-slash-burn agriculture<br>Clearings<br>Overgrazing<br>Undesirable plant invasion<br>Uncontrolled cutting of firewood<br>Immoderate felling<br>Fire<br>Drought | Reduction of vegetation cover |

such as Mexico and India, use more than 80% of their water for agricultural purposes and less than 20% for industrial and domestic uses; others, such as Russia and the U.S.A., use about 40% for agriculture, 45% for industry and the remaining 15% for domestic purposes. The estimated demand for industrial purposes is 20-40 $m^3$ per person/year, which is comparable to the domestic consumption in developed countries (6).

The agricultural potential of dryland zones is related to the availability of water. Therefore, during the coming decades, better technologies will be needed to increase efficiency in the use of this resource.

In 1970 the world agricultural area under irrigation was 187 million hectares, but for dryland farming the figure was 1350 million hectares. The water available for irrigation was 2000 $km^3$ and for dryland farming 11500 $km^3$. Ambroggi (6) estimates that in the year 2000 the area under irrigation will be 302 million hectares and that for dryland farming 2000 million hectares, with water consumption of 4800 and 17000 $km^3$ respectively.

In 1975 arable land per capita was 0.60 hectares for industrial nations and will be 0.45 hectares by the year 2000; for developing countries the figure was 0.35 in 1975 and only 0.20 estimated for the year 2000. This indicates that the average yield of basic grains must increase from 1.74 ton/ha in 1975 to 2.76 ton/ha in 2000 to supply the food demand (Figure 1) (2).

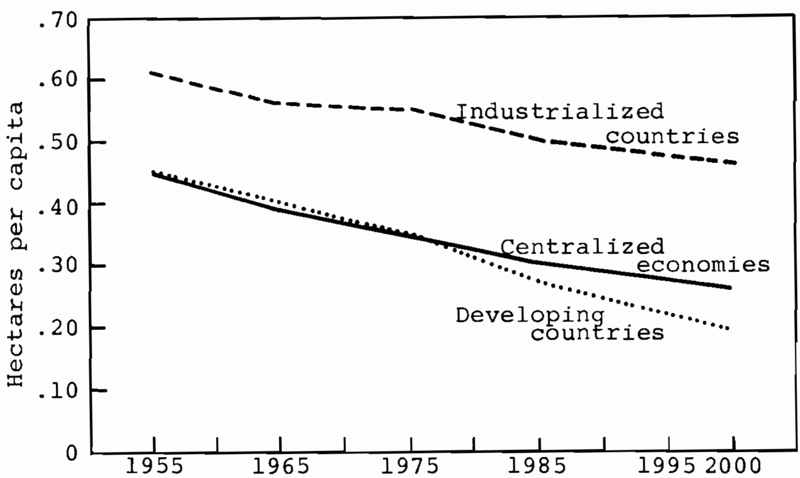



FIGURE 1. Arable land per capita in 1955, 1975 and 2000

## Land Ownership and Parcel Size

Insecurity over land ownership causes socio-economic problems in agricultural and forestry production systems and, in the majority of cases, diminishes production. Other problems arise when parcel sizes are very small and have a low production capacity. This causes the farmer to seek other work and partially or totally abandon the parcel.

On many occasions, soil erosion affects various parcels and necessitates the participation of a group of farmers for its effective control before it continues and affects other parcels. The abandonment of parcels produces low-remuneration marginal areas and at the same time favors the desertification process. It would be desirable to consider each community as a production unit and make it responsible for the rational management of its natural resources. In the case of a lack of food, the best land should not be dedicated to the production of highly remunerative crops and the marginal land to food production. Therefore a rational plan of action should be established to assure the production of basic food crops (4).

## Input Availability

All the land-use systems require the availability of certain inputs (e.g., credit, fertilizers, mechanization, seeds, etc.) in order to improve productivity and prevent the development of desertification. Unfortunately the most degraded land-use systems require high investment. When such investment is not forthcoming, a viscious circle is initiated which results in ever-worsening desertification, principally in the countries with a low development capacity.

Extensive production systems with low productivity per unit of area and per unit of time are the most widespread in the world. Therefore, plans of action for the short and long-term are urgently needed to induce a gradual change to more intensive production systems with greater unitary yields. The technology utilized should be chosen to facilitate this transition in order to augment production and profits - part of which should be reinvested in these production systems. Security in the improvement of the standard of living for the population would motivate them to work with more enthusiasm and to stay within their communities - so reducing the massive migration to urban centers.

## Mechanization Level

In the developing countries, it is frequently found that the principal energy sources in land-use systems are man and animals, which, in the majority of cases, do not satisfy the energy demands for the opportune execution of certain agricultural activities. Greater efforts should be made to develop the traditional equipment and tools by means of an industry that evaluates, designs and produces the necessary tools at a local, national and international level.

## STRATEGIES TO CONTROL DESERTIFICATION

In summary, the causes and consequences of desertification are the following: 1) environmental deterioration, 2) diminishing of the ecosystem's productivity, 3) reduction in food production and 4) social, economic and political repercussions.

### At an International Level

The world strategy to prevent and fight against desertification is contained in the plan adopted at the World Conference on Desertification which took place in Nairobi, Kenya in 1977, and was organized by the United Nations Environmental Programme (7). It was agreed that each country should establish a National Plan to Combat Desertification. The integral planning system recommended above and the control of desertification should function in parallel as they are both related to the adequate use of water, soil, flora and fauna resources - the important heritage of present and future generations.

During the Nairobi conference, short and long-term principles and measures were established for the prevention of and fight against desertification. It was considered a problem for humanity and therefore that the success of the fight would depend upon the organized and enthusiastic actions of the communities which are responsible for the use they make of natural resources. The Action Plan should be integral and the measures should consider the adequate technological level for the production systems and the ecological, social and economic conditions.

To date, Mexico and the U.S.A. have made an agreement to improve the management of arid and semi-arid lands and to control desertification. They have shown concern as the phenomenon of degradation represents a growing threat to the economic and political well-being of the inhabitants of both countries and are therefore preparing two national documents with the idea of defining guidelines to help prevent and fight against desertification (8,9).

### Elements of a Plan to Combat Desertification

Some actions to help fight against desertification are the following: 1) selection of appropriate technology, 2) establishment of a Plan, and 3) setting-up of pilot areas.

It is crucially important to count on the support of the local population, as the objective is not only to fight against desertification and promote economic growth, but is also related to the morale of the people, especially in the most seriously affected areas where misery, unemployment and under-development are present.

Technology and Desertification. Desertification is a phenomenon promoted by man and caused by exceeding the potential limits of desertification which exist for the various land-uses. Any land-use by man signifies a potential danger for the system and selection of appropriate technology tends to minimize this danger and increase productivity. An example of this are the terraces constructed 2000 years ago by the Romans in North Africa with the aim of controlling drainage on the hillsides and achieving the transformation of this region into the granary of the Empire. The catastrophic result of this unfortunate use of technology illustrates the dangers associated with the inappropriate application of technology. On the fall of the Empire, the maintenance of the terraces was abandoned, causing the soil erosion to be even more destructive than it was before the construction of the terraces. In order to utilize the Roman experience in the 20th century, the terrace system has been reintroduced in Tunisia in conjunction with reforestation on pronounced slopes, which has achieved the restoration of productivity in the ecosystems (4).

Desertification is often caused by the need for man to subsist and many other times by the desire to overexploit the natural resources. Technology represents a link between the natural and social systems and may or may not result in the optimum management of the natural resources. There are many examples of the correct and incorrect application of technology - there are cases where the wrong application of technology has been responsible for many environmental problems of which desertification is only one.

Technology can be considered as simple, intermediate or advanced, depending on the established reference framework, although simple is not necessarily related to traditional or primitive technology. Appropriate technology can be, from the point of view of its complexity, simple, intermediate or advanced, and therefore a particular technology may be appropriate under certain specific conditions and inappropriate under others.

To date there exists a great variety of technologies generated by empirical and scientific know-how; it could be said that in general there is no limit to technological solutions to the problems of desertification. In the majority of cases, the factors inhibiting efforts to combat desertification are social, economic and political.

In cases in which there are no financial restrictions, almost any damaging effect of desertification on natural resources could be remedied. There are, however, some restrictions on the utilization of new technologies, among which are the following: 1) availability of trained personnel, 2) availability of local raw materials, 3) availability of means of transport or communications, 4) availability of fuels, and 5) motivation of the community.

The nations with limited economic resources require, at the beginning of their development, that the technologies utilized be of low cost, easy application, small scale, based on the availability of local resources, manpower intensive, in accordance with cultural conditions and acceptable from an ecological point of view. To date, there is no proper classification or evaluation of existing technologies to which developing countries could turn for information on technologies which could improve considerably their production systems. A mechanism for control over technological recommendations and a high sense of responsibility are needed desperately.

The selection and application of technologies to fight against desertification in the various countries will be based upon the education and motivation of the local population, the availability of well-trained technical personnel and the levels of investment and time dedicated to the recuperation of specific areas under the process of deterioration.

According to Anaya (4), three basic principles should be taken into account to determine the most efficient technologies:

Firstly, the logical sequence to begin to fight against desertification is to give priority to the least deteriorated production systems. This is especially important in those situations where economic limitations are severe, since little investment could produce satisfactory profits over short-term periods which could be reinvested to increase productivity gradually. Also these extra profits could be used to recuperate other more severely damaged areas.

The second principle refers to the consideration of the intermediate technology concept, always given that this is possible. Frequently the developing countries are associated with a reduced industrial capacity, a lack of health centers in good condition, low credit availability and poor technological development, all of which hinder the introduction of more advanced and complex technologies. Some characteristics of appropriate or transitional intermediate technology are the following: 1) a high sense of social justice, 2) adaptability to social and human group behavior aspects, 3) capacity for successful mixing and to be complemented by old and modern know-how and experience, 4) low cost, 5) slight damaging effects on the ecosystem, 6) more efficient use of local manpower, and 7) generation of gradual growth which is more realistic for the social and economic systems of a locality.

Thirdly, traditional technologies developed by communities, as well as other life systems, should be considered before the establishment of new land-use systems, as these have been proved over long periods of trial and error and represent proven bases for the management of natural resources. Frequently this local experience provides the starting point for the fight against desertification and the generation of development. Furthermore, when traditional technology is complemented by that of an intermediate and modern character, the capacity exists for a creative and gradual change from an extensive, low-yield system to one of intensive production.

It is important to emphasize that technology _per se_ is not sufficient to control desertification. It is also necessary to count on an adequate basic infrastructure and, even more importantly, to achieve the enthusiasm of the people and their decision to participate in the process.

_Principles for the Establishment of a Plan_. A plan is one way to organize the action for the control of desertification and is related to the planning of the following: prevention, reorientation, systemization and evaluation. A plan can comprise various action programs and the area considered can be at an international, national or local level.

The components of a plan are the following: 1) diagnosis, 2) prognosis, 3) objectives, 4) levels of application, 5) levels of coordination, 6) operation of plan, and 7) evaluation (8-10).

_1. Diagnosis_. This refers to the evaluation of that which has happened in the past and should consider the availability of water, soil, flora and fauna, the socioeconomic framework, which shows the current conditions and capacities of the population, and the legal and administrative framework which defines the legal and organizational bases for the fight against desertification. This evaluation should consider the indicators of desertification which could be grouped as follows: a) physical and biological, and b) socio-economical (11). Current methodologies are very diverse and are related to the use of satellite imagery, aerial photography, land survey backup, and mathematical models (5). The scale at which each of these methodologies are applied plays an important role. The diagnosis is a very significant component and on this depends, to a great extent, the success of the plan to prevent and combat desertification.

_2. Prognosis_. In this component, the general and specific trends will be analyzed with the idea of forecasting the advance of desertification. Also some preventive and corrective propositions could be considered.

<u>3. Objectives</u>. These can be general and specific and refer to what needs to be done in the short, medium and long term, as well as the statement of working hypotheses.

<u>4. Application level</u>. This refers to <u>how</u> the plan will be carried out according to the available instruments, such as policies and strategies, legislation and methodologies to employ. The control of desertification could be achieved by utilizing a massive application of science and appropriate technology. The extension programs to facilitate the introduction of technologies should be strengthened.

<u>5. Coordination levels with other planning levels</u>. Coordination and organization are essential ingredients for the harmony of short, medium and long-term actions. Currently, there are numerous programs for the fight against desertification in which the participation of the public and private sectors, of communities, and of technicians is observed. Nevertheless, it is necessary to improve the organization and coordination considerably.

<u>6. Operation</u>. The organized participation of the communities, technicians and private and public sectors will be sought. Negotiations will be carried out at a local, state and federal level with the idea of covering the various levels of operation and execution.

<u>7. Evaluation</u>. This will give a continuity to the plan with the object of carrying out periodic evaluations which allow the reorientation and refinement of the actions against desertification.

<u>Establishment of Pilot Areas</u>. The establishment of pilot areas to combat desertification serves three objectives: 1) research, 2) demonstration, and 3) training at various levels. Pilot areas contribute to finding viable strategies which help to impede ecological deterioration and maintain the productivity of the ecosystem. An evaluation should always be carried out in order to assess the advantages of the trial and, above all, for economic and social reasons.

Another important aspect is the siting of pilot areas. These areas should be representative of the most important ecological and socio-economic conditions. Pilot areas should not be as small as an experimental field, nor so large that they cannot be controlled easily.

Enthusiastic participation of the community and the public and private sectors will be indespensable for the achievement of the objectives. Properly chosen pilot areas will serve as the bases for the establishment of programs on a larger scale, which will be an important part of a global pattern to control the process of desertification.

In Mexico there is an interesting example of this, as seven pilot areas have been selected in regions with varying ecological and socio-economic characteristics and which form part of the states of Sonora, Coahuila, Zacatecas, Guanajuato, Mexico, Oaxaca and Tabasco (10). The first two areas correspond to the arid zone in the north of the country, the following four to the central zone of Mexico, which is the most affected by desertification due to the high population densities, and the last one is located in a tropical, humid zone.

In each one of the selected states, a regional reference framework was established, taking as a basis the dryland district in which the proposed pilot plant would be located. The regional reference framework includes the following: 1) physical characterization of the area, 2) socio-economic aspects, and 3) production systems.

Once the regional framework is analyzed, the specific area is selected through field trips and with the support of the local people from the participating institutions and the following points are considered:

1. It is best, where possible, that the chosen area be a hydrographic basin, for the purposes of measuring the incoming and outgoing water and the sediment losses which occur in the zone, considering the basin as a production system and as an ecological unit;
2. That the chosen area present various land-use systems so that an evaluation can be carried out for each one of them on their impact on the degradation of the resources, as well as their recuperation potential; and
3. That their ecological conditions be representative of the region in which they are located so that the results may be extrapolated.

The next step consists of the elaboration of the specific pilot area reference framework, which is a detailed study carried out with the collaboration of all the institutions involved, each one of them being responsible for a part of the study.

The phases of the pilot project area are: 1) elaboration of the reference framework, 2) diagnosis of the problem, 3) detection of preventive and corrective measures, 4) presentation and approval of investment projects, 5) carrying out of works, research and training at various levels, and 6) evaluation.

To date there are numerous examples of pilot areas established in various countries affected by desertification, in which scientific and empirical know-how are utilized through appropriate technologies for various production systems. Nevertheless, the diffusion of these experiences is very restricted due to limited funds and lack of qualified personnel.

## CONCLUSIONS

1. Pilot projects are urgently needed and these should be representative of the various ecological conditions and consider the aspects of training at various levels, research, demonstration and development. They should form part of local programs which could be linked to global plans for the prevention of and fight against desertification. This will require interdisciplinary teams from the natural, social and economic sciences.

2. It is indespensable to pay greater attention to those zones which support higher population densities of people and animals, as the pressure on the ecosystem could result in an imbalance which could promote the rapid advance of desertification.

3. The plan to combat desertification should be realistic and in accordance with the ecological, social, economic and political conditions at a local, national or international level. The problem of desertification is one of mankind and threatens to diminish the productive capacity of the ecosystem for agricultural products and therefore it is necessary to establish the correct levels of organization and coordination.

## REFERENCES


1. Kates, W.R., Johnson, D.L. and Johnson, K.H., Population, Society and Desertification, in Desertification: Its Causes and Consequences, Secretariat of the United Nations Conference on Desertification, Pergamon Press, (1977).
2. Barney, O.G., The Global 2000 report to the President, Entering the Twenty-First Century, Council on Environmental Quality and the Dept. of State, Washington, D.C., (1980).
3. Warren, A. and Maizels, J.K., Ecological Change and Desertification, in Desertification: Its Causes and Consequences, (see Reference 1).
4. Anaya, G.M., Technology and Desertification, in Desertification: Its Causes and Consequences, (see Reference 1).
5. FAO, A Provisional Methodology for Soil Degradation Assessment, Food and Agriculture Organization of the United Nations, Rome, (1980).
6. Ambroggi, P.R., Water Scientific American, Sept. 243, No. 3, 100-116, (1980).
7. Tolba, K.M., What Could Be Done to Combat Desertification, in Advances in Desert and Arid Land Technology and Development, Vol. 1, Bishay, A. and McGinnies, W. (eds.), Harwood Academic Publishers, London and New York, (1979).

8. Secretaría de Programación y Presupuesto, Plan Nacional de Acción para Combatir la Desertificación, Síntesis de Avances, México, D.F., (1980).
9. U.S. Department of the Interior, Desertification in the U.S., Status and Issues, Working Review Draft, Bureau of Land Development, Washington, D.C. (1980).
10. Secretaría de Agricultura y Recursos Hidráulicos, Informe General de Actividades del Programa para Prevenir y Combatir la Desertificación, México, D.F., (1980).
11. American Association for the Advancement of Science, Handbook on Desertification Indicators, compiled by Priscilla Reining, Washington, D.C., (1978).

# 11
# The Adverse Effects of Economic Development on Agriculture and Distribution of Wealth in the Tropics

*W. E. Ormerod*

## INTRODUCTION: CLIMATE AND POVERTY

The occurrence of poverty in the world is determined by social, economic and climatic conditions. Few people would dispute the importance of social and economic factors in the uneven distribution of wealth, but few also would acknowledge that climatic factors were of much consequence in determining who was rich and who was poor. Nevertheless, the fact remains that widespread poverty is mainly to be found in the tropics, the industrial and agricultural revolutions of the late 19th century having virtually abolished mass poverty from the temperate regions of the world: it is only in the tropics that mass poverty persists.

Pockets of mass poverty which do occur in temperate regions from time to time can usually be ascribed to some extraneous cause, such as the maladministration and persistant warfare in Northern China which frequently converted this otherwise fertile country into a famine area. This happily is past history. There are few land masses in the temperate zone of the southern hemisphere, hence the division of the world, made familiar by the Brandt Report of 1980 (1), into a rich North and a poor South.

There are, paradoxically, numerous foci of wealth in the poor regions of the world, notably, Hong Kong, Singapore, the oil states of the Arabian/Iranian Gulf, the cities of the West African coastal belt, the Brazilian coastal belt (notably Rio de Janiero and Sao Paulo). Hong Kong and Singapore have occurred in isolation as world trading centres and appear to have had little influence upon their hinterlands. The effect of oil wealth in the Middle East has been complicated, and its effects are by no means clear; certainly it has had an adverse effect on contiguous fertile areas such as North Yemen, and more remotely may be influencing adversely the agriculture of Sudan and Kenya. Possibly events in Iran may have been influenced by agricultural degradation (the discussion of this topic would, however, be a diversion from the main points at issue).

I have made a study of the effects of economic development in West Africa (2) and consider that a strong case can be made for ecological degradation in the hinterland (particularly the semi-arid regions) being at least partly the result of rapid economic development in the coastal region. Probably the most familiar case of contiguous economic development and ecological degradation is in Brazil where many of the booming cities of the Brazilian economic miracle are backed by a degraded hinterland where poverty has continued or has increased during 300 years of "development". No detailed study of the relationship of economic development to agricultural degradation has been made in Brazil, although the results of degradation in terms of the contrast between wealth and poverty is perhaps more striking there than in any other part of the world.

I have chosen these examples to demonstrate that massive economic development can occur in the tropics independent of any agriculture, but when the agriculture (particularly peasant agriculture) and economic development are closely contiguous and linked together, the high level of demand for food, stimulated by economic development, is liable to cause degradation. To describe this effect I propose the following hypothesis: that, in a temperate region, agriculture is stimulated by increased demand; in a tropical region, increased demand results in the degradation of agriculture.

## SCIENTIFIC SUPPORT FOR THE HYPOTHESIS

Earlier writers on climate and economic development (3,4) mainly stressed the direct effects for good or ill of raised temperatures and humidities upon man, his crops and food animals. No fundamental principles were proposed from which deductions could be drawn. A different and more quantitative approach arises from the study of soil erosion, mainly carried out in the United States in the 1930s and 40s and reviewed by Hudson (5).

The most important observations were those of Ellison (6) on the effect of rain drops on soil. Ellison constructed a "rainfall simulator" by which he showed that the ability to dislodge particles of soil depended primarily on the size of the raindrop and the height of fall, in other words, on the kinetic energy of the individual raindrop. Few measurements of kinetic energy have been made in different parts of the world, but it is generally agreed that there is a close correlation between kinetic energy and intensity of rainfall - indeed, anyone who has stood under a tin roof during a thunder storm will have received a practical demonstration of the principle that the heaviest rainfall carries the highest energy and consequently makes the most noise.

Figure 1 shows the frequency of occurrence of rainfall of different intensities at a temperate and at a tropical station; it has been shown experimentally that an intensity of approximately 35mm/h represents a threshold above which severe erosion is liable to occur. It is obvious from the figure that this threshold is exceeded more frequently in the tropical than in the temperate station. It is common experience that high-intensity rainfall is frequent in the tropics and subtropics (say between the 40th parallels of latitude) and comparatively infrequent in temperate zones.

Various factors are necessary for rainfall to give rise to erosion. One of these is the slope of the ground. Clearly, for erosion to occur, a run-off of soil and water must take place. From the practical point of view of the soil conservationist, the run-off is the most important consideration, in that commercial agriculture in the tropics cannot be carried out profitably unless the effects of slope are mitigated by terracing, bunds, contour ploughing and such devices, but in the present context the most important factor is the existing cover of vegetation. On this factor rests not only my hypothesis of the degrading effect on agriculture of increased demand, but also the paradox of tropical production based on studies by Leith (7) and Eyre (8) that the "net primary productivity" (NPP) of the natural vegetation in the tropics should be so much greater than that of temperate regions, and the actual production of food and fibers useful to man so much less.

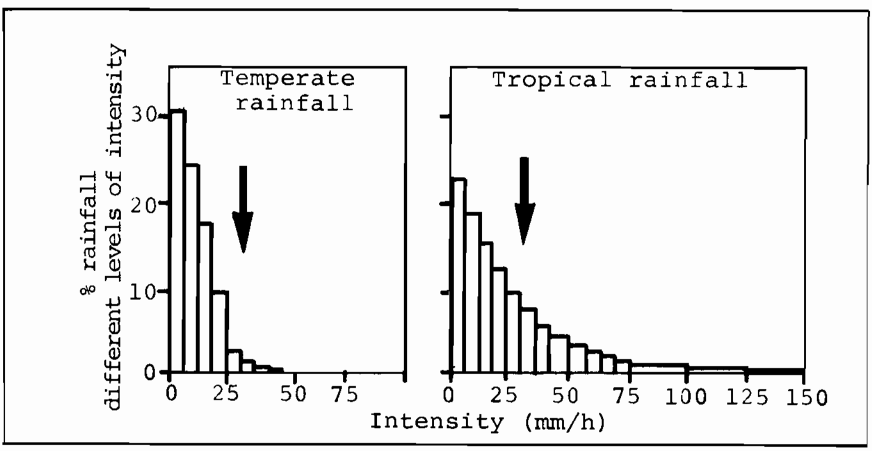



FIGURE 1.

The basic reason for this loss of productivity in the tropics is that all normal forms of agriculture involve uncovering the soil of its natural vegetation, and the greater the intensity of the agriculture, the more the soil will be uncovered and the more destruction is likely to occur.

Uncovering the soil will have other adverse effects; high intensity rainfall causes severe leaching of salts, not only of the nutrient minerals, but also of silicon salts and destruction of soluble clays, which are removed to lower soil horizons leaving Iron and Aluminium salts at the surface. The kaolinic or lateritic soils which result are the familiar red soils of the tropics; they are usually very infertile and tend, when worked by northern techniques, to form solid pans of ironstone. These red soils, together with aeolian sands, are the most common types in the tropics. Their existance indicates a past history of periodic subjection to high-intensity rainfall and desiccation occurring over periods of millenia. Another effect of uncovering the soil is the destruction of humus. Humus acts, as do clays, as an ion exchanger which enables salts and moisture to be retained in the soil. It is formed by the degradation of lignin and cellulose, to a series of molecular associations of phenolic and benzene-carboxylic acids known as humic and fluvic acids, under the action of bacteria and fungi. High temperature and high humidity, even in the presence of vegetation, tends to limit the formation of humus because the decomposition of organic matter is liable to proceed under these circumstances to completion rather than the process being arrested at the stage of humus. Nevertheless, humus does form under the conditions of a tropical rain forest and in drainage areas of savanna, but when it is denuded of vegetation it is liable to be destroyed by direct rainfall or the action of ultra-violet light.

There are also some excellent tropical soils, such as the deep clays of the Sudan or the Reconcovo (NE coast of Brazil), and numerous pockets of volcanic soil. All these soils will produce good yields but are easily destroyed if subjected to high-intensity rainfall. Destruction readily occurs if they are cultivated by techniques used in the northern hemisphere, which we regard as "good husbandry". Volcanic soils are often particularly vulnerable as they are so frequently on slopes.

While ironstone formation may prevent entirely the use of ploughs and other modern machinery, it must be recognised that many food crops can be grown on soils without clay or humus. Numerous techniques of peasant agriculture have been evolved to make this possible. Usually these are associated with periods of fallow when regrowth of the natural vegetation over a period of years restores fertility to a patch which can then be used for one or more years. Alternatively, manuring with animal dung and night soil may allow fixed intensive agriculture to be carried out. Central to all these techniques (when they are effective) is protection of the soil and its fertility by vegetation. The traditional methods used in Mexico bear a striking resemblance to those used in Africa, not (I suggest) because they are culturally related, but because the same principle for effective agriculture in the absence of fertilizers tends, on the principle of survival of the fittest, to be universal. Ploughing techniques on bad soil will also grow good crops if sufficient fertilizer is used, but the failure of the soil to retain salts and water makes their application expensive as compared with temperate agriculture. An extreme example is the coastal and oasis agriculture of Libya (9). This type of agriculture, which is carried out more for social and political than for economic reasons, is a luxury that only an oil-rich country, with a small indigenous population, can afford.

## SIGNIFICANCE OF DRY AND RAINY SEASONS

While the moist tropics, in the region of the equator, has a more-or-less continuous rainy season with constant growth of vegetation throughout the year, dry seasons of increasing length and severity occur in the higher tropical latitudes. The production of natural vegetation (NPP) decreases dramatically in areas with a long dry season, becoming almost zero in desert areas. While actual agricultural production is also very low in desert and semi-desert, it does not increase with increasing rainfall at such a steep gradient as does the NPP. Increases in productivity in relation to rainfall apply equally to animals as to plants, and particularly to insects, parasites and other pests which, being almost absent in arid lands, or at least restricted to a short rainy season, reproduce continuously and in vast numbers in the moist tropics; diseases of man and of his food animals also increase their prevalence with the length of the rainy season. The stress of human disease is particularly severe in the mid latitudes of the tropics because a "wave of illness" (malaria, diarrhoea, insect-borne viruses) occurs with the first rains when the peasant farmer may be suffering from malnutrition at the end of the dry season; this is the peak period of his activity, when his survival depends upon the success of his farming operations.

Thus the advantageous effects of increased rainfall in producing higher yields may be largely offset by the adverse effects, but the soil of both moist and dry tropics is susceptible to high-energy rainfall when vegetation has been cleared from it for agricultural or other purposes.

## THE INTERTROPICAL CONVERGENCE ZONE (ITCZ)

The clearing of vegetation, e.g. by felling of woodland or overgrazing by stock, has a particular significance in semi-arid regions. In describing the climate from equator to higher latitudes of the tropics, the point at which rainfall ceases is determined by the ITCZ; this is a relatively narrow margin at which air flow, on the equatorial side, is directed upwards with consequent precipitation, whereas, on the polar side of the margin, air flow is downwards and without precipitation. One of the factors determining the limit to which the ITCZ can pass in a polar direction is considered to be the albedo or reflectivity of the ground. An arid, sandy desert is able to reflect more energy from the sun back into the atmosphere than would a sward of vegetation of comparable size. Thus, the climatologists now believe that by denuding an area of sufficient size it is possible for man to decrease the rainfall and thus further increase the degradation of large areas of the Earth.

## IRRIGATION

Irrigated agriculture tends to be more successful in the tropics than rain-fed agriculture, especially when the dry seasons are long. But, in spite of its greater success, there are numerous complicating factors related to the climate which make irrigated agriculture in the tropics less successful than might otherwise have been expected. Environmental factors are discussed in detail by Yaron et al. (10) and in the FAO/UNESCO Source Book (11). Economic factors are discussed by Clark (12), but one of the most interesting discussions of the limitations of irrigation in the arid tropics is by Davidson (13). Although specifically about the Australian arid zone, most of the points discussed are of general application. None of these texts discuss the possibility of disease being increased by irrigation. Schistosomiasis, onchocerciasis and malaria are all potentially increased by irrigation; all are important to Mexican development and can, to a large extent, be avoided by appropriate designs being introduced in the early stages of planning an irrigation scheme.

## PLANTATION AGRICULTURE

One of the most successful forms of commercial agriculture which is, nevertheless, essentially tropical may be called "plantation agriculture". I do not use this term in the pejorative sense in which it is used by sociologists (e.g. 14) to describe a system involving forced labour, labour of migrants and other deprived people, with its roots in 18th century slavery, or at best the later systems of indentured labour transmitted from distant continents (15). Although such systems are by no means totally abolished, plantation labour today covers a spectrum from debt peonage, latifundias owned by absentees and well-run establishments of multinational companies, to productive small holdings owned or leased by peasant farmers and run by family labour. Although some plantations came into being by taking over the land cultivated by peasants who were subsequently obliged to work there, it is probably true to say that the majority of plantations in the tropics, if they are not operated by smallholders, are worked by labourers who have left their traditional farms because they could obtain a better living on the plantation; their traditional methods have frequently been broken down by economic and political pressures and particularly by increase in population, which in many parts of the world has decreased the fallow period and thus lowered fertility.

Plantation agriculture, in the sense that I wish to use the term, involves permanent or semi-permanent crops which, once planted, cover the soil and protect it over a number of years. Crops such as coffee, tea, rubber from _Hevea brasiliensis_, cocoa, bananas, coconut and oil palm, once established, create something of the original forest ecology; erosion and leaching do not occur. Humus is built up and tap roots obtain moisture from the water table when there is little available on the surface. These are the tree and bush crops which give the greatest stability to the soil. Something of the same stability is given by some forms of sugar plantation, where regrowth is allowed to occur and ploughing does not take place for several years at a time. Cotton, tobacco, the grain crops, manioc and probably rubber from Guayule give no stability, and their cultivation in the tropics can be justified only by the economic returns, balanced against ecological degradation, that they give.

## PEASANT FARMING

Economic return is usually considered to be the sole criterion of efficient agriculture. This view has a long history dating probably from Adam Smith and Ricardo, who considered the land mainly as a source of rent, as a tool in the hands of the farmer, thus replacing the earlier "physiocratic" view that the soil was the source of all wealth (16), a view which is much more appropriate to the attitude of the peasant subsistence farmer. The importance of peasant farmers is that there are so many of them. It is unlikely to be an over-estimate to state that there are 1,000 million, a quarter of the world's population, living mainly within the tropics.

It is central to my argument that, in the north, the combined industrial and agricultural revolutions have successfully replaced peasant by commercial agriculture, and this replacement has vastly improved food production; in the south, however, commercial agriculture has had only limited success, mainly in the plantation sector. Economic development which is now occurring in the tropics is destabilizing the peasant farmer but has not put anything much more productive in his place.

Most of the good land in the tropics is now used for commercial agriculture, whether irrigated or plantation; it is likely that in this way the good land, if properly managed, will produce the best return. Much, however, depends on the requirements that are set, and it seems to me that food is the highest priority, rather than commercial gain from products such as tobacco, lint or "gasohol". While the use of land and the nature of products obtained from it are essentially political decisions, it is important that planners should not be misled by the term "renewable resource" into the belief that no competition with food production is involved and that land degradation is not likely to be a major problem.

Bad land can seldom be used for commercial operations - I doubt if it can be used even for "bad land crops" such as manioc. Those who can use bad land most effectively are peasant farmers, but their operations are becoming increasingly difficult, mainly because of the pressures that the modern world is exerting upon them.

I began by stating that poverty was determined by social, economic and climatic factors, and proposed the hypothesis that economic development was liable to increase agricultural degradation. So far I have discussed the inadequacy of commercial agriculture and its inability to produce, in the tropics, yields comparable to those of the temperate zone. Actual degradation by commercial agriculture is probably rare today although it continues to occur: by far the most important degradation occurring today is due to the social and economic effects of modern life on the peasant farmer and the way in which they are destabilizing his way of life.

Throughout the tropics peasant farmers have adapted their way of life to adverse climatic conditions. This is most spectacular in the arid regions, where many appear to live on the borders of starvation; their strategies for survival are often complicated and difficult for a northerner to understand. Many groups have, of course, not survived, and others are today on the borderline between survival and extinction. The efforts of outsiders to help in this struggle by additional food, medical aid and the digging of wells have in some instances had the reverse of the effect desired, have changed the environment, have frustrated strategies of adaptation that have been evolved over centuries and have made life virtually impossible rather than improving it.

The tropical husbandman's operations are always short of labour. When the rains come, such is the rapidity of growth of both crops and weeds that the farmer's prosperity depends on the number of hands that he can muster at this time. While many strategies are used for obtaining labour, the farmer's only sure method is to increase his family: by definition, a farmer supported by many sons is a prosperous farmer. In the north, labour-saving devices have displaced hand cultivation, and, as Boserup (17) has described, the greater the demands that are placed upon the farmer, the more readily will he accept new ideas and changes in technology; thus, pressure for procreation is no longer an essential part of the northern farmer's scheme. In the tropics, on the other hand, changes in technology, especially on bad land, decrease rather than increase stability, and the higher yields which he may obtain are less desirable to him because they are more difficult to market and to store; survival rather than increased production is the southern farmer's main objective. Thus, Boserup's hypothesis is not generally applicable in the tropics.

However, great demands are today being made on the tropical peasant farmer; whatever his supposed traditions of independence, frugality and distance from the cash economy, the pace of modern economic development increases his demand for cash and for a higher standard of living: for instance, nomads living on marginal lands are being encouraged to sell their beasts for cash and arable farmers to sell their staples and to produce a wider range of cash crops. Goods such as steel hoes, machetes, shot guns, bicycles and transistor radios are increasingly desired, while world inflation makes their cost even greater in terms of crops produced but not consumed by the farmer and his family.

Figure 2 summarizes the points that I have made and relates them to one another. I am in no position to say what quantitative values can be placed on many of the factors, but I can suggest how some of the ecological factors might be determined. I have discussed in a previous paper (2) the calculation of "soil loss" as a measure of erosion. It is possible, given extensive data on soil types, gradients and different cropping patterns, to calculate the rate of degradation, but this would involve a disproportionate effort for the amount of information obtained. The same information might be obtained more easily by determining the rate of transport of silt from watersheds in relation to the rainfall statistics; this method, used extensively in Francophone Africa, might be the most appropriate method for assessing the erosion occurring in moutainous Central America. Although an assessment of the rate of erosion would not give direct information on other forms of soil degradation or of humus destruction, these factors are likely to be closely cor-

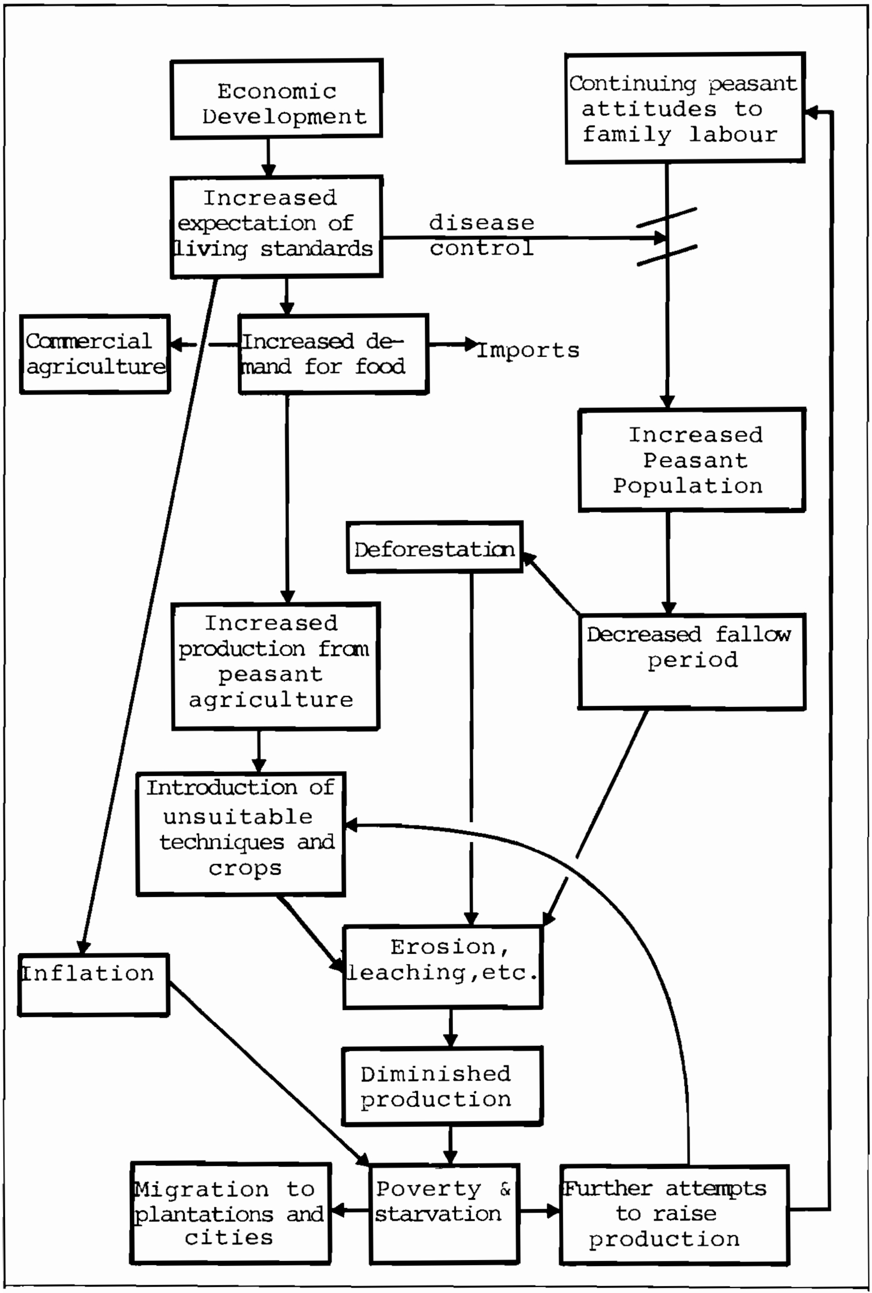

Economic Development
Increased expectation of living standards
disease control
Continuing peasant attitudes to family labour
Commercial agriculture
Increased demand for food
Imports
Increased Peasant Population
Deforestation
Increased production from peasant agriculture
Decreased fallow period
Introduction of unsuitable techniques and crops
Erosion, leaching, etc.
Inflation
Diminished production
Migration to plantations and cities
Poverty & starvation
Further attempts to raise production

FIGURE 2.

related with erosion. I assume that adequate economic and population data are available for the construction of a model following the general pattern of Figure 2; the effects of disease control on a population is likely to be difficult to evaluate, and although estimates can be made, based on rural health expenditure, the cost effectiveness of these measures, and consequently of their actual control of disease, must remain in some doubt.

Peasant agriculture is a subject on which very little information is at present available; it is usually considered that it will disappear in the south as it has done in the north. Only recently has it become apparent that the world's peasant population, their effect on the land and the extent of the reactions to the increase in wealth of other sections of the world's population has become a major force that we cannot afford to ignore.

## APPLICATION TO DEVELOPMENT OF MEXICO'S SEMI-ARID REGIONS

One of the major present concerns must be whether economic development in Mexico - as in West Africa - will cause an extension of the arid zone into what is now regarded as the moist zone. Two factors of special importance need to be considered in this connection.

Firstly, there is the possibility that climatic change might occur as a result of the removal of vegetation at desert margins, causing a significant change of albedo. A useful prediction on this subject can only be obtained by reference to the World Climatic Model operated by NASA/MIT: I think it important that this specific information be obtained. My own uninformed prediction is that the area is too small, even including the desert area to the north of the US border. The climate is likely to be influenced, and possibly stabilized, to a greater extent by other factors such as the proximity of two oceans and the mountain structure of Central America, particularly of the Sierra Madre Occidentale. Finally, the semi-desert is not in Mexico the main cattle-producing area, as it is in Africa; in Mexico the main cattle-producing area is the moister coastal area of Vera Cruz. Consequently, grazing pressure does not specifically occur at the desert margin, as in Sahelian Africa, but is more widely spread throughout the country.

Secondly, the degradation of land and vegetation by its over-use could increase the size of the Mexican arid zone, not by changes in the climate but simply by the extent of soil degradation, which is occurring on a massive scale. The position of the country as a whole is serious for the following reasons. Mexico's population is about 70 million, increasing at a rate of about 3.6% per annum; a third to a half of these depend on subsistence agriculture, 35 million are estimated to be malnourished, 19 million to be seriously malnourished. Although Mexico was previously a net exporter of grain, in recent years it has been an importer. It is not, therefore, surprising that the Government has instituted an emergency feeding programme, the Sistema Alimentario Mexicano (SAM), and individual states are reported as having the responsibility for its agricultural implementation, although a general policy is reported to consist of "compacting" small plots of land at present farmed at subsistence level into commercially viable units. A similar campaign to give a rapid increase in food production has already been mounted in Nigeria. I do not wish to comment prematurely on the long-term results of the "Feed-the-Nation Campaign" of Nigeria but would like to suggest that, allowing for environmental differences (particularly the more mountainous nature of Mexico), a close study should be made of the Nigerian experience.

It is important to consider some of the factors in the Mexican environment into which a campaign for rapid food production is being launched. The high and rising population of the country, and particularly the high proportion of peasant farmers which it contains, makes Mexico very vulnerable to ecological degradation. As I have stressed above, there is little information in terms of agricultural incentives and population dynamics of peasant farmers as a group, although I have tried to sketch (see Figure 2) the sort of responses that a peasant population might be likely to make. The location of Mexico is in the tropics, both moist and arid, with high-intensity rainfall and a tendency to erosion exacerbated by the high proportion of sloping land. Conservation Foundation surveys (18,19) have already noted severe erosion, and Watters (20) has drawn particular attention to the increase in erosion which results from "compacting".

Deserts are produced not only by drought: heavy rainfall is also a factor in their production, but removal of vegetation and subsequent soil degradation are probably the most important of all factors. If Mexico is to avoid an increase in her arid zones, greater priority will need to be placed upon the conservation of soil and vegetation than on the short-term production of food. It is also important that a better understanding of peasant agriculture should be obtained. Peasant methods of agriculture have evolved in Central America over the past seven to eight thousand years, and, despite their low productivity, they may not be replaceable by any other system when land of inherently low fertility needs to be exploited in a tropical environment.

REFERENCES


1. Brandt, W. et al., North-South: A Programme for Survival, Report of the Independent Commission on International Development Issues, Pan, London, (1980).
2. Ormerod, W.E., The Relationship between Economic Development and Ecological Degradation: How Degradation has occurred in West Africa and How Its Progress Might be Halted, Journal of Arid Environments 1, 357-379, (1978).
3. Huntington, E., Civilization and Climate, Yale University Press, New Haven, (1915).
4. Lee, D.H.K., Climate and Economic Development in the Tropics, Harper, New York, (1957).
5. Hudson, N.W., Soil Conservation, Batsford, London, (1971).
6. Ellison, W.B., Studies of Raindrop Erosion, Agricultural Engineering 25, 131-136, 181-182, (1944).
7. Leith, H., Modelling the Primary Productivity of the World, Nature and Resources 8, 5-10, (1972).
8. Eyre, S.R., The Real Wealth of Nations, Arnold, London, (1978).
9. Allan, J.A. and McLachlan, K.S., Agricultural Development in Libya after Oil, African Affairs 75, 331-348, (1976).
10. Yaron, B., Danfors, E. and Vaadia, Y. (eds.), Arid-Zone Irrigation: Ecological Studies Vol. 5, Springer-Verlag, Berlin, (1973).
11. FAO/UNESCO, Irrigation, Drainage and Salinity: A Source Book, FAO, Rome, (1973).
12. Clark, C.G., The Economics of Irrigation, Pergamon, London, (1967).
13. Davidson, B.R., Australia Wet or Dry, University Press, Melbourne, (1969).
14. Beckford, G.L., Persistent Poverty: Underdevelopment in Plantation Economies of the Third World, University Press, Oxford, (1972).
15. Checkland, S.G., The Gladstones: A Family Biography, 1764-1851, University Press, Cambridge, (1971).
16. Bronowsky, J. and Mazlish, B., The Western Intellectual Tradition: from Leonardo to Hegel, Hutchinson, London, (1960).
17. Boserup, E., The Conditions of Agricultural Growth: The Economics of Agrarian Change Under Population Pressure, Allen and Unwin, London, (1965).
18. Conservation Foundation/FAO, Soil Erosion Survey of Latin America, Journal of Soil and Water Conservation 9, 158-168, 214-219, 223-229, 237, 275-380, (1954). (Quoted by Lal (19)).
19. Lal, R., Review of Soil-erosion Research in Latin America, <u>in</u> Soil Conservation and Management in the Humid Tropics, Greenland, D.J. & Lal, R. (eds). (Symposium of the International Institute of Tropical Agriculture, Ibadan, Nigeria), Wiley, New York, (1977).

20. Watters, R.F., Shifting Cultivation in Latin America: Review Paper No. 17, FAO, Rome, (1971) (Quoted by Lal, 19).

# 12
# Small-Scale Mining in Semi-Arid Areas

*Joseph Barnea*

## INTRODUCTION

The mineral potential in any area is almost totally determined by geological conditions and not by the degree of aridity. The only major exception are evaporite deposits which are usually found in arid and semi-arid areas.

### Mineral Exploration

Mineral exploration, however, can be strongly influenced by surface conditions. Exploration in jungles, marshes and steep mountain areas are usually much more difficult and more expensive. Often exploration in arid and semi-arid areas, provided they are not very mountainous, are low-cost and comparatively easy.

### Mining Operations

Mining operations depend on size, grade and depths of deposits, as well as surface conditions, location, mining traditions, management and the availability of infrastructure, miners and markets.

With the sharp increase in the prices of many minerals and the availability of much new equipment and technology, interest in small-scale mining is again accelerating. This was demonstrated at the recent conference on the Future of Small-Scale Mining organized by UNITAR and the Government of Mexico, and held in Jurica, Queretaro, in December 1978. The proceedings containing all the technical papers are now available.

In areas which have no mining tradition, no small mines operation and no abandoned small mines, it is difficult to establish small-scale mining.

## EXPLORATION

In general, small mineral deposits are much more numerous than large deposits and are much easier to find.

However, modern exploration methods are designed to find very large deposits. An example of these methods is wide-spacing of geochemical surveys which picks up one sample for each two to four square kilometers discovering a big deposit but overlooking most of the small ones. This use of exploration methods for large deposits only is practiced by virtually all government agencies, companies, and even by United Nations exploration teams.

Today, discovery of small deposits is purely accidental in large-scale mineral surveys. In order to find small deposits at low cost, which is difficult, the following methods may be applicable. In some countries, there are still outcrops which have not been investigated and these lend themselves to low cost exploration through the individual prospector who has disappeared in most mining areas. Other low cost methods might include sampling of road cuts and other engineering works, mineral analysis of ground water and geothermal springs, study of available soil surveys, questioning of farmers showing them minerals of different colors and structures and asking them whether they have seen them in the neighborhood and, of course, abandoned mines and mine tailings.

In any area where drilling has been done and cores have been preserved, they should be studied and the mineral specimens in a mineral museum, if it exists, should be carefully examined. Where funds are available, detailed geochemical surveys should be carried out.

Practically every geologic environment has a potential of small mineral deposits. In sedimentary areas, the potential might include energy resources (small oil and gas, coal, lignite, etc.) or fertilizer material (potash, phosphates and sulfur) in addition to many industrial minerals. In other geologic environments it might consist of gold, silver, copper and other metals, the traditional minerals of the small miner.

## MINING DEVELOPMENT

Each semi-arid area has, therefore, a great potential of containing some minerals for the small miner. Consequently, if a regional semi-arid development program calls for small-scale mining, and such mining does not yet exist, an exploration program to find small mineral deposits will have to be undertaken. This might be costly, depending on the area to be covered and the density of the geochemical sampling, and may require basic geologic studies as well as mapping should it not as yet be available. It is essential in such a survey that it be broad-based and not designed to find only a few specific minerals. Geochemical samples should be analyzed for as many elements as the laboratory is able to handle. Parallel with the undertaking of detailed exploration for small deposits, a legal framework for small-scale mining must be established, miners must be trained and other supporting facilities must become available. This includes loan and financial facilities, facilities for the hiring of equipment, and in the case of metals, customs smelters within an economic reach which will buy concentrates for processing. The establishment of small-scale mining from exploration to operation is a long and complicated road.

## MINING OPERATIONS

Mining operations ultimately depend upon the profitability of small-scale mining, and in view of the sharp rise of energy prices during the last eight years, it is useful to pay attention to the potential of small energy resources.

In addition to the various categories of underground resources which are included in minerals, it is useful to expand the term and include, for the purpose of small-scale mining, all underground resources which can be produced profitably at a small scale. This will add the energy resources such as conventional oil, heavy crude, tar sand, and oil shale as well as the various types of gas, coal, lignite and geothermal energy to the traditional minerals.

The wide-spread availability of small and shallow oil and gas deposits has been fully realized only in the last few years, and it is only in the United States that these shallow resources are now undergoing a very rapid development. The main problem in the exploration and development of those shallow and small-scale resources is that in almost every developing and European country, the government alone owns all the underground resources, and, without a permit by the government, nobody is permitted to explore, especially for oil and gas. Governments in those countries restrict the right to explore for oil and gas to government-owned companies or multinational companies, which are interested only in finding larger oil and gas fields. This institutional problem is not easy to overcome, but a solution has to be found, because small oil and gas fields are very numerous and are believed to exist in almost all sedimentary basins. Moreover, they are easy to locate. In the State of Ohio, for instance, in which 600 wells were drilled for shallow gas during the first six months of 1980, the exploration success ratio is 80%, which means in eight out of ten wells drilled, the shallow gas is found. In certain areas in upstate New York, the success ratio is now 90% and, when a local driller was asked how he can have such a high success ratio, he replied, "This is very simple. We know the geological formation which carries gas, and when a village, local industry or a church want gas, I drill for them into that formation."

The availability of low cost oil and gas and local coal in semi-arid areas could have a significant impact not only on the energy supply of the rural population, but could become the basis for local development.

Similar to oil and gas, coal is found in sedimentary areas and, therefore, small coal development can also be of significant development on the local level.

Heavy crude, tar sand and oil shale all occur in small deposits as well, and their development on the local level is feasible, although the technical know-how of processing it is less well known and may require technical assistance from outside the region.

Geothermal energy, when available, is a very attractive resource for a variety of purposes. Geothermal hot water wells may carry minerals in addition to the heat and very often geothermal springs form geothermal sinters, which are small mineral deposits, sometimes carrying large quantities of gold and other valuable minerals. This resource in some arid areas can also be used for agricultural purposes such as using geothermal water for green house heating or sub-surface soil warming, as is already occurring in southern Israel. In certain cases, the geothermal water could be used for agricultural purposes by mixing with fresh water, desalinating geothermal water or directly, when the geothermal water is almost fresh.

Small-scale mining in some developing countries is still at the beginning stages. The miners are illiterate and even children are employed. They work with very little equipment and the ore is carried out of the mine by animals or in some cases by the miners themselves.

Technical expertise of small-scale mining will have to be implemented and this can be demonstrated by the basic changes now occurring in some countries. The key to the modernization of small-scale mining is technical training of the miners and mining management. Only technically educated personnel can achieve high efficiency. This applies to small-scale mining as well as to agriculture and all other areas of human activities.

The second development is specialization. The era when the prospector found a small deposit, developed it himself and then mined it and sold it himself is coming to a close.

In a number of countries, exploration and mine development can now be done by special organizations on a turnkey basis. In Mexico, for instance, it can be done by the Consejo de Recursos Minerales (1). In the United States and in Peru there are already small contracting firms which undertake the drilling of a possible deposit and the development of the mine.

The traditional link between small-scale development and an individual small-scale miner employing his family or a few workers is also undergoing structural changes. Today individual miners and partnerships, as well as mining cooperatives and small companies, each operate a number of small mines.

In the case of both cooperatives and of small companies where each operate a number of small mines and have their own engineers, geologists and financial management, a division of labor is possible.

Finally large mining companies are now becoming interested in small mines because they can be put into operation quickly and can return investments quickly whereas large mines require 10 years or more until they reach production. Moveable equipment specifically designed for small mines is presently available with the result that fixed investments in buildings, etc. can be eliminated or sharply reduced.

Small-scale mining carried out by technically trained personnel through companies or cooperatives allowing the employment of specialists and modern equipment has a promising future, especially in semi-arid areas and in countries in which minimum government support is forthcoming.

Small-scale mining has many advantages if developed in semi-arid areas, these include:

1. With very few exceptions, small-scale mining is not water intensive.
2. In most areas, production and employment is not subject to seasonal changes.
3. Small-scale mining provides cash income.
4. Products of small-scale mining are not perishable.
5. Small-scale mining can provide the raw material for rural industries.
6. In some cases small-scale mining can provide potash and phosphates needed by local agriculture.
7. Some mines can be operated in such a way as to provide employment in the mine when there is no agricultural employment.
8. Some mines can provide or contribute to local infrastructure facilities such as roads, electricity and water supplies.
9. If small-scale mining involved development of small energy resources such as oil, gas, coal, oil shale and geothermal energy, the energy produced can be of immediate advantage to the local agricultural population by providing energy and energy for agricultural processing.

REFERENCES

1. Salas, Guillermo P., p.284 in The Future of Small Scale Mining, UNITAR, McGraw Hill, (1980).

# 13
# Regional Development Assisted Through Local Renewable Energy Resources

*D. O. Hall*

## INTRODUCTION

Regionalisation is a very popular term right now, but it is difficult to be specific about successes and failures in the implementation of Regional policies. The popularity of regionalisation might be the result of Central Government opting out because they have not solved problems, or it may in fact be a genuine movement which will enable regions to help themselves. Nothing that I am going to say is indeed new and I don't claim any originality for the ideas expressed in this paper; they are a personal feeling and the result of propaganda efforts on my behalf to persuade decision makers to realise the importance of local renewable energy resources - specifically those of biomass, which is my main interest in the propaganda efforts on behalf of energy for the developing countries.

I must make it clear at the outset that the renewable energies, biomass, solar, hydro and wind, which I think will be the most significant in the near and intermediate term, are not necessarily the sole panacea for energy requirements in the rural areas of the developing world. There are obviously other energy resources which must be used: e.g. local coal, oil and gas reserves, geothermal resources etc. What energy is available must be used as efficiently as possible and this applies to renewable as well as fossil fuels - conservation should be paramount. For example, efficient stoves, charcoal kilns, and small industry must be immediately encouraged. It is important that the energy requirements and resources of individual regions be established using as much local expertise as possible since it is now realised that it is not ideal for outsiders to come in and tell people what is best for them.

This brings up another theme of mine - it is essential to train the extension officers, engineers, foresters, agriculturists, and technicians and scientists in the regions so that they are able to establish and implement energy schemes. These should be more of the local self-help type rather than a total implementation from outside organizations, national or international.

## BIOMASS

Biomass is the most important source of energy in the rural areas of the developing world. The sooner this is realised the sooner energy planners in the developing world will be able to accomplish something to help the rural poor. I'm a propagandist for the use of biomass, but I am pragmatic in realising that biomass is not the solution for the long-term energy requirements for the developing world - it will be *one* of a number of sources of energy in the long run but in the short run it is often *the* most important source of energy. Thus, biomass will be a component of the energy mix of the future, but how much it will contribute will depend very much on local circumstances dictated by resources and needs and a host of socio-politico-economic decisions. At present biomass is the main source of energy for half the world's population. The over-use of biomass is having disastrous forestry, agricultural and ecological consequences in many areas of the world that are expressed in flooding, erosion and desertification; it is also having sociological consequences which are seen in ever-increasing urbanisation as people cannot adequately sustain themselves in rural areas. People who are presently relying on biomass as their main energy source are often doing all they can to survive reasonably and are unable to consider the long-term consequences of their actions. This is the reason planners must realise the importance of rural energy requirements. The fact that the long-term use of biomass might not be as great as it is at present, presupposing other energy sources can be found *and* implemented (which I certainly hope will be the case), does not mean that biomass must be ignored now - as has generally been the case until very recently.

At present the world's population is about 4.4 billion and about three-quarters of these live in developing countries. In the developing countries themselves about 70% live in rural environments. In my estimation a rural person in a developing country uses an average of about 15 GJ of biomass-derived energy every year. This is equivalent to about one tonne or $1.4m^3$ of air-dried wood - local and regional differences in annual use abound, as do the relative proportions of wood, dung and agricultural wastes. In these rural areas biomass usually supplies about 85% of the energy - this is mostly used in the household for cooking. One can say then that about two and a quarter billion people in the world rely on biomass for their main energy requirements. There is also an urgent need to supply more local energy for agriculture and small-scale industry. Thus there is a situation where there is insufficient energy even for household use and therefore the use of energy to make agriculture and small undustries more productive is precluded.

Table 1 gives examples of village energy use showing the great preponderance of biomass-derived energy. These types of studies are very difficult to do and as a consequence there are very few available which are reliable. Such studies take many months of dedicated work in order to have them comprehensive and not many people have been willing to do this kind of work in the past. Thus official statistics have been erroneous because of the lack of detailed studies at the rural and village level. Even estimates of the use of biomass in urban areas have been too low or totally neglected. Table 2 gives examples of national energy use, again pointing out the importance of biomass in so many developing countries. We can calculate that about $3.2 \times 10^{10}$ GJ are used in the rural areas of the world. There is quite extensive use of charcoal, this charcoal is being transported over ever-increasing distances. The consequent deforestation as a result of supplying charcoal to urban areas is also becoming very serious. It is estimated that the urban population uses an average of about 8 GJ per year per capita of biomass-derived energy. The use of biomass in village and small-scale industries can also often be extensive, e.g. brick making, beer brewing, crops and food curing and drying, iron-mongering, baking, etc. If we add up rural use, the use by small industries and urban use, one can come up with a world total biomass energy use in developing countries of about $4 \times 10^{10}$ GJ. This is about one-seventh of the world's total energy use - equivalent to about 20 million barrels of oil per day.

It can also be shown that in Africa about two-thirds of the total energy use is derived from biomass; in Asia the figure is about a half, while in Latin America the amount is slightly less than half. These are I think rather significant statistics. It has been succinctly stated by Mnzava of the Tanzanian Forest Service that because the bulk of the fuelwood is produced and consumed within the village confines as a "free" good, where monetary transactions are minimal and much of it goes unrecorded, that "production figures often quoted in many publications are just a little more than intelligent guesses (1).

In a number of parts of Africa, e.g. Sudan, Tanzania and Botswana, it has become necessary for families to purchase firewood. It can take a quarter or more of their total income. They are thus becoming dependant on a cash economy whereas before they were in a subsistence economy with little exchange of money.

It must surely be realised that dependence on biomass as a source of energy has both advantages and prob-

TABLE 1.
Village Energy Studies - Summary (For original references consult Hall et al. (2)

<u>Bangladesh</u> (Energy Study, 1978)

5.7 GJ = 0.4t wood/person/yr
Biomass energy = nearly 100% of total energy
Crop residues = 54% total energy use (Briscoe 1979)
Dung = 2.7% total energy use
Firewood = 20% total energy use
Other vegetable matter = 17.7% total energy use
Total energy use = 1,615 $10^3$ Kcal/person/yr
= .5t/person/yr

<u>Bolivia</u> (Makijani & Pool, 1975)

Fuelwood use = 2t/person/yr = 30 GJ/person/yr
= 100% of energy use

<u>Botswana</u> (White, 1979)

Firewood use = 1.1t/person/yr
= 16.5 GJ/person/yr

<u>Cameroon</u> (Vennetier, 1979)

Wood fuel - average use 1.2-1.25t/person/yr
= 18 GJ/person/yr

<u>Central African Empire</u> (Gibert, 1978)

Woodfuel use = .9t/person/yr
= 13.5 GJ/person/yr

<u>China</u> (Makijani & Pool, 1975)

Biomass energy use = 21 GJ/person/yr
= 1.5t/person/yr
Biomass energy = 87% of energy use

<u>India</u> (Makijani & Pool, 1975)

Biomass energy use = 4.1 GJ/person/yr
= 0.3t wood/person/yr
= 99% of energy use
95% of total energy supplied by firewood and agro-waste (Ravindranath, 1980)
Firewood and agro-waste use = 0.6t/person/yr
Firewood use = 0.6t/person/yr (Reddy, 1979)
Firewood = 89% of total energy (including animate)

<u>Iran</u> (Vojani, 1978)

Firewood use = 1.2t/person/yr

TABLE 1. (cont'd)

Lesotho (Best, 1979)

Wood and dung use = .55t/person/yr
= 98% of total energy use

Mali (Bertram, 1977)

Wood use = 1.5t/person/yr = 22 GJ/person/yr

Mexico (Makijani & Poole, 1975)

Biomass (residue) use = 0.9t/person/yr
= 13 GJ/person/yr

Nepal (Hughart, 1979)

Fuelwood = 0.73t/person/yr

Niger (Pare, 1979)

Wood use = .73t/person/yr = 11 GJ/person/yr
= 1m$^3$/person/yr
(Delwaulle and Roederer, 1973)
Average wood use = .84t/person/yr
= 12.5 GJ/person/yr
= 1.15m$^3$/person/yr

Nigeria (Makijani & Poole, 1975)

Biomass energy = 1t wood/person/yr = 16 GJ/person/yr
Biomass = 99% of total energy
(Grut, 1972) Firewood use in eight Nigerian cities
= 1.6-2.5m$^3$/person/yr = 1.2-1.8t/person/yr

Peru (Winterhalder, Larsen, Thomas, 1974)

Peruvian highlands - 87% of families use dung as fuel
Dung use = 11t/family/yr

Rwanda (Gatera, 1978)

81% of population used only charcoal as fuel
Charcoal use = 377kg/person/yr
If 12t wood produces 1t charcoal then .38t charcoal
= 4.5t wood/person/yr

Senegal (Tall, 1974)

Charcoal use = 117kg/person/yr
= 1.4m$^3$ wood/person/yr

(Bertrand, 1977) wood use = 1.5t/person/yr
= 22 GJ/person/yr
= 2m$^3$/person/yr

TABLE 1. (cont'd)

| | |
|---|---|
| Sierra Leone (Richards, 1980) | |
| Rough estimate - Firewood use | = .6 - .7t/person/yr |
| | = 9 - 10.5 GJ/person/yr |
| (Cline-Cole, 1979) wood use | = 1.2t/person/yr |
| | = 18 GJ/person/yr |
| South Africa (Best, 1979) | |
| Transkei - Wood and dung use | = .35t/person/yr |
| | = 5.3 GJ/person/yr |
| | This was 95% of total energy use |
| Kwazulu - Wood use | = 1.1t/person/yr |
| | = 17 GJ/person/yr |
| | This was 99% of total energy use |
| Sudan (Digernes, 1979) | |
| 5.7 $m^3$ wood | = 3.2t/person/yr |
| Wood energy >90% of total energy | |
| Tanzania (Makijani & Poole, 1975) | |
| Biomass energy | = 1.5t wood/person/yr |
| Upper Volta (Ernst, 1978) | |
| (i) Biomass use | = 9 GJ/person/yr |
| | = 0.6t wood/person/yr |
| (ii) Biomass use | = 12 GJ/person/yr |
| | = 0.8t wood/person/yr |
| (Bertrand, 1977) Wood use | = 1.8t/person/yr |
| | = 27 GJ/person/yr |
| | = 2.4 $m^3$/person/yr |

lems and in Table 3 some of these are listed. These advantages and disadvantages must be recognised in any regional development programme which endeavours to improve and implement renewable energy resources. The fact that most of the world's population relies on biomass does not mean that it is always a good thing! There is no doubt that the great versatility of biomass energy systems is one of their most attractive features. There are a range of energy conversion technologies already available and being improved - these produce a diversity of products, including liquid fuels to which the world is addicted, and also to heat upon which the world depends. The fact

TABLE 2.
National Energy Studies - Summary (For original references consult Hall et al. (2)

Algeria
(Frisch, 1980) .42 million tons wood used
= 2.3% of the total energy used

(Howe and Gulick, 1980) wood fuel use = 0.66t/person/yr
= 1 GJ/person/yr
= 4% total energy

Angola (Howe and Gulick, 1980)
Wood fuel consumption = 1t/person/yr = 15 GJ/person/yr
Wood fuel = 74% total energy use

Barbados (Cox, 1978)
Bagasse use = 12 GJ/person/yr
= 0.8t wood/person/yr
Bagasse supplies 29% of primary energy

Benin
(Digernes, 1979) Wood use = 2.3t/person/yr

(Howe and Gulick, 1980) woodfuel use = .66t/person/yr
= 10 GJ/person/yr
Woodfuel = 86% total energy use

Botswana (Thipe and Mokobi, 1979)
Firewood use = 0.75 - 1t/person/yr

Brazil (Muthoo, 1978; Gochnarg, 1979)
Biomass use = 0.8t wood/person/yr
Biomass energy = 29% of total energy

Burundi (Howe and Gulick, 1980)
Woodfuel use = 0.2t/person/yr = 3.2 GJ/person/yr
Woodfuel = 89% total energy use

Cameroon (Howe and Gulick, 1980)
Woodfuel use = .96t/person/yr = 14.5 GJ/person/yr
Woodfuel = 82% total energy use

Central African Empire (Howe and Gulick, 1980)
Woodfuel consumption = .8t/person/yr = 11.6 GJ/person/yr
Woodfuel = 91% of total energy use

Chad (Howe and Gulick, 1980)
Woodfuel use = .77t/person/yr = 11.5 GJ/person/yr
Woodfuel = 94% total energy use

Chile (Frisch, 1980)
Woodfuel use = 3.3 million t wood
= 13.3% total energy use

TABLE 2. (cont'd)

China (Chen, Oct. 1980)
Total biomass use = $8.35 \times 10^{18}$ J/yr
Population = $1 \times 10^{9}$ people
But rural population = $0.8 \times 10^{9}$ people
Each person uses approx. 10 GJ/yr = .66t
Potential biomass = $11.45 \times 10^{18}$ J/yr

Congo (Howe and Gulick, 1980)
Woodfuel use = 1.3t/person/yr = 18.7 GJ/person/yr
Woodfuel use = 80% total energy use

Costa Rica
Frisch, 1980) Wood use = 1.4 million t
= 34% total energy use
(SIECA & CEPAL, 1978)
28% of total energy consumption was fuelwood and charcoal
14% of total energy consumption was bagasse
66% of households used fuelwood for cooking

Egypt
(Frisch, 1980) Wood and agricultural waste accounted for 6.6% total energy use
(Ibrahim, 1979) Crop residues = 12% total energy use
Dung = 2% total energy use
Wood = .48% total energy use
Total non-commercial energy = 14.5% total energy use

El Salvador (SIECA & CEPAL, 1978)
37% of total energy consumption was fuelwood and charcoal
9% of total energy consumption was bagasse
77% of households used fuelwood for cooking

Ethiopia (Howe and Gulick, 1980)
Woodfuel use = .78t/person/yr = 11.7 GJ/person/yr
Woodfuel = 93% total energy

Gambia
(Openshaw, 1976) Fuelwood = 1.2t/person/yr
Woodfuel energy = 62% of total energy
(Howe and Gulick, 1980) Woodfuel use = .46t/person/yr
= 7 GJ/person/yr
Woodfuel = 73% total energy use

Gabon (Howe and Gulick, 1980)
Woodfuel use = 2.3t/person/yr = 34 GJ/person/yr
Woodfuel use = 44% of total energy use

Ghana (Howe and Gulick, 1980)
Woodfuel use = 1t/person/yr = 15 GJ/person/yr
Woodfuel use = 74% of total energy use

Guatemala (SIECA & CEPAL, 1978)
41% of total energy consumption was fuelwood and charcoal
7% of total energy consumption was bagasse
88% of households used fuelwood for cooking

TABLE 2. (cont'd)

Guinea (Howe and Gulick, 1980)

Woodfuel use = .6t/person/yr = 8.7 GJ/person/yr
Woodfuel use = 74% of total energy use

Guinea Buisseau (Howe and Gulick,1980)
Woodfuel use = .82t/person/yr = 12 GJ/person/yr
Woodfuel use = 87% total energy use

Honduras (SIECA & CEPAL, 1978)
45% of total energy consumption was fuelwood and charcoal
6% of total energy consumption was bagasse
81% of households used firewood for cooking

India
(Frisch, 1980) Wood and agricultural waste provided 57% of total energy use

(Vergara & Pimentel, 1978; Argal, 1978)
Biomass use = 0.4-0.6t wood/person/day
Biomass energy = 52% of total energy use

Ivory Coast (Howe and Gulick, 1980)
Woodfuel use = .7t/person/yr = 11 GJ/person/yr
Wood use = 46% of total energy use

Jamaica (1977 study)
Bagasse use = 1.9 x $10^6$ barrels oil/yr
= 5.4 GJ/person/yr
= 0.4t wood/person/yr
Bagasse supplies 29% of local energy use (excluding bauxite industry)

Kenya
(Kyoike, 1979; Openshaw, 1979; Muchiri, 1978; Kokaro, 1979; Githinji, 1979)
Average wood use = 0.7-1.5t/person/yr
(one rural study = 1.8-2.8t/person/yr
(Howe and Gulick, 1980)
Woodfuel use = 1t/person/yr = 15 GJ/person/yr
Woodfuel = 74% total energy use

Liberia (Howe and Gulick, 1980)
Woodfuel use = 1.1t/person/yr = 16 GJ/person/yr
Wood use = 53% of total energy use

Libya (Howe and Gulick, 1980)
Woodfuel use = .2t/person/yr = 3 GJ/person/yr
Woodfuel use = 5% total energy use

Madagascar (Howe and Gulick, 1980)
Woodfuel use = .64t/person/yr = 9.6 GJ/person/yr
Woodfuel use = 80% total energy use

TABLE 2. (cont'd)

Malaysia (Frisch, 1980)
Wood use = 1.12 million t wood = 8% total energy use

Malawi (Howe and Gulick, 1980)
Woodfuel use = .6t/person/yr = 8.7 GJ/person/yr

Mali (Howe and Gulick, 1980)
Woodfuel use = 2.1t/person/yr = 32 GJ/person/yr
Woodfuel use = 97% total energy use

Mauritania (Howe and Gulick, 1980)
Woodfuel use = .4t/person/yr = 6 GJ/person/yr
Woodfuel use = 63% total energy use

Mauritius (Howe and Gulick, 1980)
Woodfuel use = .001t/person/yr = .2 GJ/person/yr
Woodfuel use = 2% total energy use

Mexico (Frisch, 1980)
Wood and agro wastes accounted for 9% of total energy use

Morocco (Howe and Gulick, 1980)
Woodfuel use = .2t/person/yr = 2.3 GJ/person/yr
Woodfuel use = 19% of total energy use

Mozambique (Howe and Gulick, 1980)
Woodfuel use = .9t/person/yr = 12.8 GJ/person/yr
Woodfuel use = 74% total energy use

Nepal (Joshy, 1979)
Wood use = 0.9t/person/yr
Biomass energy = 92% of total energy

Nicaragua (SIECA & CEPAL 1978)
25% of total energy consumption was fuelwood and charcoal
12% of total energy consumption was bagasse
75% of households used fuelwood for cooking

Niger
(Howe and Gulick, 1980) Woodfuel use = .5t/person/yr
= 8 GJ/person/yr
Wood use is 87% of total energy use
(Raynaut, 1980) Wood and grain stems use = .2t/person/yr
= 3 GJ/person/yr

Nigeria
(Ojo, 1979) Wood energy = 91% of total energy
(Howe and Gulick, 1980) Woodfuel use = 1t/person/yr
= 15 GJ/person/yr
Woodfuel use = 82% of total energy use

Panama Republic (SIECA & CEPAL, 1978)
13% of total energy consumption was fuelwood and charcoal
6% of total energy consumption was bagasse
40% of households used firewood for cooking

TABLE 2. (cont'd)

<u>Papua New Guinea</u> (Ministry of Energy, 1978)
Sinasina region - firewood use = 0.4t/person/yr
National average = 0.25t/person/yr
Biomass energy = 29% of total energy

<u>Peru</u> (Hughart, 1979)
Rural areas (50-60% of population) wood use = 1.2t/person/yr

<u>Rwanda</u> (Howe and Gulick, 1980)
Woodfuel consumption = .9t/person/yr = 13 GJ/person/yr
Woodfuel use = 96% of total energy use

<u>Senegal</u> (Howe and Gulick, 1980)
Woodfuel use = .5t/person/yr = 9 GJ/person/yr

<u>Sierra Leone</u> (Howe and Gulick, 1980)
Woodfuel use = .8t/person/yr = 12 GJ/person/yr
Woodfuel = 76% of total energy use

<u>Somalia</u> (Howe and Gulick, 1980)
Woodfuel use = 1t/person/yr = 15 GJ/person/yr
Woodfuel = 90% total energy use

<u>Sri Lanka</u> (Frisch, 1980)
Wood use = 3.3 million t wood = 54% of total energy

<u>Sudan</u>
(Vergara & Pimentel, 1978; Digernes, 1979)
Biomass use - estimates from 0.5 to 1.1t/person/yr
Biomass energy = 65-78% of total energy
(Howe and Gulick, 1980)
Woodfuel use = 1.3t/person/yr = 20 GJ/person/yr
Woodfuel use = 81% total energy use

<u>Tanzania</u>
(Openshaw 1976 & 1979; Science Council, 1979)
Wood use = 1.5t/person/yr
(Howe and Gulick, 1980)
Woodfuel use = 2.3t/person/yr = 34 GJ/person/yr
Woodfuel use = 94% total energy use

<u>Thailand</u> (Openshaw, 1976)
Fuelwood = 1.1t/person/yr

<u>Tunisia</u>
(Hamza, 1978) Wood use = 0.2t/person/yr
(Frisch, 1980) Wood use = 3.5 million t =41.8% total energy

<u>Turkey</u> (Cetelinelik, 1977)
1972 - non-commercial energy was 30% of total energy use
1977 - non-commercial energy was 20% of total energy use

<u>Upper Volta</u> (Floor, 1977)
Wood use = 0.5t/person/yr
Wood energy = 94% of total energy

TABLE 2. (cont'd)

Venezuela (Frisch, 1980)
Wood use = .28 million t. This was .4% of total energy use

Zambia
(Murisaka, 1978)
Average wood use = 0.5t/person/yr
Wood energy = 35% of total energy
(Frisch, 1980)
Wood use = .7 million t. This was 9.4% total energy use

TABLE 3.
Dependence on Biomass as a Source of Energy

| Advantages | Problems |
|---|---|
| 1. Stores energy for use at will | 1. Land use competition |
| 2. Renewable | 2. Land areas required |
| 3. Versatile conversion and products; some with high energy content | 3. Supply uncertainty in initial phases |
| 4. Dependent on technology already available with minimum capital input; available to all income levels | 4. Costs often uncertain |
| 5. Can be developed with present manpower and material resources | 5. Fertilizer, soil and water requirements |
| 6. Large biological and engineering development potential | 6. Existing agricultural, forestry and social practices |
| 7. Creates employment and develops skills | 7. Bulky resource; transport and storage can be a problem |
| 8. Reasonably priced in many instances | 8. Subject to climatic variability |
| 9. Ecologically inoffensive and safe | |
| 10. Does not increase atmospheric $CO_2$ | |

that these conversion technologies are so variable implies that there is a diversity of solutions available for solving local problems depending on available technology, manpower, resources and needs. These factors are important in implementing any regional energy policy and, of course, do not necessarily apply only to renewable energy resources.

It is striking that over the last two or so years there has been an important change which has occurred in the realisation of the importance of biomass in the world's energy scene. Prior to that there were only relatively few people in the world trying to get universal recognition of the problem. Persistence by these people has been important to the recognition at the political and international level of the crucial role that biomass is playing and realising the fact that the energy crisis for most of the world's people is not directly dependent on oil prices, but is dependent more on the lack and cost in economic and social terms of biomass. Undoubtedly this has come about through the realisation that deforestation and desertification are proceeding very rapidly and that the effect on agriculture, environment and society is much greater than most people have recognised. It is also a fact that most of the planners and policy makers live in cities and often have little concept of what concerns the rural populations of developing countries and directly affects their lives. The most important turnabout which is visible today is the recognition of the importance of renewable energy in the recently published World Bank study entitled "Energy in the Developing Countries" (3). This proposes that over the financial years 1981-1985 \$3 billion will be invested in biomass energy, mostly as fuelwood and alcohol projects; they suggest that they would like to spend at least \$6¾ billion in implementing additional biomass programmes. Other national and international agencies are coming to similar conclusions and they are searching around trying to find how to improve the biomass-for-energy situation.

## IMPLEMENTATION

In this next section, once having recognised the problem of rural energy requirements, especially with regard to biomass, I wish to discuss the problem of implementing schemes which may improve the energy resources of the rural population. The problem with biomass energy is that it is such a diverse "technology" and source of energy that actually implementing or improving biomass-for-energy schemes is often extremely difficult. In fact this might be one of the reasons why so many planners have shied away from actual recognition of the problem and stopped at half-hearted attempts to implement significant schemes. There is no doubt that only once the problem is nationally recognised, and not just internationally, can any progress be made. Then getting recognition at the regional and the local level is the next stage in solving the implementation problem.

In my estimation the main requirements for successful implementation are:

1. involvement of local people, local expertise and artisans, entrepreneurs, creditors and leaders;
2. political, public, law, bureaucratic and media involvement and co-operation;
3. a continuing commitment by leaders at national, international, regional and local levels; and
4. incentives like credits, guaranteed purchase, and salaries in the initial stages especially.

Having said this I realise that it is not easy to have all these factors come together at the same time. In fact the same can be said for developed and developing countries!

One of the first things that must be done is a local energy analysis. One needs to establish what the current (and possibly future) needs (energy and other) of the population are, what biomass resources are used now and what could be made available, what infrastructure is possible to implement new schemes, what are the land and tree tenure situations and their protection mechanisms - and so on. These local energy analyses must be done by multidisciplinary groups, in other words by teams of people which do not only include engineers, scientists and economists. One needs to involve local leaders, social workers, women's groups, extension officers - that is, have a diverse group of people to try to establish what is really needed by the community and what is available to implement any new schemes. The traditional role of women in "energy" acquiring and use needs to be understood. Again, just formulating such ideas is very easy, but how one actually gets teams of people with some degree of expertise in local areas is not that easy. Such people need to have some degree of training and direction, and they need to know what is occurring in other similar localities of their country. The survey also needs to establish why people are making existing decisions. The manner in which the surveys (and interviews) are conducted must conform with local social habits and understanding and must be unbiased in the questioning and sampling - again this is not always easy to accomplish. The community surveyed should also be where the field tests are conducted - follow through is important.

How can regional development be assisted by implementing renewable energy schemes? There must be adequate initial financing from the central or regional governments.

There is also a prerequisite for financing on a continuing basis with the costs and beneficiaries clearly understood - this is an essential requirement before proceeding. Local and regional studies can however be made before large-scale financing is required since the rationale must be established before going to the next stages. There is no doubt that demonstration and pilot schemes in a country itself are important incentives in raising adequate financing. Successful examples of similar schemes (if they exist) in other regions and countries should also be carefully analysed.

One can distinguish at least six requirements which I think are important in implementing renewable energy on a regional basis. These requirements are again not necessarily peculiar to biomass or even to renewable energies, but I think they are essential if they are going to be implemented and will obviously greatly assist regional development.

Firstly, prestige. A top-level commitment which is highly visible must be obtained in order to ensure any success in the long term. One of the greatest problems is that agriculturists, foresters and regional developers have very low prestige and few facilities in many countries. This means that it is difficult to persuade people of adequate calibre to make their main commitment to implementing regional energy schemes. This needs to be changed at the top level and examples set so that implementation occurs on a continuing basis.

Secondly, incentives. One of the problems that regional developers have is that their postings are considered hardship posts, and therefore undesirable, and are also very often lower paid with fewer privileges to go with the job. This is exactly the opposite to what the situation should be; in other words, those people who are implementing regional schemes (or local and rural schemes) should receive higher salaries in order for them to have incentives to stay on the job and they should receive additional perks, like transport, housing, schooling and so on. At least this will encourage people to stay on the job. A perk which has great practical importance and also some prestige in rural parts of the developing world is adequate transport, like a land rover, jeep or van.

Thirdly, training. It is all very well trying to implement schemes but if the trained personnel are not available the schemes are not going to get very far. What is needed are not so many scientists but rather extension workers, engineers, agriculturists, foresters and generally people who can implement pilot and also R & D schemes. Such people are needed immediately and also for long term developments; thus adequate training must be taken into account as a requirement for regional development. The training of people is not very easy - it's hard on the trainers, it's hard on the institute and it's hard on the students, but in fact a continuing commitment to training, both prior to service and in service, is a prerequisite to get many of regional development schemes under way. Besides the regular educational and technical establishments, philanthropic and community organisations should be used to the fullest since they often have useful local expertise and knowledge which can help in training (and often also in implementing schemes).

Fourthly, infrastructure. An adequate infrastructure is essential for renewable energy resources - as in the case for implementation of other schemes also. An adequate number of full time posts are a prerequisite for attracting the required quality of people - for mechanical, maintenance, extension, administrative posts, etc. The system must run smoothly otherwise it will fall into discredit. This is especially important where the returns can take 5 to 10 years and interim arrangements for employment, energy supply, etc. have to be adequately catered for.

Fifthly, monitoring and feedback. During the implementation phase it is essential that monitoring of the progress of the scheme and the attitudes of the people and their local leaders be continuously assessed. Paid monitors or informers, or whatever they might be called, should be used so that immediate feedback is available to the regional planners and others involved in implementing the schemes who can then adapt to the changing circumstances. This is not easy since bias can enter into the analysis and reports, but certainly it should be part of any renewable energy scheme from the outset.

Sixthly, demonstrations and timing. The most difficult stages are the first few years, because people usually want immediate answers and these are not always available. Therefore demonstration schemes and realistic timing should be built into the scheme from the beginning and expectations should not be too great. People should have employment and other forms of income during the initial stages and expectations should not be excessive either by the local population or by the central planners, otherwise disillusionment can set in and the whole scheme can fail. Schemes which are well integrated into the local patterns of work and social habits will obviously be most acceptable.

## CONCLUSION

There is no doubt that implementing regional renewable energy schemes is essential for the wellbeing of the rural population of the world who, after all, comprise more than half the world's population. Because they are poor and do not have a voice in the great centres of politics and economics of the world, it doesn't mean they must be ignored - the environmental and social consequences of these people's actions will be very great in the long run and could affect us all. Large commitments in the way of manpower, infrastructure and finance must be made, otherwise neglect could have serious sociological and environmental consequences.

REFERENCES

1. Mnzava, E.M., Fuelwood and Charcoal in Africa, Conf. Proceedings from Energy from Biomass, Brighton, U.K. November 1980, Applied Sci. Publ., London, (in press)
2. Hall, D.O., Barnard, G.W. and Moss, P.A., Biomass for Energy in the Developing Countries, Pergamon Press, Oxford, (1981)
3. Energy in the Developing Countries, World Bank, 1818 H St. N.W., Washington, D.C. 20433, (1980)

# 14 Crop Alternatives in Semiarid Regions

*Timothy R. Peoples*
*Jack D. Johnson*

## INTRODUCTION

More than one-third of the land on the planet earth is arid and semiarid. Of this area less than half is naturally so dry that it cannot support human life. Some 14 percent of the world's population, about 630 million people, live on the world's arid and semiarid lands (1).

The one constant factor common to the arid areas of the world is climatic variability. Mean precipitation values are misleading because a 200 millimeter (mm) average annual rainfall may be based on 400 mm rainfall one year and none at all the next. Furthermore, precipitation that falls in arid areas varies quite widely spatially, making area-specific predictions of precipitation or drought seemingly beyond the current capabilities of science.

With the variability in available precipitation, man has utilized various irrigation techniques to standardize the water available for crop production. The heavy dependence upon irrigation water, both surface and groundwater, has lead to tremendous depletions in arid and semiarid land water supplies. In Arizona, water supplies are being depleted at a rate of approximately 0.3 million hectare-meters annually through agricultural uses (2). This represents 89 percent of the total depletion of water supplies by the state. The principal crops of Arizona not only supply a tremendous cash return to the state but they also utilize more water than an arid ecosystem can maintain. For example, water requirements can range up to 3 hectare-meter for pecans. While current harvested land totals approximately 530,000 hectares (ha), projections to the year 2000 estimate a reduction of 36 percent to approximately 340,000 ha (3). Based upon these projections, agriculture as we now know it, in Arizona and other arid regions, will soon change drastically.

Two research approaches are being taken by the University of Arizona to examine methods to circumvent the problem reflected in these projections. They are:

1. to alter current agricultural production techniques of the traditional crops, and
2. to develop alternative or non-traditional low water use crops.

The work reported in this article will be limited to the second approach with an emphasis upon production of low molecular weight hydrocarbons.

## ALTERNATIVE CROP SPECIES

While all plants are affected by drought, those adapted to survive in arid zones have the ability, through one mechanism or another, to withstand the impacts of severe drought. Some store water, others survive heat and drought by shedding leaves and becoming dormant, while a few plants mine water. Mesquite roots, for instance, have been found 175 feet below the surface in a copper pit mine (4). Ephermerals, which avoid the dry seasons altogether, are a group of primarily annual desert plants. Following adequate rains they germinate, mature, flower, and produce seeds during the brief time that soil moisture is available.

In the process of evolving to survive in arid environments, arid-adapted plants have developed some unique properties, many of which are of economic interest. Many produce chemicals to retard water loss, e.g., leaves and stems may be coated with waxes; some plants produce hydrocarbons or oils, and strong fibers. With minimal irrigation a respectable biomass may be produced on land that is of marginal agricultural value. Descriptions of low-water use and alternative crop species follow.

### Simmondsia chinensis

Jojoba (Simmondsia chinensis) is a shrub that grows naturally in the Sonoran Desert of the United States and Mexico. Jojoba has appeared in the botanical literature since 1821. The earliest records of its uses were written in a 1701 correspondence from Eusebio F. Kino to King Phillip V that referred to the medicinal fruit of jojoba and in 1789 by the Italian Jesuit Clavijera who described a medicinal use of jojoba "berries" (5).

Jojoba seeds are about 50 percent oil by weight and the expressed oil is similar to sperm whale oil. Jojoba seeds are harvested entirely from natural stands. Oil expressed from these harvested seeds is being sold in limited quantities for an average price of $14 per kilogram (kg).

Jojoba oil has potential uses as a fuel, as a chemical feedstock, and, because it does not become rancid, as a replacement for vegetable oils in foods, cosmetics, and hair oil. The oil also can be a source of long-chain alcohols, antifoaming agents and lubricants.

Hydrogenated jojoba oil is a hard, white crystalline wax. It has potential uses in preparing floor and automobile waxes, in waxing fruit, in impregnating paper containers, in manufacturing carbon paper, and in making candles that have slow burning and wilt resistant qualities.

Maximum yields of jojoba seed in the wild or under cultivation are unknown. Wild plants 3 meters (m) to 5 m in width and 5 m to 7 m in height have been found that yield 14 kg to 18 kg of clean dry seeds. In the United States, only the experimental plots at the University of California, Riverside, are old enough to produce sufficient quantities of seeds to be converted to per-hectare-yield values. Yermanos (6) reports yields of about 400 kilograms per hectare (kg/ha) from 5-year-old plants. Hogan (7) has experimental plantings at several sites in Arizona and reports seed yields of up to 73 grams (g) per plant from a few 2.5-year-old plants at Mesa, Arizona. Mexican researchers have reported annual seed yields of 2 kg from 4-year-old plants in Hermosillo. Israeli researchers have reported an annual seed yield of more than 3 kg from a 9-year-old jojoba plant at Gilat, Israel.

Approximately 7,200 ha of commercial plantings exist in Mexico, 1,500 ha in California, 400 ha in Arizona, and lesser amounts in the states of Florida, New Mexico and Texas, and in Australia, Israel, Saudi Arabia, Iran, Egypt, Jordan, and Ghana. Jojoba, without doubt, eventually will become an important arid lands agricultural product.

## Parthenium argentatum

Guayule (*Parthenium argentatum*) is a rubber-producing shrub native to the Chihuahuan Desert in southwestern Texas and northern Mexico. Tests indicate Guayule rubber has chemical and physical properties essentially identical to that produced by the rubber tree, *Hevea brasiliensis*. The principal barriers to commercial development are establishment and processing costs. Harvesting and cultivating procedures are fairly well established using currently available farming equipment.

Guayule was a commercial source of rubber in the early 1900s. During World War II, Emergency Rubber Project (ERP) personnel planted 12,500 ha of Guayule. The conclusion of World War II and the development of synthetic rubber resulted in project termination.

In the early 1970s several circumstances rekindled interest in the production of natural rubber from Guayule. Increased petroleum prices resulted in an increase in the price of synthetic rubber; and natural rubber prices rose apace with synthetic rubber prices. The continued availability of natural rubber supplies from foreign sources is uncertain and is of national concern. New Guayule rubber extraction processes developed in Mexico have brought the quality of the product to a level equal to that of *Hevea* rubber.

Guayule rubber produced by the improved extraction methods developed at the Saltillo plant has been tested. In evaluations conducted by Goodyear Tire and Rubber Company, experimental radial tires containing 30 percent to 40 percent Guayule rubber passed all U.S. Department of Transportation high speed and endurance tests. A U.S. Department of Defense project is in progress to evaluate Guayule rubber as a substitute for *Hevea* rubber.

As yet the only Guayule yield figures available are estimates developed during the ERP. During the life of the ERP the 1,800 ha planted yielded approximately 480 kg/ha of Guayule rubber per year. Kelly (8) showed higher yields of approximately 860 kg/ha per year from one special test plot in California.

As a result of a National Science Foundation technology assessment study, a document has been published that outlines the state-of-the-art of Guayule technology. It describes present and projected world rubber market conditions and areas of the United States where conditions favor Guayule cultivation (9).

## *Cucurbita foetidissima*

Potential uses of *Cucurbita* spp. include producing edible oil and protein by-products from the seed, industrial starch from the roots, and forage from the vines. The species most often discussed are *Cucurbita foetidissima* (buffalo gourd), *C. digitata*, *C. palmata* (coyote melon), and *C. pepo*. While all of these species have an economic potential, the work reported in this article is related to the buffalo gourd.

A major effort to domesticate the buffalo gourd and to industrialize its production is being conducted at the University of Arizona by Professors Bemis, Berry and Weber (10). The plants are perennial, they reproduce asexually, they grow as a weed in regions of low rainfall, and they produce a large crop of seeds rich in oil and protein. The roots are extremely large and store starch that may be of commercial value. The vines grow along the ground and may have forage value.

The oil of the seed has a high ratio of unsaturated fatty acids that makes it attractive for possible use in preparing food. Linoleic acid, recognized as essential in the diet of humans and animals, is the predominant fatty acid in the oil. Bemis reports that incorporating the crude oil into the diet of weanling mice in amounts up to 11 percent of the total diet has produced excellent growth with no deleterious effects. The crude oil can be extracted from the seed by a solvent process or by mechanical pressing.

The remaining seed meal contains about 45 percent protein and 45 percent fiber. The meal may be used in raw form as a component of animal feeds. Rodent feeding studies rank buffalo gourd, soybean, and cottonseed meals in close proximity in terms of protein quality.

Other than water, starch is the major component in the roots of buffalo gourd. It can be hydrolyzed, by chemical or enzymatic means, to glucose (dextrose) that has value as a sweetner in foods and beverages.

Bemis reports a fruit analysis indicating 32.9 percent crude protein and 33.0 percent crude fat. Hoffmann (11) indicates a fruit cyclohexane extract of 16.5 percent. The cyclohexane extract is indicative of a relatively high caloric and high hydrocarbons contents. Bemis estimates seed yields of up to 3,000 kg/ha. Assuming a 16 percent hydrocarbon yield, about 3.5 barrels per hectare (bbl/ha) of crude oil could be produced. At this juncture the buffalo gourd is not particularly promising as a producer of crude oils for hydrocarbon use.

Crude oils extracted from buffalo gourd may have economic value as food for humans in the forms of vegetable oil and protein. Assuming production of 1 ton per ha of vegetable oil and 0.5 ton per ha of protein, and values of \$.55 per kg of crude vegetable oil and \$.20 per kg of crude protein, the potential crop value is \$650 per ha. Bemis estimates that 13.5 tons per ha of crude starch could be produced every three years. With an approximate value of \$10 per ton, the crude starch would add about \$45 annually to the crop value to generate a gross cash income; but, until additional, substantial research and funds are directed toward agronomy, processing and product development, the buffalo gourd probably will remain an interesting but underutilized plant.

## ENERGY PRODUCING PLANTS

The world, and the United States in particular, relies upon sources of energy that are being depleted or subject to control by small and sometimes unstable cartels. About 50 percent of the petroleum and all natural rubber used in the United States is imported. The importance of developing indigenous sources to alleviate U.S. dependence on these imports is clear. Energy may be derived from plants that can be grown on arid lands.

Ever since man discovered the usefulness of fire, he has had an insatiable appetite for new and better sources of energy. The energy source experience of the United States illustrates that point. From the beginning of U.S. history until the mid-19th century, wood was the almost exclusive energy source. Near the latter quarter of the 19th century, however, coal rivaled wood as the dominant energy source. By the turn of the century more than 70 percent of the total energy used in the United States was generated by coal. Petroleum and natural gas were just beginning to emerge as major energy sources. Wind, hydro- and geothermal power then, as now, constituted only a minor part of the total U.S. energy supplies; conversion of solar energy was practically non-existent. By 1950, however, petroleum products accounted for approximately 50 percent of the U.S. energy sources, and the role of coal was declining rapidly. By 1976, petroleum products accounted for more than 75 percent of the energy used in the United States. A similar pattern exists throughout the industrialized world.

Because of the rapid consumption of petroleum products it is inevitable that oil reserves will be depleted, and that oil will lose its pre-eminence as an energy source. In fact, it is generally accepted that by the year 2020 no single energy source will supply more than 25 percent of the U.S. energy needs.

The problem of increasing use of petroleum is illustrated by the following statement, "...in the 1950s, we found 1¼ barrels of oil for every barrel we extracted; but by the late 1970s, this has dropped to about ½ barrel" (12). Another indication is that it now requires more than five times as much drilling to produce the same quantity of oil as it did 25 years ago. Recent drilling experience in the Atlantic Outer Continental Shelf has been very discouraging - 15 drillings produced no oil and only two small amounts of gas. Recent drillings in Southern California, Eastern Gulf of Alaska and Eastern Gulf of Mexico also have been discouraging.

A particularly exciting new era of research is the development of new crop plants that produce hydrocarbons for fuel and materials (13). Because of their high levels of incident solar radiation, arid lands are ideally suited for hydrocarbon-farming. Several plant species have milky latex, a rich source of plant hydrocarbons, and thus have the potential of becoming energy crops. These species include many plants native to the arid regions of the southwestern United States and northwestern Mexico.

## Euphorbia lathyris

The development of *Euphorbia lathyris* as a source of low molecular weight hydrocarbons was undertaken in a joint research program between the Diamond Shamrock Corporation and the University of Arizona. Two basic considerations are being investigated: 1) agronomic practicality in arid regions, and 2) economic feasibility of hydrocarbon farming.

Botanical History. *E. lathyris* is a biennial herb which may be native only to the central and mediterranean region (14). It is an upright growing herb that can attain a height of 200 centimeters (cm). As a weed, it is distributed throughout the temperate areas of the world. In California it is found along the coast. While it has never become established in arid regions of the world, we are attempting to adapt it to the arid climes.

This crop has been utilized in the past as both a medicinal and food crop. The fruits of the plant have been used as a substitute for capers and the seeds have substituted for coffee. In addition, the seeds have been used as an emetic and a treatment in the cure of dropsy. The plant also has been cultivated for its seed oil in Japan, China and the Soviet Union (15).

Hydrocarbon Chemistry. Using the Arizona method for the chemical extraction of low molecular weight hydrocarbons has been shown to be practical for both analytical and commercial processing (15). Extraction of the dried plant material with cyclohexane, followed by ethanol, leads to the isolation of three fractions (Figure 1). The cyclohexane extract is a high quality fuel yielding approximately 17,500 British thermal units per pound (Btu/lb).

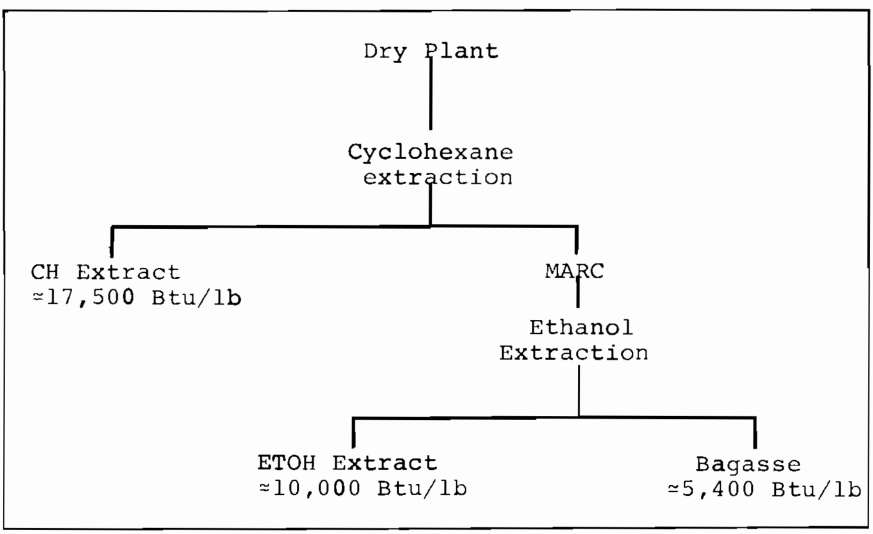



FIGURE 1. Hydrocarbon extraction scheme by the Arizona method

A medium quality fuel is derived from the ethanol extract with an energy value of 10,000 Btu/lb and the bagasse serves as a low quality fuel at 5,400 Btu/lb. The potential utility of the *E. lathyris* crude product has been demonstrated by Mobil Oil Corporation. Catalytic cracking of the crude product using a zeolite-charged fluid bed at 500°C yielded products which have been estimated to have 25 percent to 40 percent more economic value than conventional crude oil. The products obtained from cracking not only have potential value as fuels, but also as an excellent source of chemical feed stocks (Table 1).

*Agricultural Development*. The time for optimum establishment of *E. lathyris* appears to be when soil temperatures average between 16°C and 26°C. In 1979, planting in March, April, May and October in Marana and Tucson, Arizona, resulted in the most rapid and maximum percentage emergence (Figure 2). Sachs and Mock (16) have demonstrated similar results and it is recommended that *E. lathyris* be planted when the average daily soil temperature is greater than 16°C and less than 26°C for a minimum of four days prior to planting. Utilizing high quality seed, emergence will occur in 10 to 14 days at a rate greater than 70 percent.

Planting *E. lathyris* in the spring or fall in southern Arizona will result in summer and winter crops, respectively. At present, a spring planting is discouraged because of the high level of pathogenic inocula present in the summer soils. Fungi isolated from infected plants in Marana, Arizona were identified as *Rhizoctonia solani*, *Macrophomina phaseoline* and *Pythium aphanidermatum*. *Macrophomina phaseoline* was also isolated from infected

TABLE 1.
Product Distribution of *E. lathyris* Crude Product Cracked on a Zeolite-Charged Fluid Bed

| Product | Percent |
|---|---|
| Ethylene | 10 |
| Propylene | 10 |
| Toluene | 20 |
| Xylenes | 15 |
| Fuel Oil | 10 |
| $C_1$ - $C_4$ Alkenes | 10 |
| $C_5$ - $C_{20}$ Units | 10 |
| Coke | 5 |

Source: Hinman et al. (15)

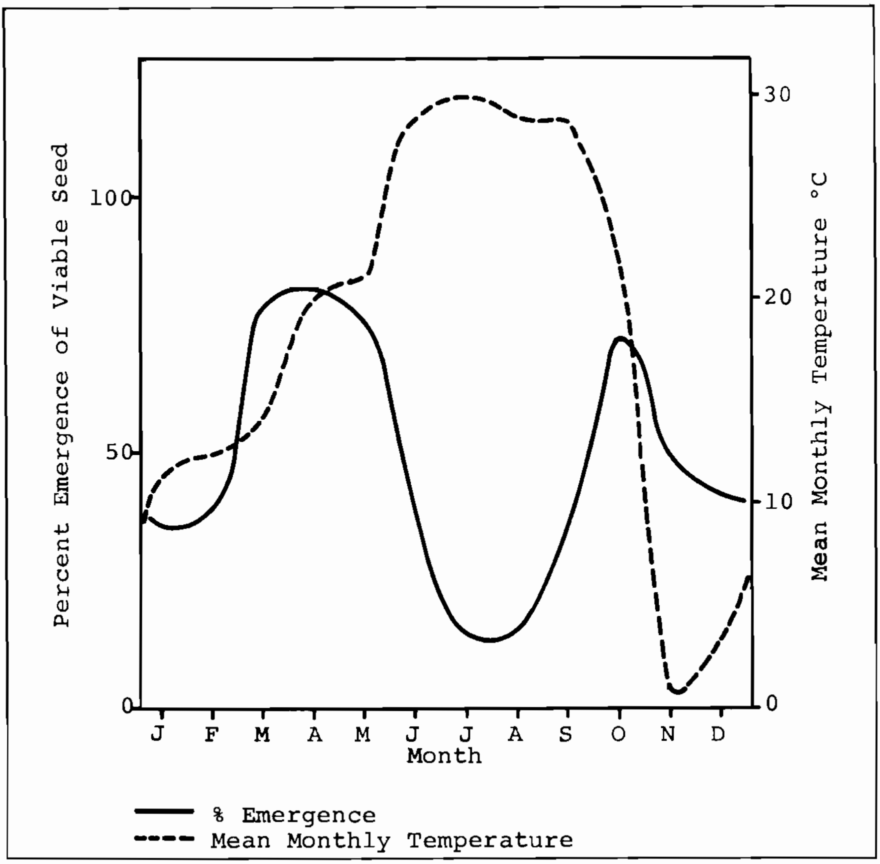



FIGURE 2. Mean monthly temperatures and percent field emergence of *Euphorbia lathyris* (from Hinman et al. (15))

plants grown in Bakersfield, California (17). The recommended fall planting avoids these fungi, such that the winter crop will survive and produce harvestable biomass in the spring. Greenhouse and field experiments are currently under way to identify various chemical, cultural and biological controls to protect the summer *E. lathyris* crop from these pathogenic fungi.

Optimizing the plant population density for *E. lathyris* was evaluated on 102 cm beds during the winter of 1979-80. Plants were established at 30,000, 70,000, 130,000 and 250,000 plants per ha (one row per bed) and 520,000 plants per ha (two rows per bed). Table 2 indicates that although increasing population densities to

TABLE 2.
Dry Matter and Hydrocarbon Yield of _Euphorbia lathyris_ as Affected by Population Density

| | Population Density (plants/ha X1000) 30 | 70 | 130 | 250 | 520 |
|---|---|---|---|---|---|
| Dry Matter Yield (kg/ha) | 1250 | 2070 | 2260 | 2930 | 5770 |
| Hydrocarbon Yield (kg/ha) | 120 | 450 | 540 | 620 | 1120 |

520,000 plants per ha increased both dry matter and hydrocarbon yields, the optimum population density was not obtained. Utilizing this planting scheme we produced the equivalent of 5,770 kg/ha of dry matter and 1,120 kg/ha extractable hydrocarbons (9 bbl/ha). While the obtained 9 bbl/ha is below the project design goal of 60 bbl/ha, we anticipate a doubling to about 18 bbl/ha simply by planting twice the number of rows per ha, thus utilizing the entire available land area. To further increase yields to attain the 60 bbl/ha yield, several experiments have been designed to improve agronomics and genetic stock.

The response of _E. lathyris_ to phosphate is significant; in greenhouse studies, yields have been increased from 8 g per plant to 5 kg per plant by increasing available phosphate (Table 3). While these results are not directly translatable to field conditions, they do indicate the potentiality of increasing _E. lathyris_ yields by optimizing fertilizer application.

Optimizing water also will result in increased yields. While we do not have enough data to evaluate optimization we do know that a fall planting will not produce a crop on 25 cm of water but will produce 5,770 kg/ha with 50 cm of water (precipitation and irrigation). Present investigations will provide the necessary data to determine the optimum requirement of _E. lathyris_.

The greatest potential for increasing yields lies in the field of plant breeding. At present, all yield data are based upon experiments with wild, unimproved seed. Through selection, cross-pollination and further selection it will be possible to capitalize upon the natural variability we have found in wild collections of plants. The significant variability in percent hydrocarbons, dry matter yield, and growth habit, and through the application of selection pressure it will be possible to identify disease resistance and drought and salt tolerance.

TABLE 3. Response of *Euphorbia lathyris* to Increasing Levels of Phosphorus Fertilizer

| Phosphorus (ppm) | Fresh Weight (kg/plant) |
|---|---|
| 0 | .01 |
| 15 | 1.80 |
| 30 | 4.20 |
| 60 | 5.20 |

In addition to the traditional breeding approach, we have made advances in tissue culture techniques with *E. lathyris*. Callus and single-cell cultures of various seedlings have been established to aid in identifying potentially vigorous genetic material for future development. Micropropagation techniques have also been refined, such that we are able to mass produce superior stocks in a matter of months. Both the tissue culture and micropropagation techniques will be useful for rapidly increasing our selected seedlines.

## CONCLUSION

While only selected arid land economic plants have been discussed in this report, we believe their potential uses have been demonstrated. In this era when we no longer talk of free water and unlimited energy, and when we now realize that resources are limited, we need to look with firm determination at employing our renewable natural resources. This is particularly true in arid areas where water is in short supply and often expensive. While those of us in arid areas must pay a high price to import energy, we do enjoy plentiful solar energy and arid land plants appear to be efficient solar energy converters.

Finally, the economic use of arid land plants must be considered as a crop production system with minimal water and energy inputs, grown on land that may not be economically suitable for other uses. In terms of income per hectare we must compare new crop development in arid areas with other potential uses for the same piece of land, and not make comparisons with per acre income potentials in more humid areas.

## REFERENCES

1. Eckholm, E. and Brown, L.R., Spreading Deserts: The Hand of Man, Worldwatch Paper 13, Worldwatch Institute, Washington, D.C., (1977).

2. Arizona Water Commission, Water Conservation, Arizona State Water Plan Phase III Part 1, Arizona Water Commission, (1978).
3. Foster, K.E., Arid Lands Biomass Production in Arizona, Arizona Water Resources Project Information Bulletin No. 22, (1979).
4. Felger, R.S., Nutritionally Significant New Crops for Arid Lands: A Model from the Sonoran Desert, pp. 373-403 _in_ Mayer J. and Dyer, J.W. (eds.), Priorities in Child Nutrition in Developing Countries, UNICEF, New York, (1975).
5. Sherbrooke, W.C., New Historical Reference to Jojoba, Jojoba Happenings 28:5, University of Arizona, Tucson, Office of Arid Lands Studies, (1979).
6. Yermanos, D.M., Jojoba: A Crop whose Time Has Come, California Agriculture 33 (7-8):4-11, (1979).
7. Hogan, L., Jojoba, A New Crop for Arid Regions, pp. 177-206 _in_ Ritchie, G.A. (ed.), New Agricultural Crops, American Association for the Advancement of Science, Washington, D.C., A.A.A.S. Selected Symposium No. 38, (1979).
8. Kelly, O.J., Soil-Plant Relationships: Guayule, pp. 83-93 _in_ McGinnies, W.G. and Haase, E.F. (eds.), An International Conference on the Utilization of Guayule, Proceedings, University of Arizona, Tucson, Office of Arid Lands Studies, (1975).
9. Foster, K.E. et al., A Sociotechnical Survey of Guayule Rubber Commercialization, Midwest Research Institute, Kansas City, Missouri and University of Arizona, Tucson, Office of Arid Lands Studies, (1979).
10. Bemis, W.P., Berry, J.W. and Weber, C.W., The Buffalo Gourd, A Potential Crop for Arid Lands, University of Arizona, Tucson, Office of Arid Lands Studies, Arid Lands Newsletter No. 8, p.1-7, (1978).
11. Hoffmann, J.J., Personal communication, (1980).
12. Kerr, R.A., Petroleum Exploration: Discouragement about the Atlantic Outer Continental Shelf Deepens, Science 204 (4397):1069-1072, (1979).
13. Calvin, M., Green Factories, Chemical and Engineering News 56 (12):30-36, (1978).
14. Smith, A.R. and Tutin, T.G., _Euphorbia_, Flora Europea 2:213-226, (1968).
15. Hinman, C.W., Hoffman, J.J., McLaughlin, S.P. and Peoples, T.R., Hydrocarbon Production from Arid Land Plant Species, pp. 110-114 _in_ Franta, G.E. and Glenn, B.H. (eds.), Proceedings of the 1980 Meeting of the American Section of the International Solar Energy Society, (1980).
16. Sachs, R.M. and Mock, T., _Euphorbia lathyris_: A Preliminary Guide to Planting, University of California Ag. Exp. St. Report No. 103, (1980).
17. Young, D. and Alcorn, S.M., Personal communication, (1980).

15

# Botanochemicals from Arid Lands: Toward Development of Production, Marketing, and Consumption Systems

*Russell A. Buchanan, Ellis G. Knox, Arthur A. Theisen, and Gary L. Laidig*

## INTRODUCTION

Our previous work on multi-use botanochemical crops has been done in the context of intensive main-line U.S. agriculture; i.e. highly mechanized crop production on fertile, level, well-watered soils with high inputs of fertilizer, chemicals and cultivation (1,2). Similarly, those major U.S. petrochemical companies that have recently made an investment toward developing technologies for production of Guayule rubber, pine chemicals, and whole-plant oils seem to be directing their efforts toward intensively managed "plantations" requiring high inputs (3-5). For example, Guayule, which is naturally adapted to arid lands, seems destined to become an irrigated row-crop in the U.S. (5).

However, environmental limitations of arid (and other distressed) lands require important departures from conventional intensive agricultural practices. We concur with others (6-8) in concluding that intensive agricultural with its relatively great usage of irrigation water, fertilizer and other inputs is generally inappropriate for arid land Production-Marketing-Consumption (PMC) systems that are designed to provide materials and fuels. In the long run, it is much better to manage arid lands in a sound low-intensity silviculture or range-land mode.

In championing the introduction of new crops into U.S. agriculture, we have developed a systems approach because new crops require not only the solution to technical problems but also the development of functioning PMC systems. Previously, we studied the feasibility of introducing new food crops better adapted to environmental stress (9) and are now working toward development of PMC systems and subsystems for six potential new stress-adapted crops. Our objective is to provide a basis for making adoption of these new and vitally needed crops actually happen. Our efforts on behalf of these crops include the formulation of descriptive models of development processes and PMC systems and the employment of the Delphi technique to identify and define constraints so that time-framed remedial strategies may be postulated. In the last several months, we have expanded our consideration of arid land management to include multi-use botanochemical crops.

In this paper, we explicitly discuss aspects of PMC systems for botanochemicals from arid lands with particular emphasis on those that differ greatly from botanochemical systems in the midwestern U.S. family farm setting discussed previously.

## SYSTEMS APPROACH

Production of botanochemicals necessarily involves growing, harvesting and processing whole-plant produce and thus is naturally adapted to the "multi-use" concept, i.e. to the integrated production of primary and secondary botanochemicals, protein feeds, fibers and solid biomass fuels or feedstocks (1,10). Multi-use botanochemical PMC systems consist of several interacting sub-systems as illustrated in a generalized way in Figure 1. This figure lists some important inputs and several potential products with their utility, but is necessarily sketchy and incomplete. Individual PMC systems have to relate to specific crops and regions. The generalized PMC system idea is introduced here just to serve as a basis for subsequent discussion.

Major constraints in the Crop Production Subsystem of arid land botanochemical PMC systems (see Figure 1) are due to limited water supplies, highly variable (often poor) land quality, shortages of highly trained labor, and lack of technology to deal with the complex problems associated with arid-land crop production PMC systems (8). These limitations probably make intensive agriculture impractical, limit productivity and require a forestry mode of cropping. The arid-forestry mode severely limits the number and type of plant species that may be considered as potential crops and may require mixed-stands in some situations.

Furthermore, constraints in the Crop Production Subsystem interact with the Procurement and Transport and the Primary Processing Subsystems (see Figure 1) to limit scale of processing. In general, low biomass productivity of arid lands increases the cost of collecting produce to a distant central processing site and thus favors even smaller scale processing than would be needed for more highly productive lands. In turn, small scale processing may limit the options for conversion to some products and thus the Primary Processing Subsystem interacts with the Consumption Subsystem, as shown in Figure 1. Hence, there are complex interrelationships between subsystems, and aspects of each, that make it extremely important to take a systems approach to arid-land botanochemical production and evaluate alternatives in relation to the entire PMC system.

## ASPECTS OF CROP PRODUCTION SUBSYSTEMS

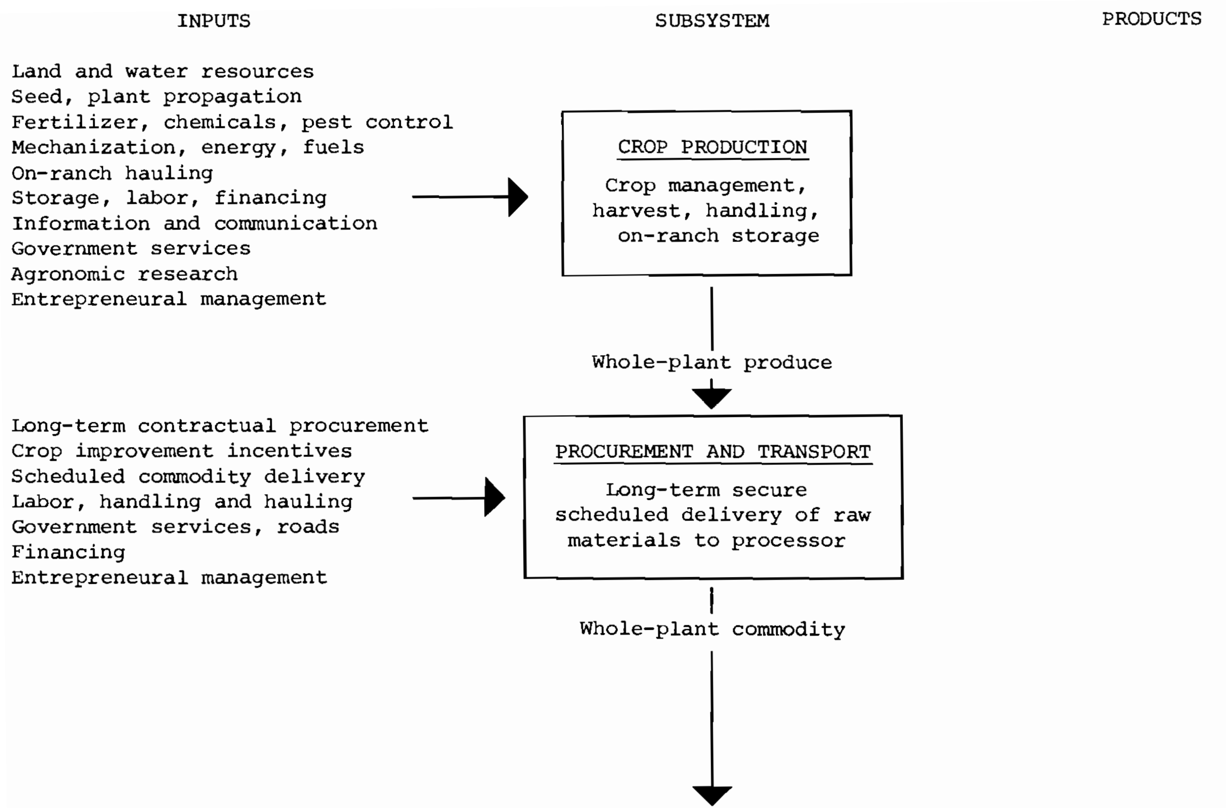
### Crop Selection

Constraints and Opportunities. In current efforts directed toward development of energy and material producing agricultural systems, crops which give very high yields of dry matter (biomass) per unit of input (e.g. hybrid popular, *Populus* sp.), sugar crops for ethanol by fermentation (sugar cane, *Saccharum officinarum*; sweet sorghum, *Sorghum vulgare*), and some multi-use crops for high-energy "petroleum substitute" coproducts (resin pines, *Pinus* sp.; mesophyte milkweeds, *Asclepias* sp.), are being considered for intensive agriculture in areas with adequate water. Because these crops generally have relatively high water and fertility requirements, they cannot reasonably be considered for arid lands.

However, arid lands are the natural habitat of a wide variety of plant species that have high contents of organic soluble extractives. The unique biosynthetic and energy storage capabilities of these plants present a good opportunity for exploitation of arid lands. Interest in arid lands will continue to be directed mainly toward production of high-value and high-energy-content materials; for example, Guayule rubber, jojoba liquid wax and euphorbia latex-oils.

Energy-Efficiency Considerations. Simply because industrial chemical conversion is less efficient than biological conversion, Calvin, Abelson, and others have suggested that green plants be grown to produce hydrocarbons (or near-hydrocarbon oils) directly useful as fuels (11,12). Phytosynthesis of natural rubber illustrates the green plants' efficiency in converting photosynthate to high-energy materials, as shown in Figure 2 (13). The energy driving this conversion is carried by ATP and is considered here as coming from the coupled glycolytic pathway and Krebs' cycle in the complete oxidation of simple sugars, Equation 1 (see Figure 2). Oxidation of glucose gives 38 moles of ATP with an energy efficiency of about 40% by this route (14). The net phytochemical reaction is that a kilogram of photosynthate with a heating value of about 15.59 MJ/Kg is converted to 0.32 Kg of natural rubber with a heating value of about 45.21 MJ/Kg, Figure 2.

The remarkable efficiency of phytochemical and biological conversions in general, as contrasted with industrial chemical synthesis is illustrated in Table 1. However, the energy accounting is incomplete unless the cost


INPUTS
SUBSYSTEM
PRODUCTS
Land and water resources
Seed, plant propagation
Fertilizer, chemicals, pest control
Mechanization, energy, fuels
On-ranch hauling
Storage, labor, financing
Information and communication
Government services
Agronomic research
Entrepreneural management
CROP PRODUCTION
Crop management, harvest, handling, on-ranch storage
Whole-plant produce
Long-term contractual procurement
Crop improvement incentives
Scheduled commodity delivery
Labor, handling and hauling
Government services, roads
Financing
Entrepreneural management
PROCUREMENT AND TRANSPORT
Long-term secure scheduled delivery of raw materials to processor
Whole-plant commodity

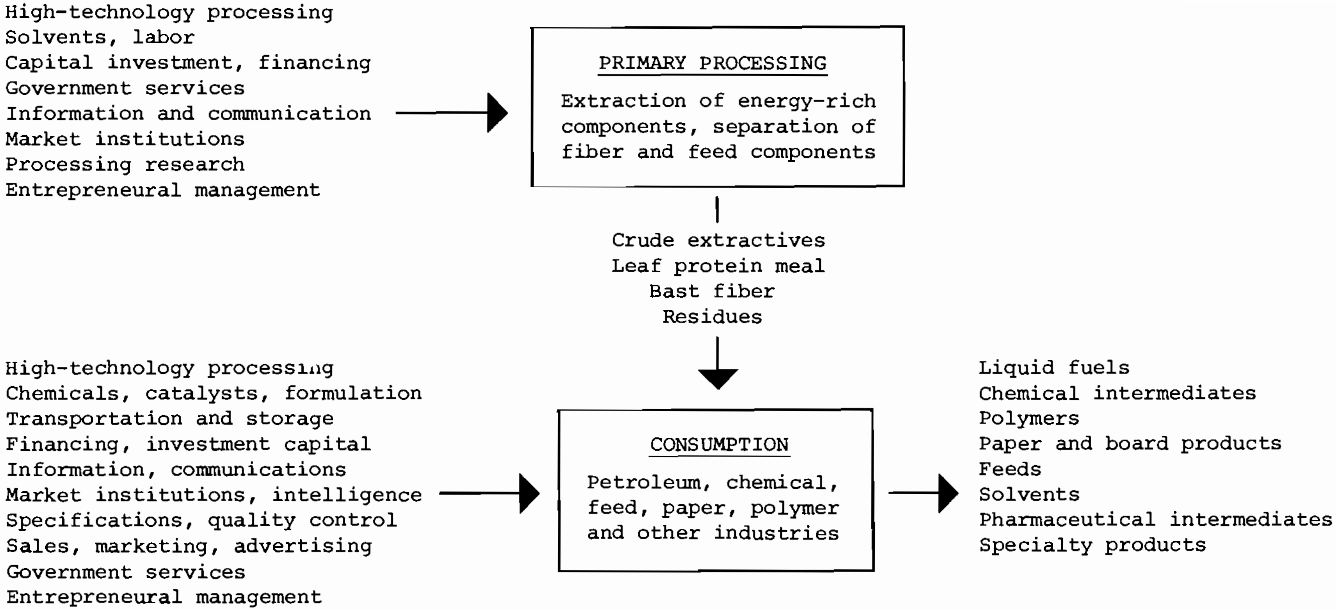



FIGURE 1. Multi-use botanochemical Production-Marketing-Consumption (PMC) system

1) $$\underset{\text{Photosynthate}}{\underline{(\text{-HCOH-})}} + 3\text{AMP} + 3\text{ADP} + 2\text{NADP} + \text{H}_3\text{PO}_4 + 4\text{H}_4\text{P}_2\text{O}_7 \searrow 6\text{ATP} + 2\text{NADPH} + 2\text{H}^+ + \text{CO}_2 + 4\text{H}_2\text{O}$$

2) $$(\text{-HCOH-})_6 + 3\text{H-CoA} + 3\text{ATP} \rightarrow \underset{\text{Acetyl-coenzyme A}}{\underline{3\text{CH}_3\text{CO-CoA}}} + 3\text{AMP} + 3\text{H}_4\text{P}_2\text{O}_7$$

3) $$3\text{CH}_3\text{CO-CoA} + \text{H}_2\text{O} \rightarrow \underset{\text{B-hydroxy-B methyl glutaryl-CoA}}{\underline{\text{CH}_3\overset{\text{OH}}{\underset{\text{CH}_2\text{COOH}}{\text{C}}}\text{CH}_2\text{CO-CoA}}} + 2\text{H-CoA}$$

4) $$\text{CH}_3\overset{\text{OH}}{\underset{\text{CH}_2\text{COOH}}{\text{C}}}\text{CH}_2\text{CO-CoA} + 2\text{H}^+ + 2\text{NADPH} \longrightarrow \underset{\text{mevalonic acid}}{\underline{\text{CH}_3\overset{\text{OH}}{\underset{\text{CH}_2\text{COOH}}{\text{C}}}\text{CH}_2\text{CH}_2\text{OH}}} + 2\text{NADP} + \text{H-CoA}$$

5) $$\text{CH}_3\overset{\text{OH}}{\underset{\text{CH}_2\text{COOH}}{\text{C}}}\text{CH}_2\text{CH}_2\text{OH} + 2\text{ATP} \longrightarrow \underset{\text{mevalonic acid-5-pyrophosphate}}{\underline{\text{CH}_3\overset{\text{OH}}{\underset{\text{CH}_2\text{COOH}}{\text{C}}}\text{CH}_2\text{CH}_2\text{-P}_2\text{O}_7\text{H}_3}} + 2\text{ADP}$$

6) $$\underset{CH_2COOH}{CH_3\overset{OH}{C}CH_2CH_2\text{-}P_2O_7H_3} + ATP \longrightarrow \underbrace{CH_2{=}\overset{CH_3}{C}CH_2CH_2\text{-}P_2O_7H_3}_{\text{isopentenyl pyrophosphate}} + ADP + H_3PO_4 + CO_2$$

7) $$\left(\frac{1}{n}\ n\ CH_2{=}\overset{CH_3}{C}CH_2CH_2\text{-}P_2O_7H_3 \longrightarrow \underbrace{(\text{-}CH_2\overset{CH_3}{C}{=}CHCH_2\text{-})n}_{\text{polyisoprene}} + n\ H_4P_2O_7\right)$$

1-7) $$\frac{(\text{-}HCOH\text{-})_7}{\text{Photosynthate}} \longrightarrow \frac{(\text{-}CH_2\overset{CH_3}{C}{=}CHCH_2\text{-})}{\text{rubber, repeating unit}} + 2CO_2 + 3H_2O$$

210.9g $\longrightarrow$ 68.12g

15.59 MJ/Kg  45.21 MJ/Kg

Energy Conversion Efficiency = 93%

FIGURE 2. Energy conversion efficiency in the phytosynthesis of rubber

TABLE 1. Weight and Energy Relationships for Biological and Chemical Conversions

| Starting Materials: Material | Starting Materials: Heating Value[1] MJ/Kg | Product: Substance | Product: Heating Value[1] MJ/Kg | Ratio, Product/Starting Material: Mass | Ratio, Product/Starting Material: Heating Value | Efficiency of Energy Conversion, % |
|---|---|---|---|---|---|---|
| Photosynthetic conversions: | | | | | | |
| Photosynthate | 15.59[2] | Glucose | 15.64 | 1 | 1 | 100 |
| Glucose | 15.64 | Cellulose | 17.43 | 0.90 | 1.11 | 100 |
| Photosynthate | 15.59 | Flavanoids[3] | 21[3] | 0.72 | 1.35 | 97 |
| Photosynthate | 15.59 | Phenylalanine | 28.16 | 0.55 | 1.81 | 100[4] |
| Photosynthate | 15.59 | Lignin[5] | 29.53 | 0.51[5] | 1.89 | 96 |
| Glucose | 15.64 | Triolein | 41.93 | 0.37 | 2.68 | 99 |
| Glucose | 15.64 | Stearic Acid | 39.90 | 0.36 | 2.55 | 92 |
| Photosynthate | 15.59 | Polyisoprene | 45.21 | 0.32 | 2.90 | 93 |
| Fermentation: | | | | | | |
| Glucose | 15.64 | Ethanol | 29.77 | 0.51 | 1.90 | 97 |
| Glucose | 15.64 | Acetic Acid | 14.60 | 1.00 | 0.93 | 93 |
| Acetic Acid | 14.60 | Methane | 55.01 | 0.27 | 3.77 | 100 |
| Industrial Chemical conversion: | | | | | | |
| Wood, dry | 20.9 | Methanol | 22.33 | ca 0.48 | 1.07 | ca 51 |
| Wood, dry | 20.9 | Hydrocarbons | 44 | 0.06-0.30 | 2.10 | 13-63 |

[1]Higher heating value, i.e., heat of combustion at 20°C, gaseous $CO_2$, liquid $H_2O$

[2]Average value for a number of simple sugars

[3]Calculations based on quercitin ($C_{15}H_{10}O_7$), heating value estimated from C, H, O content

[4]Assumes N available as ammonium with no photosynthate cost to the plant

[5]Mass calculation based on pentamer of coniferyl alcohol, heating value for spruce lignin from literature

of producing and maintaining the phytosynthetic apparatus (mature green plant with functioning enzyme and cellular transport systems) is compared with the energy cost of constructing and operating an industrial facility and unless all the comparable energy requirements for harvest, transport, product recovery and work-up, etc. are considered. For example, energy-efficiency favors ethanol production by fermentation if sugar or starch is available as feedstock; but if lignocellulose is the raw material, thermocatalytic conversion to methanol is favored because of the energy cost for conversion of cellulose to sugar and the inability of fermentation to convert lignin.

A full energy accounting has been made for natural rubbers in comparison to petroleum-derived synthetic rubbers and indicates an enormous energy savings for the agricultural products (5). An exact comparison is difficult, but intuitively, one expects that the energy cost for making synthetic rubbers from biomass (sugar, 2-3 butylene glycol, butadiene route for example) would be lower than for producing it from petroleum, but much higher than for producing natural rubber.

To summarize the above discussion, energy-efficiency considerations, by themselves, favor selection of species with the desired phytosynthetic and storage capabilities if high-energy materials or liquid fuels are the goal. However, plant varieties selected and bred to produce larger amounts of oils, waxes, or hydrocarbons cannot be expected to equal less resinous varieties in total dry matter production, cf. mass ratios in Table 1.

Another aspect of energy-efficiency is that evergreen and perennial plants have an inherent advantage over annual plants in that the phytochemical apparatus does not have to be completely reconstructed each year. For example, the common milkweed (Asclepias syriaca) potentially outproduces soybean in biomass, oil, and protein (15) because the milkweed keeps its root and energy storage intact during Northern winters, thus the plant is able to quickly resume a large photosynthetic capacity early in the growing season. Certainly the high productivity of Hevea is only possible because the fully developed tree is able to divert a large portion of its photosynthate to rubber synthesis when subjected to a tapping regime with, or without, yield stimulation. Similar considerations apply to Guayule since it is perennial and has a rubber storage capacity.

Species Adaptability and Composition. Rather than modifying the arid environment to accommodate conventional crops, plant species should be selected for their adaptation to the arid environment. The species that can be considered are those that thrive in arid lands, that are adapted to low intensity plant husbandry, and that either give high biomass yields or have promising chemical compositions. Other desirable attributes are a strong regenerative capacity in response to severe disturbance, particularly harvest, and an ability to maintain pure stands in the face of competition from other species. Relevant botanical characteristics of several arid land species that have been suggested for utilization are given in Table 2. Note particularly the Great Basin desert species suggested by Van Epps on the basis of wide adaptation, easy propagation, lack of response to fertilizers, and high biomass and energy productivity (16).

Only relatively few plant species have been characterized as to their gross chemical composition. For several of the species listed in Table 2, extractive contents may be found in the literature. These are reported in Table 3. Most of these analyses were done in an effort to identify rubber producing species. The closely related *Chrysothamnus* and *Haplopappus* genera have been suggested for natural rubber production because their climatic adaptation in the U.S. is wider than Guayule's. Three representative entries are given for rubber rabbitbrush (*Chrysothamnus nauseosus*) to illustrate its wide range of intraspecific variation in resin and rubber contents (see Table 3). Simple selection of rubber rabbitbrush subspecies on the basis of morphological characteristics could give varieties high in rubber content, or alternative resin producing varieties (17).

Several other arid land species are high in total extractive content and have significant rubber contents (see Table 3). Most of these rubbers are probably low in molecular weight but are of interest as a high-energy component of the extractives (whole-plant oils) which are increasingly considered as potential petroleum substitutes.

Encienso (*Encelia farinosa*), ocotillo (*Fouquieria splendens*), manzanita (*Xerococcus bicolor*), tarweed (*Grindelia squairosa*), and *Jatropha* species seem to have some potential as botanochemical sources, but have not been given much consideration previously (see Table 3).

## ARID LAND CROP MANAGEMENT TECHNIQUES

### General

One of the greatest tragedies of our times is that poor arid land management techniques are accelerating desertification in many regions. Low plant growth rates in arid regions cannot sustain heavy grazing or frequent harvests unless irrigation water and other expensive inputs are provided.

The traditional approach to increasing the productivity of arid lands is to construct irrigation systems at great (often public) expense in order to apply intensive, high-input agriculture to conventional humid or sub-humid economic crops. In the U.S., arid land is irrigated to grow cotton, corn, alfalfa and other forages, vegetables, citrus and other fruits, and sugar cane. But this type of agriculture has been extended to the limit imposed by supply and cost of irrigation water. In fact, higher energy costs have recently forced the abandonment of deep-well irrigation in areas of Texas. Alternative arid-land farming techniques are essential to the social and economic health of the entire great basin and southwestern U.S. One alternative that is being intensively studied is to grow new stress-adapted fruit, vegetable, fiber, and industrial crops that demand fewer inputs (9).

The other alternative, suggested by the intrinsic low-yield capacity of arid lands, is low-cost management based on natural regeneration or inexpensive establishment of adapted species, less frequent than annual harvest of perennial plants and full utilization of multiple products from the biomass produced (8). These concepts can provide the basis for entirely new arid land PMC systems.

## Biomass from Mixed Stands

A program has been proposed for harvesting arid land pinyon-juniper, chaparral and mountain brush for use as fuel in California. Environmental impacts of using such natural mixed stands of vegetation for energy production apparently can be favorable if harvesting is integrated with fire management and erosion control. The proposed harvest program involves strip clear-cutting on level land as an aid to fire control and thinning on slopes for erosion control. Harvest would be based on 10 to 20 year rotations on extensive tracts of land. An important volume of fuel ($652 \times 10^{15}$ J/year in California) would be produced at low cost. Other benefits might include improved wildlife habitats and easier access for recreational use (18).

Long range management of arid lands for production of biomass should be directed toward maintenance of stable productive animal-plant-soil-resource ecosystems consistent with long-term improved economic return. It has been suggested that productivity of arid lands is limited more by reduced nitrogen fixation than by limited water availability (7). Thus, leguminous nitrogen-fixing trees seem assured of an important position in long-term management. Such nitrogen-fixing species may be grown as pure stands or intercropped, companion cropped or even rotated with improved fast growing biomass producing species. In the long run, we suggest that economics will favor multi-use botanochemical producing crops as a major element in a balanced crop production subsystem.

TABLE 2. Representative Xerophytic Plant Species with Potential for Multi-Use Botanochemical Utilization

| | | Growth Characteristics | | | Ecological Characteristics | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Family, genus, species | Common name | Mature plant height m | Adaptable to clipping | Period for regeneration[1] yrs | Native pure stands | Ecological region[2] | Hardiness zone | U.S. geographic distribution | Reference |
| AGAVACEAE | | | | | | | | | |
| _Agave lecheguilla_ | Lechuguilla | 0.7 | yes | 2 | yes | 2,Southern 11 | 8 | TX,NM,AZ,CA | (19) |
| _Nolina microcarpa_ | Beargrass | 0.5 | yes | 1 | yes | 2,Southern 11 | 7 | TX,NM,AZ,CA | (19,20) |
| _Yucca glauca_ | Soapweed | 1 | yes | 1 | yes | Extensive | 4 | SD to NM | (19) |
| ASCLEPIADACEAE | | | | | | | | | |
| _Asclepias brachystephana_ | - | 0.7 | yes | 1 | yes | 2,Southern 11 | 8 | TX,NM,AZ,CA | (21) |
| _A. californica_ | California milkweed | 1 | yes | 1 | no | Coastal 2, 13 | 9 | CA | (21) |
| _A. erosa_ | - | 1 | yes | 2 | no | 2, 11 | 6 | CO,AZ,CA | (22) |
| _A. galioides_ | Horsetail milkweed | 1 | yes | 1 | yes | 2, 11 | 6 | UT,CO,AZ,NM | (21) |
| _A. latifolia_ | Broadleaf milkweed | 0.6 | yes | 1 | no | Extensive | 5 | KS to TX,CO, AZ | (21) |
| _A. mexicana_ | Mexican whorled milkweed | 1.5 | yes | 1 | no | 2, 11 | 5 | ID,NV,NM,AZ, CA | (21) |
| _A. subulata_ | Desert milkweed | 2 | yes | 2 | no | 2, 11 | 6 | NV,AZ,CA | (22) |
| BUXACEAE | | | | | | | | | |
| _Simmondsia chinensis_ | Jojoba | 2 | yes | 3 | yes | 2 | 9 | AZ,CA | |
| CACTACEAE | | | | | | | | | |
| _Opuntia ficusindica_ | Prickly pear | 3 | yes | 3 | yes | 2,8 Southern 11 | 7 | TX,NM,AZ,CA | (19,20) |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| CHENOPODIACEAE | | | | | | | | | |
| *Atriplex canescens* | Fourwing saltbush | 2 | yes | 3 | no | 11 | 5 | WA to NM,AZ | (16) |
| *A. lentiformis* | Big Saltbush | 2 | yes | 3 | yes | 11 | 5 | UT,NM,AZ,CA | (16) |
| *Sarcobatus vermiculatus* | Greasewood | 3 | yes | 3 | yes | 11 | 5 | ND to TX,CA | (16) |
| COMPOSITAE | | | | | | | | | |
| *Artemisia tridentata* | Big sagebrush | 3 | yes | 3 | yes | 11 | 5 | WY to NM,CA | (16) |
| *Chrysothamnus linifolius* | Speading rabbitbrush | 1.5 | yes | 3 | yes | 11 | 5 | WY to NM,CA | (16) |
| *C. nauseosus* | Rubber rabbitbrush | 2 | yes | 3 | yes | 11 | 5 | WY to NM,CA | (16) |
| *Encelia farinosa* | Brittle bush, Encienso | 1.5 | | | | | | UT,NM,AZ,CA | (21) |
| *Grindelia squarrosa* | Tarweed | 1 | no | - | yes | Extensive | 4 | SD,WY to TX | |
| *Haplopappus spinulosus* | - | 0.7 | yes | 3 | yes | Extensive | 4 | MN to NM | (21) |
| *Hymenoxys floribunda* | Pinguay, Rubberweed | 0.4 | yes | 2 | yes | 11 | 6 | OR,CO,TX,NM, AZ | (21) |
| *H. odorata* | Bitter rubberweed | 0.5 | no | - | yes | 2,Southern 11 | 7 | TX,NM,AZ,CA | (23) |
| *Parthenium argentatum* | Guayule | 1 | yes | 2 | yes | Southern 8 | 9 | TX,NM | |
| CRUCIFERAE | | | | | | | | | |
| *Lesquerella fendleri* | Bladderpod | 0.3 | no | - | yes | 11 | 4 | ID,WY,NM,AZ | (24) |
| CUCURBITACEAE | | | | | | | | | |
| *Cucurbita foetidissima* | Buffalo gourd | - | yes | 1 | no | Extensive | 5 | SD to AZ | (25) |

TABLE 2. (cont'd)

| | | Growth Characteristics | | | Ecological Characteristics | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Family, genus, species | Common name | Mature plant height m | Adaptable to clipping | Period for re-generation[1] yrs | Native pure stands | Ecological region[2] | Hardi-ness zone | U.S. geographic distribution | Refer-ence |
| ERICACEAE | | | | | | | | | |
| Xylococcus bicolor | Manzanita, Woodberry | 2 | yes | 4 | no | 2,13 | 7 | CA | (26) |
| EUPHORBIACEAE | | | | | | | | | |
| Euphorbia anti-syphilitica | Candelilla | 1 | probably | 2 | yes | Southern 11 | 9 | TX | (27) |
| E. lathyris | Mole or gopher plant | 1 | no | - | yes | Extensive | 4 | CT,VA,AZ,CA | (11) |
| Jatropha cardiophylla | | 1 | yes | 2 | - | 2,Southern 11 | 8 | NM,AZ,CA | (21) |
| FOUQUIERIACEAE | | | | | | | | | |
| Fouquieria splendens | Ocotillo, Coach whip | 6 | - | - | - | - | - | TX,NM,AZ,CA | (21) |
| LEGUMINOSAE | | | | | | | | | |
| Leucaena glauea | Leucaena | 12 | yes | 5 | no | Extensive | 8 | FL,TX,NM,AZ | (28) |
| Olneya tesota | Desert ironwood | 8 | - | - | - | 2,Southern 11 | 8 | NM,AZ,CA | (9) |
| Prosopis glandulosa | Mesquite | 9 | yes | 4 | yes | 2,8,11,13 | 7 | KS to TX,NM, AZ | (6) |
| PINACEAE | | | | | | | | | |
| Pinus edulis | Pinyon | 8 | no | - | yes | 10,11 | 5 | WY to TX,NM, CA | (9) |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| POLYGONACEAE | | | | | | | | | |
| Rumex hymenosepalus | Canaigre, Wild rhubarb | 1 | no | - | yes | 2,Southern 11 | 8 | TX,NM,AZ | (29) |
| TAMARICACEAE | | | | | | | | | |
| Tamarix chinensis | Salt cedar | 4 | - | - | - | 2,Southern 11 | 8 | TX,NM,AZ,CA | (19) |
| ZYGOPHYLLACEAE | | | | | | | | | |
| Larrea tridentata | Creosote bush | 3 | yes | 3 | yes | 2,Southern 11 | 8 | TX,NM,AZ,CA | (30) |

[1] A rough estimate of the time required for regeneration, under very favorable conditions, of nearly full-sized plants from rootstocks after pollarding at near ground level

[2] Broad ecological region, see Theisen (9)

TABLE 3. Extractive Content of Representative Xerophytic Species Having Potential Multi-Use Botanchemical Utility

| Family, genus, species | Common name | Suggested utility[1] | Plant part | Extraction data: Resin, % (acetone extract) | Extraction data: Hydrocarbon fraction[2], % | Reference |
|---|---|---|---|---|---|---|
| ASCLEPIADACEAE | | | | | | |
| *Asclepias brachystephana* | - | Rubber,resin,fiber | Whole | 7.8 | 2.1 | (21) |
| *A. californica* | California milkweed | Rubber,resin,fiber | Leaves | 8.0 | 3.0 | (21) |
| *A. erosa* | - | Rubber,resin,fiber | Leaves | 9.1 | 2.5 | (21) |
| *A. galioides* | Horsetail milkweed | Rubber,resin,fiber | Whole | 6.0 | 1.5 | (21) |
| *A. latifolia* | Broadleaf milkweed | Rubber,resin,fiber | Leaves | 7.0 | 3.8 | (21) |
| *A. mexicana* | Mexican whorl-ed milkweed | Rubber,resin,fiber | Whole | 9.0 | 1.5 | (21) |
| *A. subulata* | Desert milkweed | Rubber,resin,fiber | Stems | 14.0 | 5.2 | (21) |
| CHENOPODIACEAE | | | | | | |
| *Atriplex canescens* | Fourwing saltbush | Biomass | Whole | 3.6 | 0.5 | (31) |
| *A. lentiformis* | Big saltbush | Biomass | Whole | 5.0 | 0.2 | (31) |
| *Sarcobatus vermiculates* | Greasewood | Biomass | Woody stems | 3.1 | 0.1 | (32) |
| COMPOSITAE | | | | | | |
| *Artemisia tridentata* | Big sagebrush | Biomass | Whole | - | 0.6 | |
| *Chyrsothamnus linifolius* | Spreading rabbitbrush | Biomass | Trimmed trunk | - | 1.0 | (17) |

| | | | | | | |
|---|---|---|---|---|---|---|
| C. nauseosus consimilus | Rubber rabbitbrush | Rubber, resin, biomass | Trimmed trunk | 3.9 | 2.0 | (17) |
| C. nauseosus pinifolius | Rubber rabbitbrush | Rubber, resin biomass | Trimmed trunk | 4.0 | 3.0 | (17) |
| C. nauseosus frigidus | Rubber rabbitbrush | Rubber, resin biomass | Trimmed trunk | 16.6 | 1.9 | (17) |
| Encelia farinosa | Brittle bush, Encienso | Resin | Leaves | 18.0 | 0.2 | (31) |
| Grindelia squarrosa | Tarweed | Resin | Whole | 13.1 | 0.5 | (21) |
| Haplopappus laricifolius | - | Rubber, resin | Whole | 15.2 | 1.8 | (31) |
| H. nanus | - | Rubber, resin | Whole | 9.6 | 6.7 | (31) |
| H. spinulosus | - | Rubber, resin | Whole | 5.6 | 0.3 | (32) |
| Hymenoxys odorata | Bitter rubberweed | Rubber | Whole | - | 2.0 | (21) |
| Parthenium argentatum | Guayule | Rubber | Whole | 11.1 | 4.6 | - |
| CRUCIFERAE | | | | | | |
| Lesquerella fendleri | Bladderpod | Oilseed | Seed | (28% oil, | 22% protein) | (24) |
| CUCURBITACEAE | | | | | | |
| Cucurbita foetidissima | Buffalo gourd | Oilseed | Seed | (34% oil, | 32% protein) | (25) |
| ERICACEAE | | | | | | |
| Xylococcus bicolor | Manzanita, Woodberry | Resin, rubber | Whole | 20.3 | 1.0 | (26) |
| EUPHORBIACEAE | | | | | | |
| Euphorbia lathyris | Mole or Gopher plant | Resin | Whole | 13.3 | 0.2 | (32) |
| Jatropha sp. | - | - | Whole | 9.9 | 0.5 | (31) |

TABLE 3. (Cont'd)

| Family, genus, species | Common name | Suggested utility[1] | Plant part | Extraction data: Resin, % (acetone extract) | Extraction data: Hydrocarbon fraction[2], % | Reference |
|---|---|---|---|---|---|---|
| FOUQUIERIACEAE | | | | | | |
| *Fouquieria spendens* | Ocotillo, Coach whip | Resin | Bark | 18.1 | 0.4 | (31) |
| LEGUMINOSAE | | | | | | |
| *Prosopis velutina* | Mesquite | Biomass | Whole | 11.0 | 0.4 | (31) |
| POLYGONACEAE | | | | | | |
| *Rumex hymenosepalus* | Canaigre, Wild rhubarb | Tannin | Root | (11.2-35.3% tannin) | | (29) |
| ZYGOPHYLLACEAE | | | | | | |
| *Larrea tridentata* | Creosote bush | Resin | Leaves | 23.3 | 0.6 | (31) |

[1]See Table 2 references for earlier discussions on utilization of these or related species.

[2]Plant products extracted with benzene following exhaustive acetone extraction. Usually polyisoprenes but sometimes contaminated with hard waxes.

## Productivity

Crucial to low-intensity management of arid lands is an estimate of the potential productivity of arid lands. Studies indicate a potential for relatively high yields (6,7,16,18). Estimates of biomass present in mature native stands of a few arid land plant species are given in Table 4.

Although data is meager, it does indicate high yield potential for some plant species in favored sites. If the standing biomass yields for rabbitbrush and greasewood reported in Table 4 could be achieved in a 10-year cycle, they would represent a substantial resource. Rabbitbrush can potentially equal Guayule in total resin and rubber production. Because of its short growth cycle, the arid land milkweed (Asclepias latifolia) appears to offer high potential botanochemical yields. The millions of hectares of under-utilized arid and semi-arid lands in the western U.S. indicates a very large potential for fuel and materials production.

## Technique

Also crucial to low intensity management of arid lands is a consideration of relevant techniques. The basic idea is to apply management techniques borrowed from silviculture, range management, pasture management, and other types of exploitation of non-cultivated land. Aspects of the crop production systems that relate to management techniques are illustrated in Figure 3. The subsystem's goal is to provide, in an environmentally sound way, a maximum of plant produce of the desired chemical composition at minimum cost.

If existing native stands (of rabbitbrush, in certain U.S. arid regions, for example) can provide a basis for beginning botanochemical production, then establishment of PMC systems will be greatly facilitated. Produce harvested from native stands could justify the cost of primary botanochemical extraction (or at least of those portions of the facility involved in processing residues) plants and provide income to land owners for reestablishment and improvement of the crops. Depending on the particular plant species, natural regeneration after harvest can be achieved through such devices as :

1. clipping of plants above ground level to allow sprouting and regrowth from roots,
2. alternate clear-cutting in narrow strips so that plants can easily spread or reseed themselves back into the cut over areas,
3. selective harvesting to leave seed producing plants standing, or
4. combinations of these techniques.

TABLE 4. Estimated Yields and Fuel Values for Representative Arid Land Plants

| | | | Quantity, in select high yielding wild stands | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Extractives[1] | | |
| Genus, species | Common name | State where grown | Average plants dryweight, Kg | Density of plants, #/ha | Biomass, dry tonne/ha | Fuel Value, GJ/ha | Resin, Kg/ha | Hydrocarbon fraction, Kg/ha | Reference for biomass data |
| *Artimisia tridentata* | Big sagebrush | WY | 15.9 | 1316 | 20.9 | 410 | - | 125 | (16) |
| *Aselepias latifolia* | Broadleaf milkweed | AZ | 0.025[2] | 430500 | 10.8[2] | - | 760[2] | 410[2] | (21) |
| *Atriplex canescens* | Fourwing saltbush | UT | 33.6 | 292 | 9.81 | 186 | 353 | 49 | (16) |
| *Chrysothamnus nauseosus* | Rubber rabbitbrush | UT | 29.0 | 2632 | 76.3 | 1540 | 3052 | 2289 | (16) |
| *Larrea tridentata* | Creosote bush | NM | 1.8 | 5767 | (0.3 - 4.6)[3] | - | - | - | (30) |
| *Sarcobatus vermiculatus* | Greasewood | UT | 44.8 | 2174 | 97.4 | 1920 | 3019 | - | (16) |

[1]Calculated using resin and hydrocarbon fraction values from Table 3.

[2]Leaf weight only, stems were not included in these calculations because they were low in rubber content.

[3]Range of net productivity (tonne/ha/yr) during the period 1971-1975.

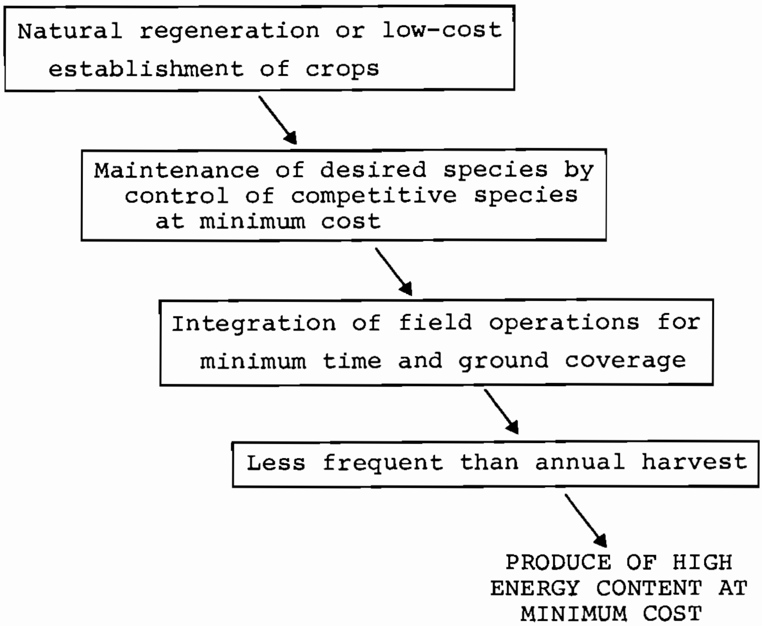



FIGURE 3.

In general, it may be desirable to replace existing native stands with improved varieties (or with combinations of varieties if intercropping or companion cropping is required to maintain soil fertility). Replacement of existing stands with new varieties represents a major cost that would be justified only if the replacement variety regenerates itself for repeated harvests. If applicable, direct seeding represents the lowest cost method for changing varieties. Using nursery or greenhouse produced planting materials would be much more expensive, but might make it possible to establish highly productive clone plantings.

Growing highly adapted native species that tend to increase with disturbance should make control of competitive species (weeds in this context) relatively easy. Inexpensive interventions that may be useful include carefully controlled grazing by livestock, controlled burning as is done in maintaining prairie restoration projects, use of selective herbicides and integration of the complete removal of competitive plants with crop harvest.

Harvest is likely to be the most expensive operation in the envisioned crop management system. Harvest frequency for a selected perennial crop would depend on its growth rate and age-related chemical content, and would vary with growing site. Several of the perennial species (cf. Table 2) may take up to 10 years. Cost can probably be reduced by integrating other crop production operations such as replanting or herbicide treatment with harvest. Ideally, a low intensity management system could involve only one intrusion into a given site per crop rotation period.

## ASPECTS OF PROCUREMENT AND TRANSPORT SUBSYSTEMS

### General

Botanochemical production will require sophisticated business systems for long term procurement of feedstock. Primary processors will not be willing to construct expensive extraction facilities unless adequate feedstocks can be guaranteed over a long enough period at reasonable cost. Moreover, delivery of produce must be scheduled so that processing plants can operate year round without having to invest in excessive storage capacity. Special financial arrangements may be needed by crop producers. Special incentives will have to be provided to induce growers to make long term investments in improving their plantings. Nursery or greenhouse, seed and plant producing, facilities may be needed to provide replanting materials. Furthermore, high transport costs for bulky whole-plant produce has implications for handling, storage, processing plant size and plant site. Special situations have to be dealt with in regard to land ownership in U.S. arid regions.

Thus, because botanochemical crop procurement has so many complications, we believe there is potentially an important role for specialists in land management as intermediaries between botanochemical crop producers and processors. These specialists would set up the requisite business systems and handle procurement in conjunction with primary processors to guarantee long term availability of feedstock.

### Land Ownership

As mentioned in the introduction to this paper, major U.S. companies seem to be modeling their botanochemical crop production efforts on plantation systems. Plantations offer the advantage of centralized control over crop production and its tight integration with processing. Disadvantages of plantations are high capital investment in land and facilities, anti-trust considerations and perceived social undesirability with some states having laws to limit land ownership by large corporations. For these reasons, it would be better to model botanochemical procurement on that of fruit and vegetable processing plants.

Fruit and vegetable procurement is usually through contractual arrangements with individual growers or their cooperatives. Two special situations in the Western U.S. are large areas of public lands administered by the Bureau of Land Management and sizeable Indian Reservations. Thus, the role of intermediary land management specialists might vary, depending on predominant land ownership in a given area.

In general the specialist organization would handle procurement through contracts with growers that would specify critical elements in the production, harvest, storage and transport regimes. Contracts would perhaps specify crop varieties, certain agronomic details, harvest dates, storage methods and quality standards. The intermediary procurement organization would likely have to assume responsibility for supplying planting materials; specialized fertilizers and herbicides; specialized planting and harvesting machinery and other inputs. Another important function of the intermediary would be to provide incentives and methods for improvement of plantings and financial arrangements to make it possible.

Alternative organizations, besides plantations and intermediary procurement companies, for performing these functions might include grower's cooperatives themselves and, for Indian Reservations, tribal organizations. Utilization of public lands for botanochemical production could be arranged through leases to growers. In general, there is no apparent reason why land ownership in U.S. arid regions would have to be restructured to facilitate botanochemical production.

Financing

Another reason for an intermediary between grower and processor might be to make special financing possible for growers entering production or for improving plantings. Growers with long term contracts could probably use crop liens as collateral to borrow money. But, an alternative might be for the procurement organization to advance needed inputs to growers. The intermediary would have to expect a reasonable return on investment but might be able to offer better terms than lending institutions because of his profit from input sales and commissions on feedstock procurement.

Cost of Transport-Processing Scale

Cost of transport seriously constrains the system because it increases significantly as distance to a central processing facility increases. Cost of harvest, on-ranch storage, loading and transport by a contract carrier of baled whole-plant produce to a site 25 km distant is apt to be about $20/ton plus about $0.06 per additional ton-Km for greater distances (2,33). Probably the maximum economic hauling distance would be about 75 Km, allowing two loads per truck per 8-hr shift assuming 1 hr each for loading and unloading.

If it is assumed that one-fourth of a given land area is devoted to botanochemical production and that the average biomass productivity is 500 Kg/ha/yr, then a primary processing plant would not likely exceed a capacity of 220 thousand tons of feedstock per year. This represents little more than one-half the capacity considered in our feasibility assessment based on a midwestern scenario (2).

## ASPECTS OF THE PRIMARY PROCESSING SUBSYSTEM

### Small-Scale High-Technology Processing

Small-scale but high-technology (appropriate technology) processing is essential in making practical use of biomass for fuel and materials because of the high cost of collecting enough feedstock for large-scale processing. Botanochemical plants probably could be dispersed throughout arid land crop regions, scaled and situated to handle perhaps 100,000 tonnes of produce per year.

Primary processing is outlined in block diagram form in Figure 4. Four main operations are indicated:

1. preparation by chipping or flaking of whole-plant produce for solvent extraction,
2. solvent extraction of energy-rich condensed substances,
3. mechanical separation of quality fiber and high protein fractions as appropriate, and
4. densification by pelletizing or briqueting of extractive-free woody residues.

Main potential products of primary processing are extractives, protein rich fractions, quality fiber fractions and compacted residues. Not all these products would be available from all feedstocks; composition, yield and quality of products would vary according to crop species. Adjustment of product quality may also be achieved through processing variations.

The early investigative approach has been to form whole-plant produce into coherent flakes and then solvent extract using equipment designed for soybean oil extraction (2). Countercurrent percolation extractors quantitatively remove extractives at low cost (34). Various organic solvents may be employed depending on desired product composition. If low-molecular weight rubber containing oils are desired as high-quality petroleum substitutes, hexane might be the solvent choice. For total extraction of polyphenols, oils, waxes and hydrocarbon

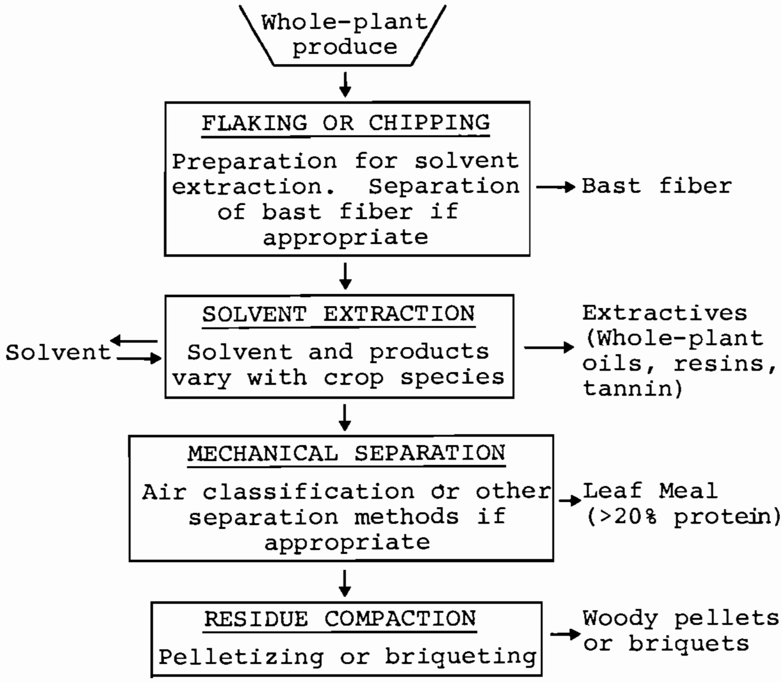



FIGURE 4. Multi-use botanochemical Primary Processing Subsystem

polymers, mixed hexane-acetone or hexane-ethanol solvents could be used. Quality of extractives can be adapted to market needs by choice of solvent and adjustment of extraction parameters.

The mechanical separations of fiber and protein fractions are important processing steps which may feasibly be accomplished by various techniques at various stages of processing. For some crop species, most of the extractives are contained in leaves or roots and extraction of other plant parts might not be necessary. For other species, it would be best to extract whole plants, then use air classification or some other method to separate components.

Compaction of extractive-free residues is included as a processing step (see Figure 4) in the belief that a good market will exist for excess residue not used as a fuel for primary processing energy. Pelletizing or briquetting would lower transport costs for the consumer.

## Processing Costs

Extraction of botanochemicals is a very similar process to extraction of oil from soybeans. Even the mechanical separation has a counterpart in soybean dehulling. Over the past several years soybeans have been processed for $0.022/Kg or less including return on investment. The process envisioned here is so similar that the cost should be similar on the basis of dry matter processed. On an oil basis, cost for extracting whole-plant oils would be about twice that for soybean oil because whole-plants would have only about half the oil content of soybeans.

# ASPECTS OF THE CONSUMPTION SUBSYSTEM

## General

In this discussion, consumption is defined relative to markets for products generated by the primary processor. Consumption, therefore, is synonomous with large-scale secondary processing; i.e. the consumer of quality fiber, extractives, protein meals, and residue pellets might be, respectively, the paper industry, the petroleum industry, the feed industry and the synthetic chemical industry. These industries would do market development and research resulting in product differentiation and convert commodities from the Primary Processing Subsystem to energy, fuels, materials or items for sale through ordinary wholesale and retail distribution channels to tertiary processors or ultimate users.

## Markets for Primary Products

Whole-Plant Oils. Hexane extraction of whole-plant produce could be the source of oils that can potentially become major industrial feedstocks or petroleum substitutes, as illustrated in Figure 5. These oils are like petroleum and the current commercial plant-derived feedstocks, naval stores and tall oil, in that their composition is complex. They are more complex than industrial vegetable oils which consist mainly of triglycerides from seed or plant storage organs; whole-plant oils generally contain an entire spectrum of polar to non-polar lipids. Their detailed composition depends not only on plant species but also on the maturity of the plant and method of extraction or partitioning.

Thus, whole-plant oils are mixtures of a wide variety of valuable chemical intermediates including sterols, long-chain alcohols, rosin and fatty acids, esters, waxes, terpenes and other hydrocarbons. However, the cost of separation is likely to be high. Accordingly, a

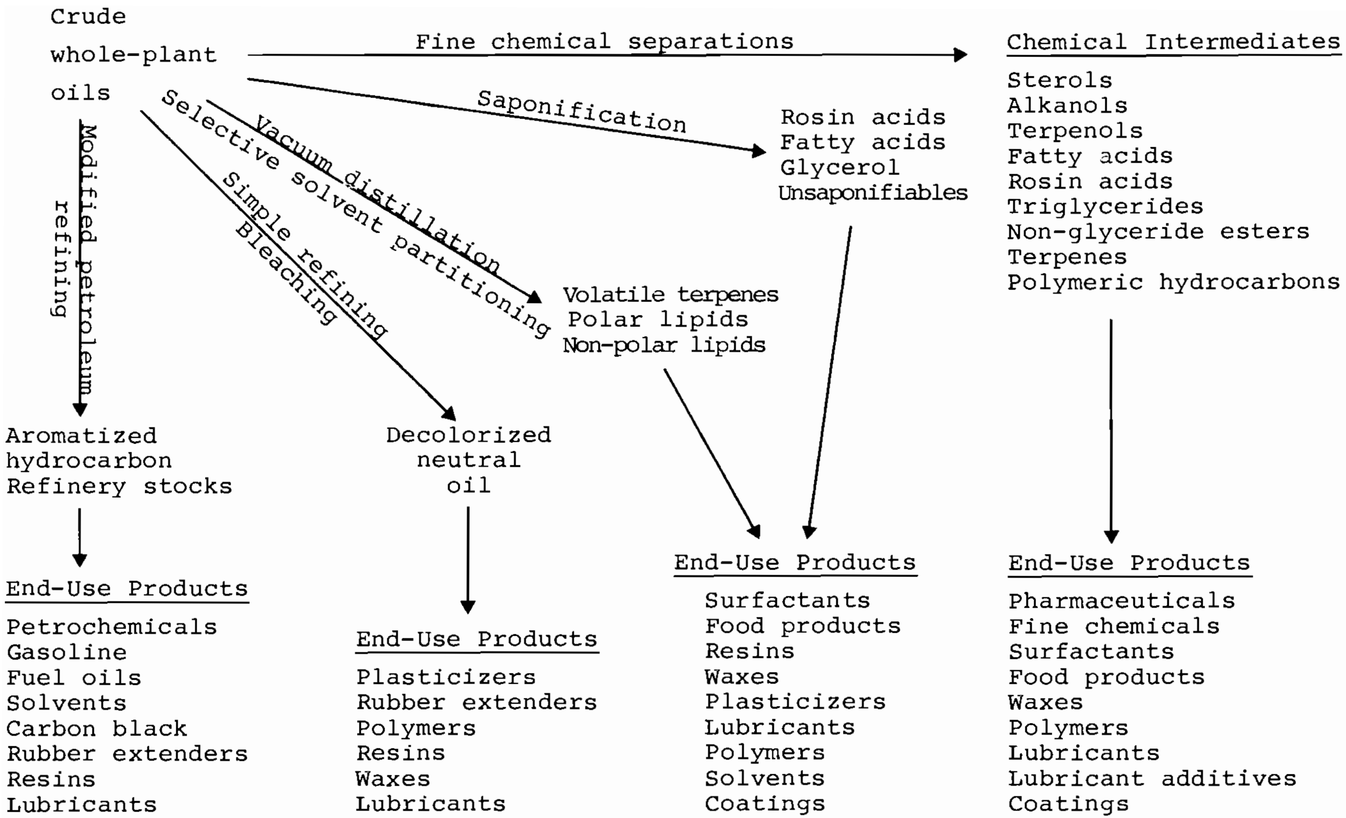



FIGURE 5. Consumption of whole-plant oils

likely strategy is to employ crude separations to obtain marketable fractions for various end uses. Alternatively, the whole-plant oil can be used as about a $CH_{1.8}O_{0.07}$ feedstock for a petroleum refinery. We have documented that petroleum refiners would be willing to purchase whole-plant oils as a substitute crude. Whole-plant oils would be unusually versatile feedstocks for production of the entire range of petrochemicals as well as tall oil, naval store and inedible fat products.

Tannins, Polyphenols. If whole-plant produce is extracted with polar organic solvents (methanol, ethanol or acetone, for example), or with mixed solvents having a polar component (ethanol-mineral spirits, for example), the product is a resin which is rich in the complex mixture of phytochemicals referred to as "polyphenols". Polyphenols can economically be separated from the less-polar lipid fraction of a resin (whole-plant oil) by partitioning between a non-polar and an immiscible highly-polar solvent (hexane and 90% methanol, for example). Moreover, at least one of the arid land plant species, wild rhubarb (Rumex hymenosepalus), of Tables 2 and 3, is a tannin source. (Tannin is a sub-classification for those polyphenols reactive toward protein). Polyphenols have about a $C_2H_2O$ ratio and thus generally have higher heating values than methanol, but considerably lower heating values than whole-plant oils.

If large volumes of low-cost polyphenols become available, they could become important chemical feedstocks, as is illustrated in Figure 6. However, their composition is species dependent and most have not been characterized. Product and market development cannot begin until crop species have been selected. Conversion to simple phenols might be less sensitive to feedstock variations than alternative routes to utilization.

Commercial tannins and bark extractives from tree species used for lumber and pulp wood have been studied with a view toward expanded industrial utilization (35,36). Tannin-based plywood adhesives and water treatment compounds are commercial products in South Africa. A polyphenol fraction from creosote bush (Larrea tridentata) resin has much potential as a rubber antioxidant. About 30 million Kg/yr of vegetable tanning materials are imported into the U.S. However, most of the uses for polyphenols are today only potential uses.

Protein and Fiber Fractions. Low cost mechanical separation of such products as extractive-free leaf meal is not only critical to the economics of botanochemical systems but is important also because it would return much of the plant's protein to the food production system if used as a feed supplement. Leaf meal of more than 20% protein content could be marketed for animal feed formula-

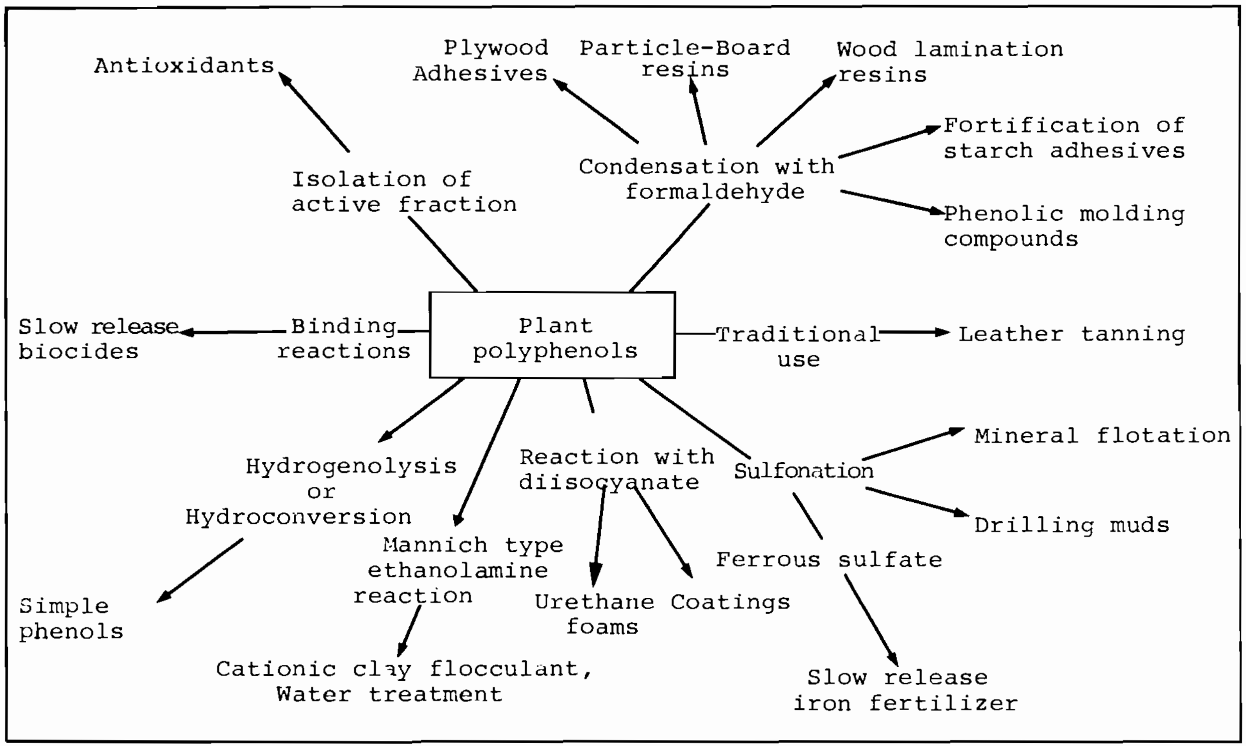



FIGURE 6. Consumption of polyphenols

tion or perhaps even as a food supplement. For crop plant species having good quality fiber, the mechanical separation of that fiber would provide another valuable, readily saleable primary product. Bast fiber would be a high-quality raw material for papermaking.

Many resinous arid land plants of interest for botanochemicals are unpalatable or toxic to livestock. However, solvent extraction would be expected to remove anti-nutritional factors and give a bland product, particularly if polar solvents were employed to remove polyphenols. Nevertheless, considerable effort would be required to prove that such products meet nutritional and safety requirements for approval by the consumer protection agencies of the U.S. government.

Residues. A substantial fraction of the lowest value extractive-free woody residues from primary processing (see Figure 4) would be used as fuel for process energy. Its value as a fuel would be about \$50 per ton (\$3.30/GJ). The balance of the residue, not consumed in primary processing, could be marketed either as a solid fuel or for conversion to liquid or gaseous fuels or as secondary botanochemicals, as shown in Figure 7. Actually, plant residues are potentially as versatile a raw-material base as petroleum or coal for the fuel and chemical industries.

Extractive-free residues are especially attractive microbiological and chemical feedstocks because the flaking and extraction treatments destroy cellular structures and remove lipid barriers to water penetration so that enzymatic and chemical attack of lignocellulose is facilitated.

The cost of saccharifying lignocellulose has prevented it from becoming a practical source of sugars for fermentation. However, new enzyme technology may reduce the cost of sugars from lignocellulose. A pilot-plant has recently been operated to produce up to 310 liters of fuel ethanol per ton of residue (37). Other secondary botanochemicals that potentially can be produced by fermentation, if low cost sugars become available from lignocellulose, include acetone, butanol, and 2,3-butanediol. Fermentation alcohols can be dehydrated efficiently to olefins for polymerization or other uses as chemical intermediates.

Pentosans in plant residues can either be converted to 5-carbon sugars as substrates for some fermentations or to furfural. Furfural is a valuable chemical intermediate with established and potential new uses, and it also can be efficiently converted to hydrocarbons.

Direct anaerobic fermentation of residues, without prior conversion of cellulose to sugar, can be an economical method for making methane for fuel or chemical use.

At least two pilot-plant processes have been operated for converting lignocellulosics directly to liquid hydrocarbon fuels. One of these processes is particularly

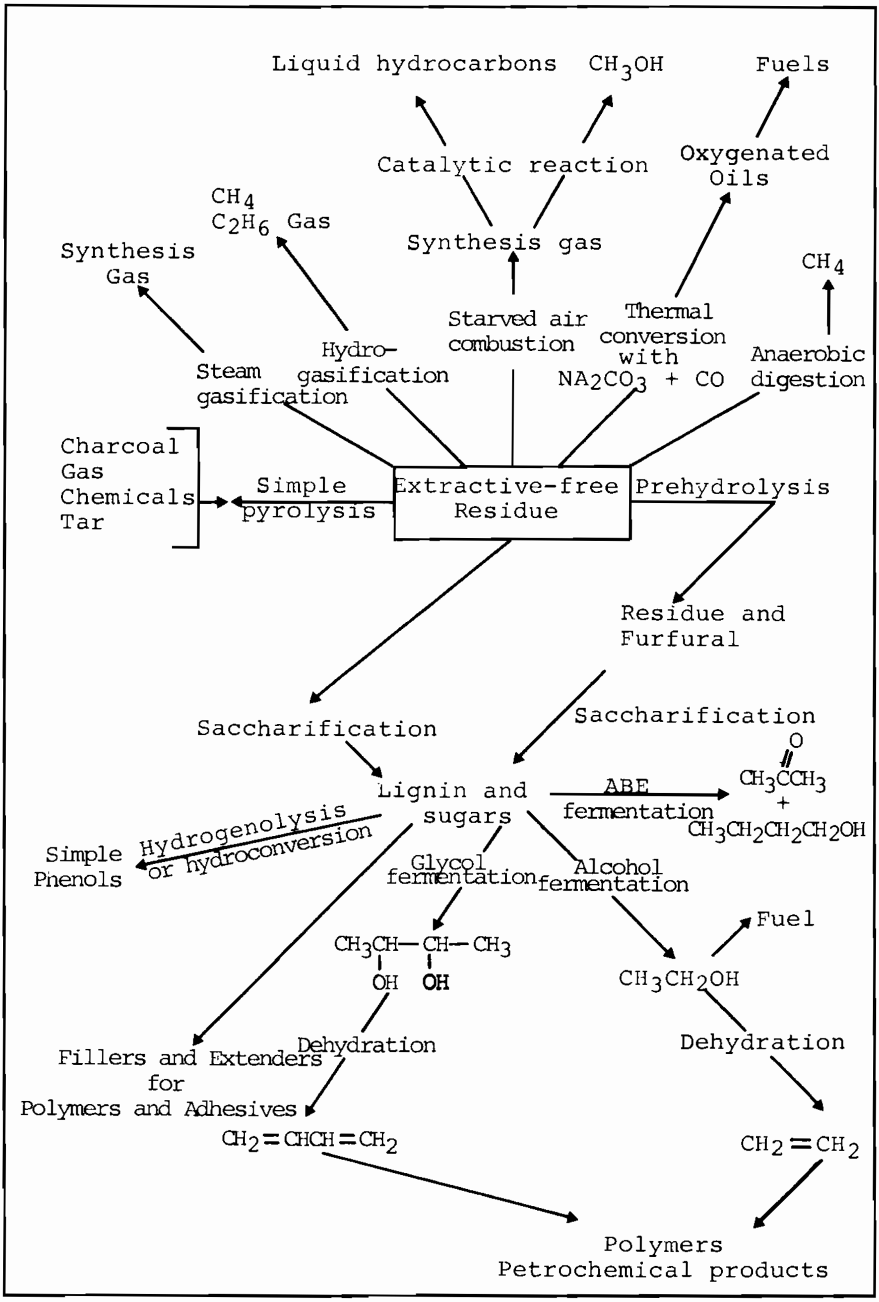



FIGURE 7. Consumption of residues

attractive in that its products are high grade diesel fuel and gasoline, respectively (38). At a residue value of $33/ton (fuel value, July 1979) the materials cost/basis for gasoline was $0.16/liter (at 209 liter gasoline/ton residue).

Extractive-free residues are also attractive feedstocks for synthesis gas for methanol (or ammonia) production yielding nearly 0.5 tonne of methanol per tonne of residue. Methanol can be made from lignocellulosic residues by the thermocatalytic route at a much lower cost than ethanol can be made by the lignocellulose to sugar fermentation route.

There are other competitive uses for extractive-free residues besides its use for fuels or as a raw material for chemical synthesis. It could be converted to an animal feed by fortifying it with nitrogen and increasing its digestability by any of several treatments. The residues could also be used in paper and board making.

## ECONOMICS

In our earlier economic study on botanochemical production in a midwestern U.S. setting, we concluded that it would be highly profitable to both growers and producers providing the following fairly reasonable requirements were met:

1. Crops were developed that contain more than 10% oil on a dry whole-plant basis, where polymeric hydrocarbons, if present, are included as an oil component.
2. The price of produce with the required oil content at the processing site did not exceed by much $50/oven dry ton.
3. Total processing costs were not much above 1.5 times the cost of processing oilseeds on a dry feed basis.

Tables 3 and 4 reveal a few undeveloped wild plant species that may meet the compositional requirements for successful botanochemical production on arid lands. Several others present likely possibilities. Furthermore, it is most likely that genotypes exist within species that have high extractive contents. Certainly there are possibilities for easily developing satisfactory varieties, as pointed out above for rabbitbrush.

The discussion of the Crop Production and Transport Subsystems implied that it would cost less to produce plant dry matter by low-intensity crop management techniques in arid lands than by high-intensity crop management in temperate regions of the U.S.; but, that the lower production cost would be offset by higher collection and transport costs. Thus, whole-plant produce from arid lands can probably be delivered to processing sites at about the same price as whole-plant produce grown in the midwest.

Because processing plants in arid regions might tend to be smaller-scale than in more productive agricultural regions, their processing costs may be somewhat higher. However, in general the processing cost constraint can be met in either region. A trade-off exists between economy of scale and cost of transport.

External to potential botanochemical PMC systems, there are several economic trends favoring their development in the U.S. Public interest in shifting industry toward a renewable resource base has already resulted in governmental incentives favoring biomass fuels, vegetation derived fuel alcohols and Guayule rubber. Social concern for economically depressed rural areas and Indian Reservations also has resulted in further special governmental incentives for establishment of new industries in such non-urban communities. During the last decade, the trend in the U.S. has been for fuels and industrial raw materials to increase in price much faster than agricultural commodities; continuation of this trend relative to fossil fuels favors development of botanochemical PMC systems. Environmental concerns relating to increased consumption of coal also favor the biomass alternative. Finally, there is strong public sentiment for dispersed small-scale energy and basic materials production, i.e. farm, local or regional self-sufficiency in energy (39).

## CONCLUSIONS

It appears highly feasible to utilize arid lands in the U.S. for production of fuels and basic raw materials for industry without interference with the nation's food supply. The first step toward development of PMC systems to accomplish this is to identify suitable plant species. Then varieties with high contents of organic soluble extractives should be developed concurrent with development of low intensity crop management techniques specific for each crop and each arid region. Once consensus has been established concerning crop species, process and market development can proceed.

The California suggestion to begin harvest of desert shrub for fuel, coupled with development and replanting of high-producing resinous varieties, represents an attrative and practical way to begin the establishment of arid land botanochemical PMC systems.

REFERENCES

1. Buchanan, R.A. and Otey, F.H. Multi-use oil- and hydrocarbon-producing crops in adaptive systems for food, material and energy production, In Larrea, Campos-Lopez, E., Mabry, T.J. and Fernandez-Tavizon, S. (eds.) Centro de Investigación en Química Aplicada (CIQA), Saltillo, Coahuila, Mexico, (1979).
2. Buchanan, R.A. and Otey, F.H., Multi-use botanochemical crops: Economic assessment and feasibility study, Ind. Eng. Chem., Prod. Res. Develop., (in press).
3. Diamond Shamrock Co., Plants to be studied as petroleum sources, Chem. Eng. News 56 (44), 21, (1978).
4. Goodyear Tire and Rubber Company, Pine trees supply styrene substitute, Rubber World 179 (4), 21, (1979).
5. Weihe, D.L. and Nivert, J.J., Assessing Guayule's potential: An update of Firestone's development program and economic studies, Presented at 3rd International Guayule Conference, Pasadena, California, April 27-May 1, (1980).
6. Felker, P. and Bandurski, R., Uses and potential uses of leguminous trees for minimal energy-input agriculture, Econ. Botany 33 (2), 172, April-June, (1979).
7. Felker, P., Tree legumes as a source of protein and timber, Symp. Legumes, 21st Annual meeting, The Society for Economic Botany, Bloomington, Indiana, June 15-18, (1980).
8. Lipinsky, E.S. and Kresovich, S., Fuels from biomass systems for arid land environments, In Arid Land Plant Resources, Goodin, J.R. and Northington, D.K. (eds.), International Center for Arid and Semi-Arid Land Studies, Texas Tech University, Lubbock, Texas, July (1979).
9. Theisen, A.A., Knox, E.G. and Mann, F.L., Feasibility of introducing food crops better adapted to environmental stress, National Science Foundation, Washington, D.C., (1978).
10. Lipinsky, E.S., Fuels from biomass: Integration with food and materials systems, Science 199, 644, (1978).
11. Calven, M., Green factories, Chem. Eng. News, 56 (12) 30, (1978).
12. Abelson, P.H., Bio-energy, Science 204 (4398), 6, (1979).
13. Bonner, J. and Varner, J.E., Plant Biochemistry, Academic Press, New York and London, (1965).
14. Keenan, J.D., Review of biomass to fuels, Process Biochem. 14 (5), 9, May (1979).
15. Buchanan, R.A. and Duke, J.A., Potential multi-use botanochemical crops, In CRC Handbook of Biosolar Resources, Vol. II, Photosynthetic Resources, Lipinsky, E.S. and McClure, T.A. (eds.), CRC Press Inc., West Palm Beach, Florida, In press.

16. Van Epps, G., Barker, J., and McKell, C.M., Selection of high producing rangeland shrubs of the Western United States for energy biomass, Unpublished manuscript, Range Science Dept. and Institute for Land Rehabilitation, Utah State University, Logan, Utah, (1980).
17. Hall, H.M. and Goodspeed, T.H., A rubber plant survey of western North America, Parts I, II, III, University of California publication, Botany, 7 (6,7,8), 159-278, (1919).
18. California, Energy systems mapped for California's future, Chem. Eng. News, 56 (19), 15, (1978).
19. Duisberg, P.C., Desert plant utilization, Texas J. Science, 1952 (3), 269, September, (1952).
20. Cruse, R.L., A chemurgic survey of the desert flora in the American southwest, Econ. Botany 3 (2), 111, April-June, (1949).
21. Hall, H.M. and Long, F.L., Rubber content of North American plants, Carnegie Institution of Washington, Washington, D.C., (1921).
22. Beckett, et al., The desert milkweed as a possible source of rubber, USDA Tech. Bulls. 472 and 604, Washington, D.C., (1935) and (1937).
23. Agricultural Handbook 366, Selected weeds of the U.S. ARS, USDA, Washington, D.C., (1970).
24. Gentry, H.S. and Barclay, A.S., The search for new crops III, Prospectus of <u>Lesquerella fendleri</u>, Econ. Botany 16 (3), 206, July-September, (1962).
25. Bemis, W.P., Curtis, L.D., Weber, C.W. and Berry, J., The feral buffalo gourd, <u>Cucurbita foetidissima</u>, Econ. Botany 32 (1), 87 January-March, (1978).
26. Roth, W.B., Buchanan, R.A., Cull, I.M., Swanson, C.L., Duke, J.A. and Bagby, M., Hydrocarbon and rubber producing crops: Evaluation of a 3rd set of 100 U.S. plant species, Presented at the 21st Annual Meeting, The Society for Economic Botany, Indiana University, Bloomington, Indiana, June 15-18, (1980).
27. Hodge, W.H. and Sneath, H.H., The Mexican Candelilla plant and its wax, Econ. Botany 10 (2), 134, April-June, (1956).
28. Dijkman, M.J., Leucana - A promising soil erosion control plant, Econ. Botany 4 (4), 337, October - December, (1950).
29. Krochmal, A. and Paar, S., Canaigre - A desert source of tannin, Econ. Botany 5 (4), 367, October-December (1951).
30. Campos-Lopez, E., Mabry, T.J. and Fernandez-Tavizon, S. (eds.), <u>Larrea</u>, Centro de Investigación en Química Aplicada (CIQA), Saltillo, Coahuila, Mexico, (1979).
31. Buehrer, T.F. and Benson, L., Rubber content of native plants of the southwestern desert, Arizona Agr. Expt. Station, Tech. Bull. 108, (1945).

32. Minshall, W.H., Rubber and resin content of native and introduced plants of Canada, Canada Dept. of Agriculture, Ottawa, Ontario, (1957).
33. Miles, T.R., Logistics of energy resources and residues, In Fuels and Energy from Renewable Resources, Tillman, D.A., Sarkanen, K.V. and Anderson, L.L., (eds.), Academic Press, New York, (1977).
34. Becker, W., Solvent extraction of soybeans, J. Am. Oil Chem. Soc. 55 (11), 754, November, (1978).
35. Hemmingway, R.W., Bark, a renewable resource of specialty chemicals, Symp. Chemicals from Renewable Resources, W.R. Grace and Co., Columbia, Md., Nov.14, (1977).
36. Pizzi, A. and Roug, D.G., The chemistry and development of tannin-based weather- and boil-proof cold-setting and fast-setting adhesives for wood, J. Appl. Polym. Sci. 22, (7), (1978).
37. Emert, G.H. and Katzen, R., Chemicals from biomass by improved enzyme technology, Symp. Biomass as a non-fossil fuel source, Division of Petroleum Chemistry, Joint meeting of the American Chemical Society and Chemical Society of Japan, Honolulu, Hawaii, April 1-6, (1979).
38. Kuester, J.L., Liquid fuels from biomass, AIAA/ASERC Conference on Solar Energy: Technology Status, Phoenix, Arizona, November 27-29, (1978).
39. Bayh, B. U.S. Senator, Dinner Speech, Mid-American Biomass Energy Workshop, Purdue University, Lafayette Indiana, May 21, (1979).

# 16 Solar Radiation and Its Utilization*

*Rafael Almanza*

## INTRODUCTION

The functioning and economics of devices that employ solar energy depend on solar intensity received on Earth, which is a function of the weather as well as of geographical position. The annual average solar flux received outside the atmosphere is called the solar constant and its value is 1.94 cal/cm$^2$ per min. However, the quantity of solar energy which is received on the surface of the Earth is attenuated by the atmosphere. On a clear day the solar energy reaching the Earth's surface is only about 15% of its original value outside of the atmosphere. This attenuation is due to effects of molecular dispersion by particles smaller than the length of the solar radiation wave(Rayleigh dispersion); by absorption of ozone, oxygen, water and carbon dioxide; by dispersion of dust, smoke and smog existing in the atmosphere; and by absorption by clouds.

For these reasons, the solar radiation incident to Earth is composed of direct radiation and diffused radiation. The direct solar radiation is the solar flux incident onto a surface which has not suffered any change of direction while passing through the atmosphere; diffused solar radiation is the solar flux which has been dispersed in the atmosphere and reaches the Earth's surface without any specific angle of incidence. In Figure 1 the solar spectrum and its absorption due to various gases existing in the atmosphere is shown.

As noted above, the total amount of radiation received on Earth is the sum of the direct and diffused components, and is sometimes called global radiation. Global radiation is measured by a pyranometer (Figure 2); diffused radiation by a diffusometer (Figure 3); and direct radiation by a pyrheliometer (Figure 4). All of these devices function on the basis of a photocell that has to be calibrated according to very exact norms in order to be able to measure the amount of incident solar energy. Such

*Translated from Spanish

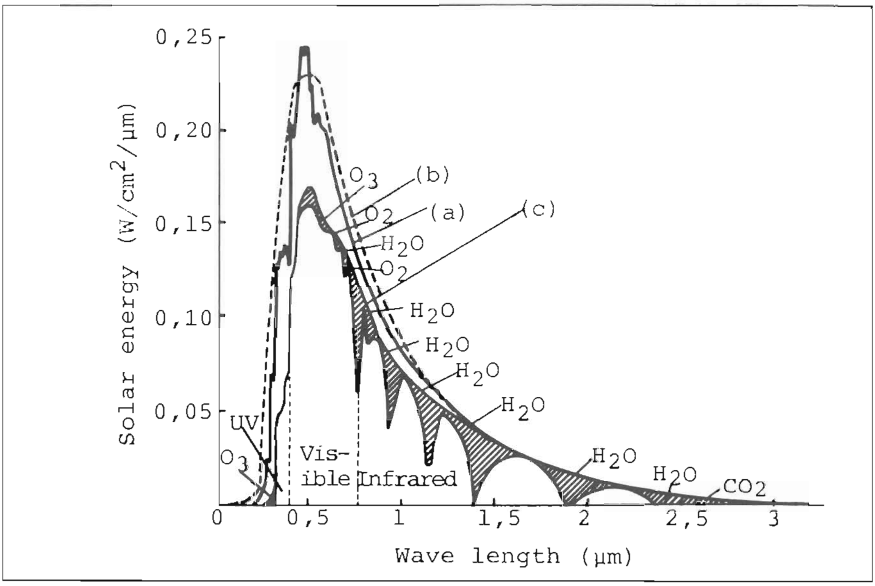



FIGURE 1. Solar spectrum (a) outside the atmosphere; (b) radiation of a black body at 6000° K; (c) at sea level

FIGURE 2. Pyranometer

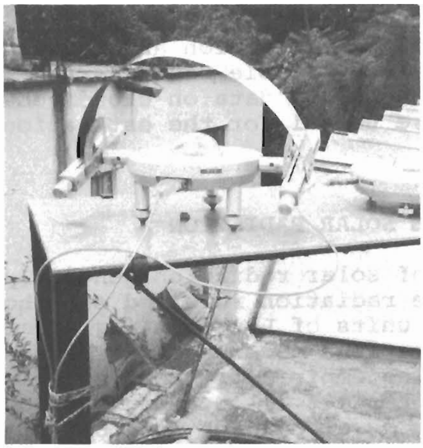


FIGURE 3. Diffusometer

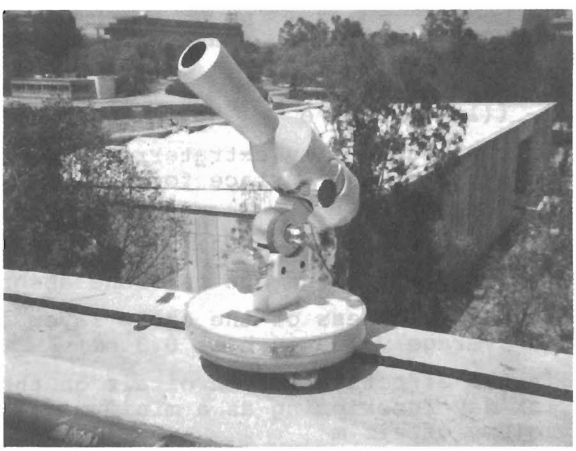


FIGURE 4. Pyrheliometer

equipment is expensive and in order to register and process the data an additional device is necessary.

Because of the expense and difficulty of usage of measurement equipment, attempts have been made to estimate (instead of measure) solar radiation by means of climatological data such as temperature, humidity, hours of insolation, pluvial precipitation and rainy days. These data generally are available for several decades all over the world. In addition, data on cloudiness sometimes are available and are useful for the estimation of solar radiation.

## ESTIMATING TOTAL SOLAR RADIATION

Estimates of solar radiation generally are made on the basis of the radiation received on a horizontal plane and reported in units of Langleys (lg) ($cal/cm^2$) per day.

There are various models to estimate solar radiation, the majority being empirical. Most existing models have a precision of ±5 to ±10% (1). Among the most important models are those developped by Anstrom (2), Fritz (3), Page (4), Black (5), Sivkov (6), Sabbagh (7), Birlow (8), Liu and Jordan (9), Goldberg and Klein (10), and Jeevananda (11).

These models utilize various types of meteorological parameters. The method of Liu and Jordan, for instance, indicates the monthly average radiation as follows:

$$\bar{H} = \bar{K}_0 \bar{H}_0$$

$\bar{H}_0$ being the extraterrestrial radiation on a monthly average over a horizontal surface, and $\bar{K}_0$ an empirically obtained value.

The model due to Goldberg and Klein gives the radiation as follows:

$$G = \frac{H_0}{2} \{(1 + e^{-m^*R})\ e^{-m^*(\alpha_{03}x + \tau)} + 0.1\}Fc$$

where $H_0$ is the total daily extraterrestrial radiation on a horizontal surface for wave lengths less than 2 800 nm.

$R$ is the dispersion coefficient of Rayleigh, 0.104

$\alpha$ is the coefficient due to ozone absorption, 0.045

$x$ is the thickness of the ozone layer (one takes an average value such as 0.3 cm)

$m^*$ is the effective volume of air on the particular day functioning as a minimum value of the volume of air m

$\tau$ is the opacity plus the albedo effect

$Fc$ is the correction for cloudiness

$$m^* = 0.346 + 1.011\ m + 0.0786\ m^2$$

$m$ = secant Z at noon

$Z$ zenithal angle

The Sabbagh model estimates radiation as follows:

$$H = 1.53\ K \exp\{\phi\ (D - R^{1/3}/100 - 1/T_{max})\}$$

or

$$= 1.53\ K \exp\{\phi\ (D' - R^{1/3}/100 - 1/T_{max})\}$$

where $\phi$ is the latitude of the site in radians

$D$ is the ratio of average hours of real insolation with respect to noon time

$D'$ is the ratio of real insolation hours with respect to the length of the day

$R$ is the relative humidity in percent

$T_{max}$ is the average maximum temperature

$K$ is the latitude factor in g cal/cm$^2$ day, depending on the latitude and the time of the year

In the model by Jeevananda Reddy, the average monthly radiation, $R_t$, on a horizontal surface in cal/cm$^2$ per day appears as:

$$R_t = K\ (1 + 0.8\ s)\ (1 - 0.2t)\ (h)^{-1/2}$$

where $K = (\lambda N + \psi_{ij} \cos\phi)\ 10^2$

$\phi$ = latitude of the site in degrees

$$\lambda = \frac{0.2}{1 + 0.1\ \phi}$$

$N$ is the average length of the day during the month in hours

$n$ is the average insolation hours per day for the month that is being considered

$s = n/N$

$t$ is the proportion of days with rain for the month in question

$h$ is the relative average humidity

$\psi_{ij}$ is given in Table 1

Among the various models available at present, the one developed by Reddy can be applied in Mexico with relative ease since the meteorological data which it requires have been collected in Mexico for several years. Some of the data series cover more than 25 years; the shortest data series cover the last 7 years.

TABLE 1.
$\psi_{ij}$

| (j) Month of the Year | (i) $\psi_1$ (for inland stations) | $\psi_2$ (for coastal stations) | $\psi_3$ (for stations in mountains) |
|---|---|---|---|
| 1 | 1.28 | 1.46 | 1.60 |
| 2 | 1.38 | 1.77 | 1.81 |
| 3 | 1.54 | 2.05 | 2.00 |
| 4 | 1.77 | 2.15 | 2.17 |
| 5 | 2.05 | 2.05 | 2.25 |
| 6 | 2.30 | 2.05 | 2.26 |
| 7 | 2.48 | 2.10 | 2.24 |
| 8 | 2.41 | 2.17 | 2.20 |
| 9 | 2.36 | 2.14 | 2.10 |
| 10 | 1.73 | 1.96 | 1.92 |
| 11 | 1.38 | 1.60 | 1.74 |
| 12 | 1.17 | 1.43 | 1.60 |

Using Reddy's model, 12 maps were constructed for monthly averages, and one map with an annual average (12). In the annual map it can be observed that the regions with the highest degree of insolation are those of Sonora, Chihuahua and the northeast part of Baja California Norte. There are two other quite well-defined regions with an annual radiation between 450 lg/day and 500 lg/day: one region that comprises the greater part of the Baja California Peninsula, Durango, Zacatecas, Aguascalientes, the greater part of Guanajuato and Northwest Jalisco; and another region that includes part of Puebla and the greater part of Oaxaca. The month in which the greatest quantity of solar radiation is received is June, since more than 700 lg/day are received on a monthly average basis in the northwestern part of the Republic. In Figure 5 the annual average total radiation in the Mexican Republic is shown.

## SOLAR RADIATION STATIONS

The Instituto de Ingenieria (Engineering Institute) has at present five solar radiation stations for measuring the total and diffused components. These stations are situated in Ciudad Universitaria, Federal District; in Cuernavaca, Morelos; in Huemantla, Tlaxcala; in Tonanzintla, Puebla; and in Celaya, Guanajuato.

In Figure 6, one of the stations with a pyranometer and a diffusometer is shown. The data are registered in a system of data acquisition that consists of a micro-

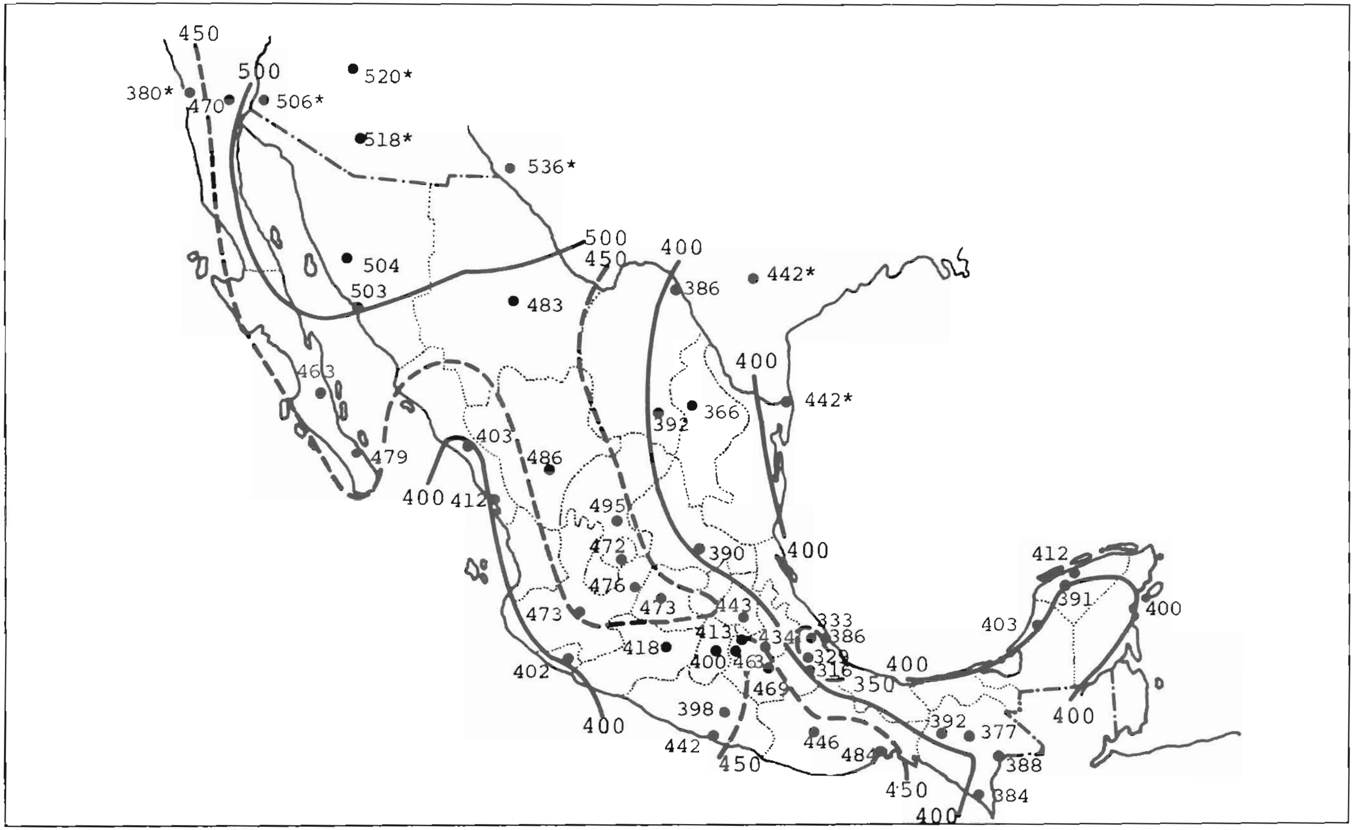



FIGURE 5. Total annual average daily radiation in Langleys/day

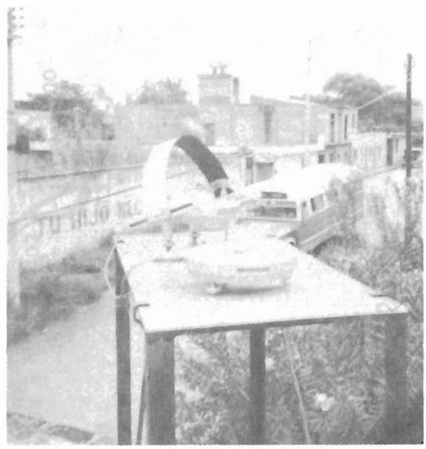


FIGURE 6. Solar radiation station in Cuernavaca

processor with a memory of 1K. It takes in data every 7 seconds, storing them in the memory in order to sum them and to calculate the average every half an hour. This system has a capacity for storing these average data for 7 days; then they are transferred to a magnetic tape and processed by a computer for statistical analysis.

With this type of data, total and diffused solar radiation can be measured, and their difference gives us the direct component. This direct component is important when using solar concentrators (mirrors).

The precision with which these data are registered is less than 5% error.

## ESTIMATING THE DIRECT COMPONENT

The formula developed by Threlkeld and Jordan (13) to estimate the direct component on a clear day on the surface of the Earth is as follows:

$$I_D = \frac{A}{\exp\ (B/\sin\beta)} \quad \text{in W/m}^2$$

where A is the apparent solar radiation for air volume equal to 0 (outer space) (Watts/$m^2$)

B is the coefficient of atmospheric extinction

$\beta$ is the solar altitude

The values of A and B vary throughout the year since the content of water vapor and particles in the atmosphere vary during the year; besides, the Earth-sun distance also varies with time. The constants A and B have been obtained at the University of Minnesota (13) for latitudes of 24 to 56 degrees for the Northern hemisphere for the 21st of each month, with the possibility of extrapolating them for lower latitudes.

The data obtained with this method do not give us maximum values of $I_D$, but rather those that are the most representative, on an average, of conditions on clear days throughout the month.

## SOLAR ENERGY APPLICATIONS

Some of the investigations carried out by the Instituto de Ingenieria with relation to the utilization of solar energy could have immediate applications in the arid zones of the country.

In arid regions with high insolation, flat collectors as well as focusing collectors could be employed in order to heat up liquids which could be utilized in various ways, such as generation of electricity and mechanical energy, water heating, drying and solar refrigeration. Another possible application is to use biomass in anaerobic digesters to produce useful gases and solids with organic wastes.

### Generation of Electricity and Mechanical Energy

For five years investigations have been carried out by the Instituto de Ingenieria in the field of generation of electricity and mechanical energy through photothermic processes, using radiation concentrating mirrors which follow the apparent movement of the sun. The first step was the development of a 1Kw system consisting of a collector mirror area of about 28 $m^2$ which has a parabolic cylindrical form with an aperture of 2 m. In the focal axis of the parabola there is an absorbing tube for the solar radiation which has a diameter of 2.54 cm, and on which the collected solar rays are focused by means of the mirrors in order to transform them into useful heat. The absorber tube is made of copper and is covered with a selective CuO film which has the property of high absorptivity of the visible solar radiation and a low emissivity of infrareds, thereby reducing the losses due to radiation. The absorber tube is within pyrex glass tubes in order to reduce losses due to convection and conduction. In this system water vapor is generated at a temperature of 160°C and 3 atm pressure and is directed to a piston motor to which a water pump or an electricity generator can be connected (Figure 7).

FIGURE 7. 1Kw generator

Currently we are working on a more powerful system consisting of a collection area of approximately 500 $m^2$ based on cylindrical parabolical mirrors in which oil circulates through the absorption tubes. The heated oil is directed to a thermally insulated tank which stores it. The hot oil is sent from the tank to a steam interchanger in order to produce superheated steam which will be utilized in a mechanical expander to transform it into mechanical energy.

## Methane Digesters

Another important application is the production of methane gas and fertilizers from organic waste materials through anaerobic fermentation. In addition, the process reduces environmental pollution due to the fact that about 90% of the pathogenic bacteria die and the effluent is odorless (14).

In the Instituto de Ingenieria, digesters that work with cow manure have been developed. At present there is a digester of 15 $m^3$ (Figure 8) which produces about 60% methane gas and approximately 40% $CO_2$, plus traces of Hydrosulfuric acid; the digested sludge is a good fertilizer containing nitrogen, phosphorus and potassium.

This digester is connected to a solar water heater, since the anaerobic bacteria which are involved in the organic decomposition must be maintained at a temperature between 30 and 35°C. The manure is mixed daily with the hot water to feed the digester, so that the percentage of solids is maintained at 8 to 10 percent. Other important

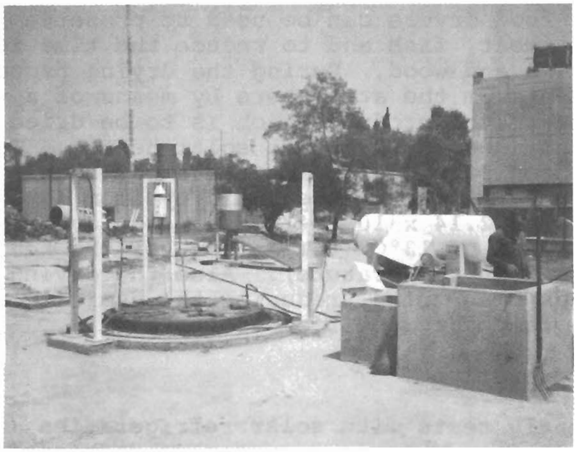


FIGURE 8. Digester of 15 $m^3$

conditions in the anaerobic digestion process are the carbon/nitrogen ratio and the pH (a C/N ratio of 30:1 and a pH of between 6.5 and 8.5 are recommended).

Solar Heaters

Systems that work through natural convection with flat solar heaters with a storage tank (15) are being used more and more in Mexico. The system most commonly used consists of a flat collector of 2 $m^2$ with a thermally insulated storage reservoir of 200 liters.

Depending on position and time of year, the stored water temperature in the tank is from 40°C to 80°C.

In projects carried out with SAHOP, bathrooms with solar heaters have been installed in rural areas (15), especially in regions where fire wood for heating the water is scarce.

Solar Drying

The solar food dryers (15) have a great number of potential applications in underdeveloped countries in order to preserve agricultural products in small rural communities. In some rural areas of Mexico, the peasants dry their seeds by spreading them out over the ground and exposing them to the sun's rays. This makes them vulnerable to insects, rain, dirt and rodents.

Moreover this method of drying takes time. For instance in some places the corn is left for one or two months in the fields, exposed to rodents and other pests.

Solar food dryers can be used to preserve fruits, vegetables, meat, fish and to reduce the time required for drying grains and wood. During the drying process, the air is taken from the atmosphere by means of a ventilator and is sent to the product which is to be dried. The air is previously heated in a flat solar heater. The tests that have been done in the Instituto de Ingenieria for drying corn have lowered the humidity from 19% to 11% with an air flow of 2.14 x $10^{-2}m^3$/sec. and an average temperature difference of 13°C (temperature of the heated air less ambient air temperature). Also the drying of fish (tilapa) has been tried, reducing the humidity from 60% to 20% with a temperature difference of 27°C.

## Solar Refrigeration

Currently tests with solar refrigeration (16) are being carried out. This is a system of refrigeration by absorption with a mixture of ammonia and water, and it utilizes a flat collector for the evaporation of the ammonia.

## REFERENCES

1. Sayigh, A.A.M., Solar Energy Availability Prediction from Climatological Data, Solar Energy Engineering, Academic Press, (1977).
2. Angstrom, A., Solar and Atmospheric Radiation, Quarterly Journal of the Royal Meteorological Society 50, 121, (1924).
3. Fritz, S., Solar Radiation Energy and its Modification by the Earth and its Atmosphere, Compendium of Meteorology, American Meteorological Society, (1951).
4. Page, J.K. The Estimation of Monthly Mean Values of Daily Total Short Wave Radiation on Vertical and Inclined Surfaces from Sunshine Records for Latitudes 40° North-40° South, Process, UN Conference on New Sources of Energy 40, 378, (1964).
5. Black, J.N., Bonython, C.N. and Prescott, J.M., Solar Radiation and the Duration of Sunshine, Quarterly Journal of the Royal Meteorological Society 80, (1954).
6. Sivkov, S.I., Computation of Solar Radiation Characteristics, Israel Program for Scientific Translations Jerusalem, (1971).
7. Sabbagh, J.A., Sayigh, A.A.M. and El-Salam, E.M.A., Estimations of the Total Solar Radiation from Meteorological Data, ISES Conference, Los Angeles, (1975).
8. Barbaso, S., Cappolino, S., Leone, C. and Sinigra, E. Global Solar Radiation in Italy, Solar Energy 20, 5, (1978).

9. Liu, B.Y.H. and Jordan, R.C., A Rational Procedure for Predicting the Long Term Average Performance of Flat-Plate Solar Energy Collectors, Solar Energy 7, 2, (1963).
10. Goldberg, B. and Klein, W.H., A Simplified Model for Determining the Spectral Quality of Daylight and the Availability of Solar Energy at any Location, Proc. ISES Congress, Vol. 1, New Delhi, India, (1978).
11. Jeevananda Reddy, S., An Empirical Method for the Estimation of Total Solar Radiation, Solar Energy 13, 2, (1971).
12. Almanza, R. and Lopez, S., Total Solar Radiation in Mexico using Sunshine Hours and Meteorological Data, Solar Energy, 21, 5, (1978).
13. Threlkeld, J.L. and Jordan, R.C., Direct Solar Radiation Available on Clear Days, ASHAE Transactions Vol. 64, (1958).
14. Methane Generation from Human, Animal and Agricultural Wastes, National Academy of Sciences, (1977).
15. Almanza, R., Fernandez, J.L. and Muñoz, F., Solar Energy Programme at the Institute of Engineering of the National University of Mexico, 14th Intersociety Energy Conversion Engineering Conference, Boston, Mass., (1979).
16. Gutierrez, F., Acondicionamiento de un Refrigerador Comercial de Absorción para Funcionamiento con Captadores Planos, Instituto de Ingenieria (Reporte Interno 9181), (1980).

# 17 The Application of Solar Energy in Arid Lands

*J.I.B. Wilson*

## INTRODUCTION

If we want to answer the question of how much useful energy can be otained from the sun, it is necessary to examine not only the irradiance available but also to discuss a particular application. There is no general answer, because the type of operation (intermittent or continuous), the type of energy required (electrical, thermal, mechanical, etc.), and the competing alternative sources, all affect the answer. For instance, a simple flat-plate collector is quite suitable for producing small quantities of hot water, but a water pump may be driven either electrically by solar cells, or mechanically or electrically by a heat engine. An acceptable energy source should be cheap (including both capital and operating costs), reliable (requiring little down-time for servicing and have a long life) and easy to install and operate if at an isolated site. When comparing solar energy with other resources, it may be a criterion that more energy is delivered by the solar collector than was consumed during its production. (Conventional fossil-fuel-fired electricity generating stations do not satisfy this limitation, but are accepted because of the ease of transmission of electrical energy). Solar energy itself may be cheap, but its collection is not necessarily so, nor is it always available: storage of thermal, chemical, or electrical energy is always possible, but the cost is usually high, which is main reason for pessimism concerning widespread solar energy usage.

A brief description of some types of solar collectors and energy converters will be given, with some mention of those only at a research stage. Then there will follow a discussion of those jobs which can be satisfied by existing solar energy converters despite their shortcomings. Even if solar energy is able to provide only a small fraction of national needs, it will become obvious that this fraction is a most important one for the welfare and improvement of small isolated communities; a need which may otherwise be neglected.

## SOLAR ENERGY AVAILABILITY

Solar radiation is a low intensity energy supply, reaching only ~ 1 kW $m^{-2}$ irradiance under the best terrestrial conditions. Outside the Earth's atmosphere it has a value of 1.4 kW $m^{-2}$ and is of course unaffected by atmospheric scattering and absorption. Thus large collector areas are needed for industrial applications, whatever the efficiency of the energy conversion stage. Countries like Mexico have a high annual mean value of daily irradiance, whereas countries like Great Britain not only receive about one-half this, but more seriously, receive a large proportion of their solar radiation as diffuse and scattered, and have a large ratio of peak-to-mean daily irradiance throughout the year. The solar radiation spectrum varies according to atmospheric conditions, but "air mass one" (AM1) irradiance (which is that provided by the sun through one thickness of standard Earth's atmosphere) may be roughly divided into 51% infrared, 40% visible, and 9% ultraviolet. Radiation data is now collected at an increasing number of sites around the World, but complete characterisation of the diffuse and direct components as well as their spectral contents is not generally available. Several empirical methods allow one to calculate the annual solar irradiance expected at any chosen site, given data from neighbouring sites and with some allowance for local geographical and meteorological conditions. To avoid overestimating the area of collector needed at a particular site to provide the required energy, it is often necessary to make previous on-site measurements of the solar energy.

## PHOTOTHERMAL COLLECTORS

The simplest way of using the sun is to heat up an absorbing object, and to transfer the heat by a working fluid, such as air or water, to the place where it is required. Such "photothermal" collectors can use the whole solar spectrum, converting even the high energy photons to low-grade heat energy (1).

For the lowest range of useful temperatures (<100°C), a simple flat-plate absorber may be used, with insulation and a transparent cover to reduce conduction and convection losses (Figure 1A). Thousands of these heaters are used around the World to provide domestic hot water, and even to provide washing water for industrial uses. Their alignment is not critical, although an inclination some degrees above the latitude of their site is preferred, and they require very little maintenance. Their efficiency falls off almost linearly with the temperature increase produced in the absorber, according to the heat balance

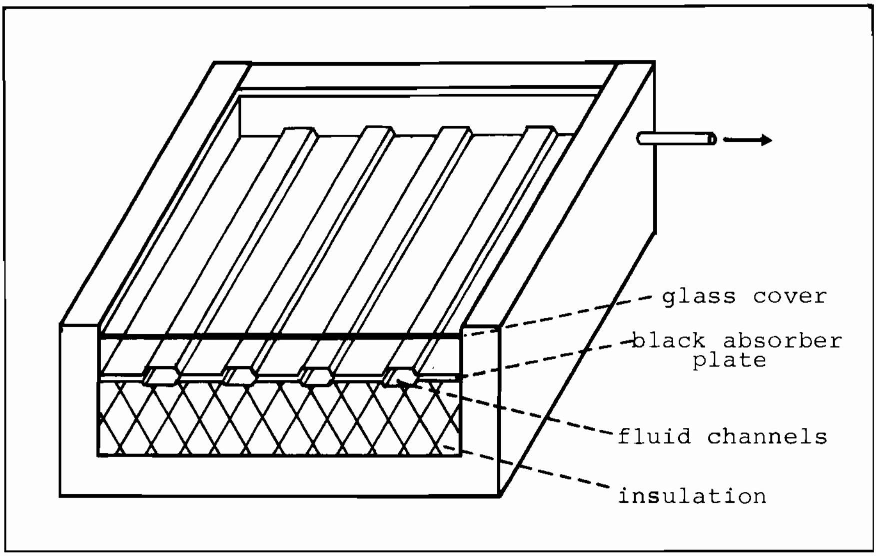



FIGURE 1A. Schematic cross-section through a simple flat-plate collector

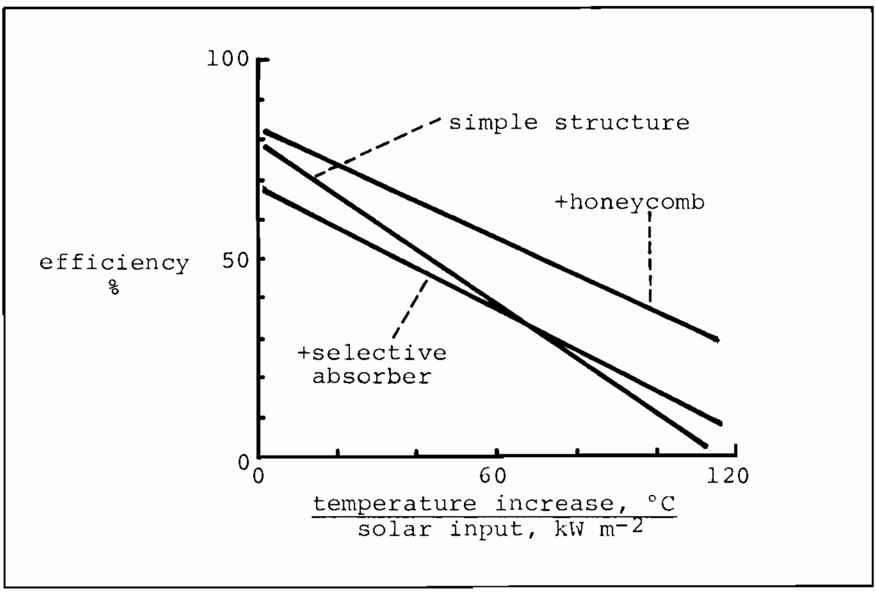



FIGURE 1B. Performance curves of some typical collectors with single glass covers, and the improvements shown equation of Hottel, Whillier and Bliss. This adds all the heat losses in one coefficient, U:

$$\text{efficiency}, \eta = t \,.\, \alpha - \frac{U\,\Delta T}{P}$$

where: $t$ = transmittance of cover,
$\alpha$ = absorptance of plate,
$\Delta T$ = temperature of plate above ambient,
$P$ = solar irradiance.

If the conduction and convection losses are eliminated by using a vacuum between absorber and cover, then a much higher equilibrium temperature is reached, but this is not practical in the flat-plate construction. Nonetheless, appreciable improvement is possible by using more than one cover glass, or by adding a honeycomb of short tubes perpendicular to the absorber to reduce convection currents (Figure 1B) (2). These coatings are less effective absorbers than a "blackbody", but have a much lower infrared emittance than a blackbody. Figure 2A shows that a blackbody at 5500°C (the effective temperature of the sun) emits most of its radiation in the visible and near infrared (below 2 μm), whereas a hot absorber at 700°C emits most energy beyond this region. We should like a selective absorber with high solar absorbance (and consequently a high emittance here), and low infrared emittance (and consequently a low absorbance here). Real coatings can approach this ideal (Figure 2B), but only have a steep cut-off if they are made of several layers. Thus cost will decide whether it is worthwhile reducing radiative losses in this way, and for absorber temperatures below ~200°C it is probably better to retain the high overall absorbance of simple black coatings.

In order to reach the high temperatures suggested above, some form of optical concentrator must be used, either lenses or mirrors. Large lenses are expensive, although plastic Fresnel lenses may be used with small solar cells, and it is mirror concentrators which have attracted most attention. Figure 3 shows some of the many possible configurations, and the temperatures which they can give. The systems with the highest concentration ratio (the ratio of collector area to absorber area) must track the sun's path across the sky, and so are expensive to build, operate, and maintain. (They are only effective with direct sunlight). The compound parabolic concentrator (CPC) developed by Winston, has a large acceptance angle if its concentration ratio is not designed too high, and so need not be tracked (3,4). The linear array of mirrors which make up Fresnel reflectors synthesise a larger mirror, but do not have the wind-loading of a solid curved surface or dish. These collectors may operate with high pressure steam or an organic vapour, and will drive heat engines, as was demonstrated over one hundred years ago (5).

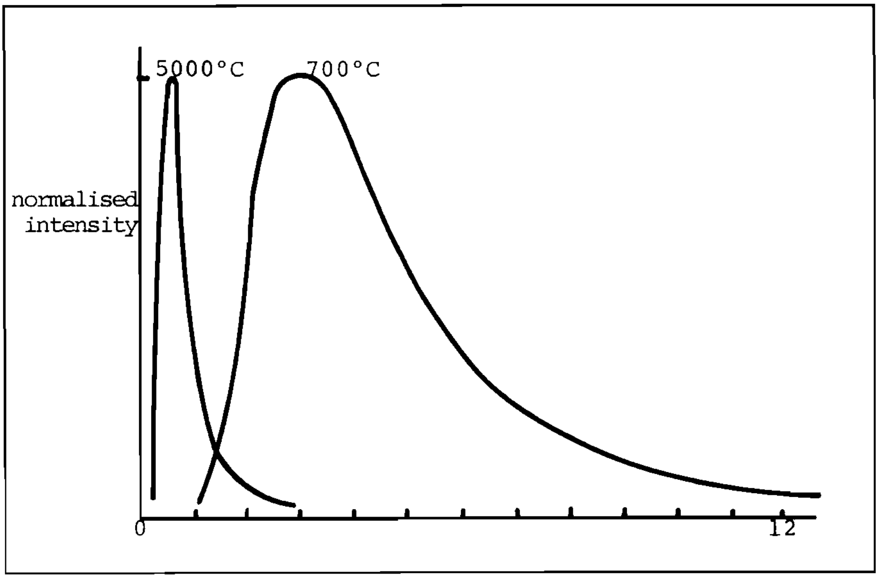



FIGURE 2A. Blackbody radiation from sources at the solar temperature and at the focus of a highly concentrating collector

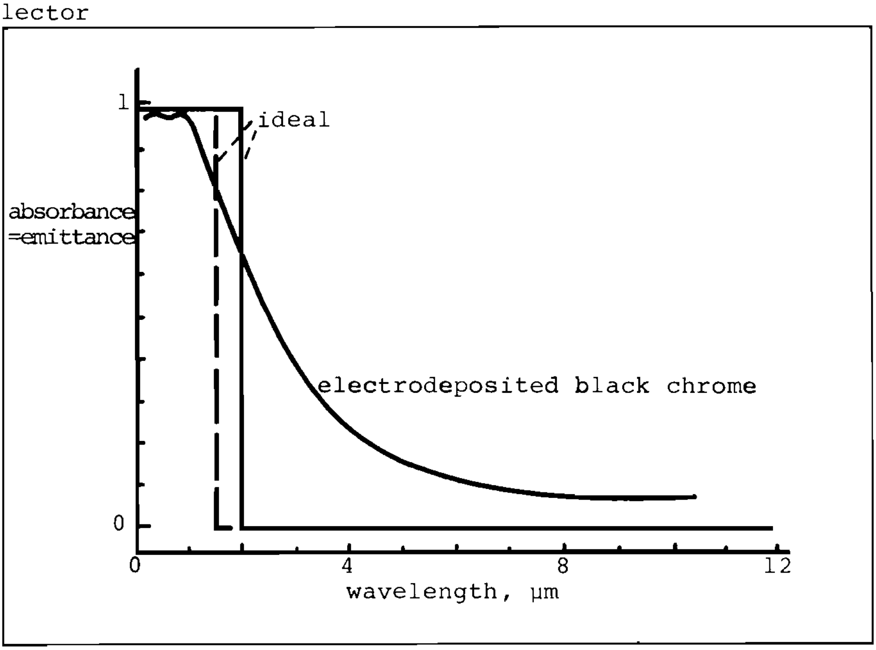



FIGURE 2B. Absorptance and emittance of ideal selective absorbers compared with that of a simple practical coating

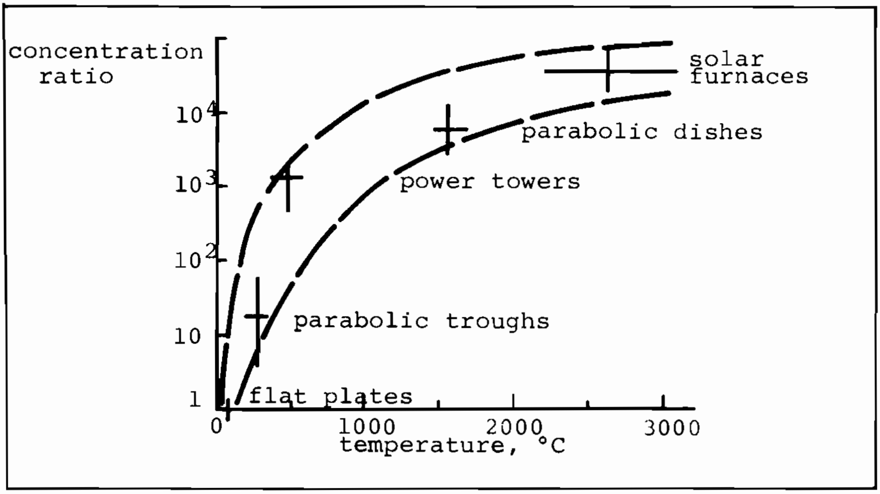



FIGURE 3A. Temperatures achieved by concentrator collectors

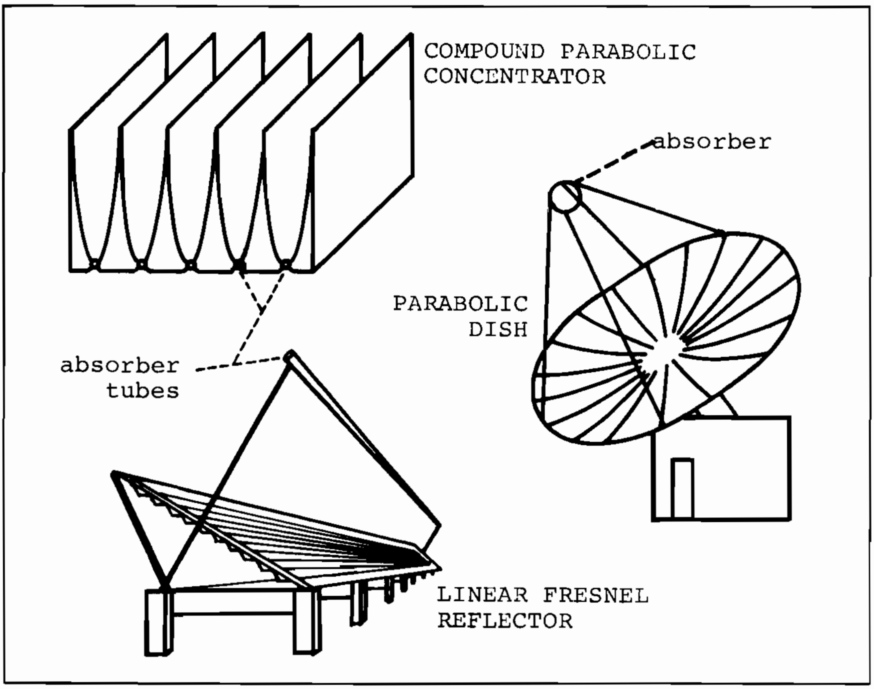



FIGURE 3B. Some practical concentrator collectors. The parabolic dish tracks on two axes, the Fresnel mirror strips track together, and the compound parabolic array is fixed

QUANTUM CONVERTERS

High grade energy may be derived from solar radiation by a "quantum converter", which uses photovoltaic or photochemical action to convert high energy photons directly to electrical or chemical energy without an intermediate thermal process.

Photosynthesis is the most obvious example of a photochemical solar converter, but it is not very efficient because it takes eight photons from two narrow wavebands to fix one molecule of carbon dioxide as starch or sugar (6,7). Most photochemical reactions need ultraviolet photons and so waste most of the solar spectrum. Although "biomass" is a very important fuel source throughout the World, and one capable of more efficient harvesting to meet the demand for a concentrated fuel for transport units, it is unlikely that the arid regions will be useful in this way: the overall energy balance of importing water, nutrients, and pest controllers, and converting vegetation into liquid hydrocarbons may be negative.

If present efforts to decompose water by photocatalysis at a semiconductor electrode are successful on a large scale, then hydrogen may be economically produced as a fuel (8). Unfortunately, those electrodes which are efficient absorbers of solar radiation are also those which decompose readily in aqueous electrolytes. Less efficient solar absorbers such as titanium oxide and related compounds absorb less than 2% of the solar spectrum, but are stable and have produced oxygen and hydrogen (at a platinum counter-electrode) from aqueous solution. Dye sensitisation of these electrodes widens their spectral response, but it appears that the dyes themselves are gradually oxidised and so deteriorate. Many other redox reactions and electrolytes are being examined, and there is some confidence that a useful converter will be developed.

In contrast to these converters, the photovoltaic effect does not involve a chemical reaction and so photovoltaic diodes, or "solar cells", do not suffer from chemical degradation. They are in fact the most efficient producers of solar electricity, with laboratory efficiencies of over 20% for the more complex semiconductors, and commercial efficiencies of 12-14% for silicon p-n cells (9,10). Once again, the most efficient cells are the most expensive, although their cost can be reduced by using optical concentrators to increase their effective area. Before describing their energy losses and possible improvements, here is a brief explanation of how they work. There are three features which are common to all cells:

1. a semiconductor which absorbs solar photons to produce free electrical charges;

2. a built-in electrical field which separates the positive and negative charges before they recombine;
3. metal contacts which transfer the electrical charges to an external circuit, without screening the light.

A silicon p-n solar cell is a larger version of the rectifying diodes used in electronic circuits: the internal electric field appears at the junction between the two types of silicon (each one produced by adding traces of selected elements to ultra-pure single-crystal silicon) (Figure 4). A solar cell can be short-circuited without

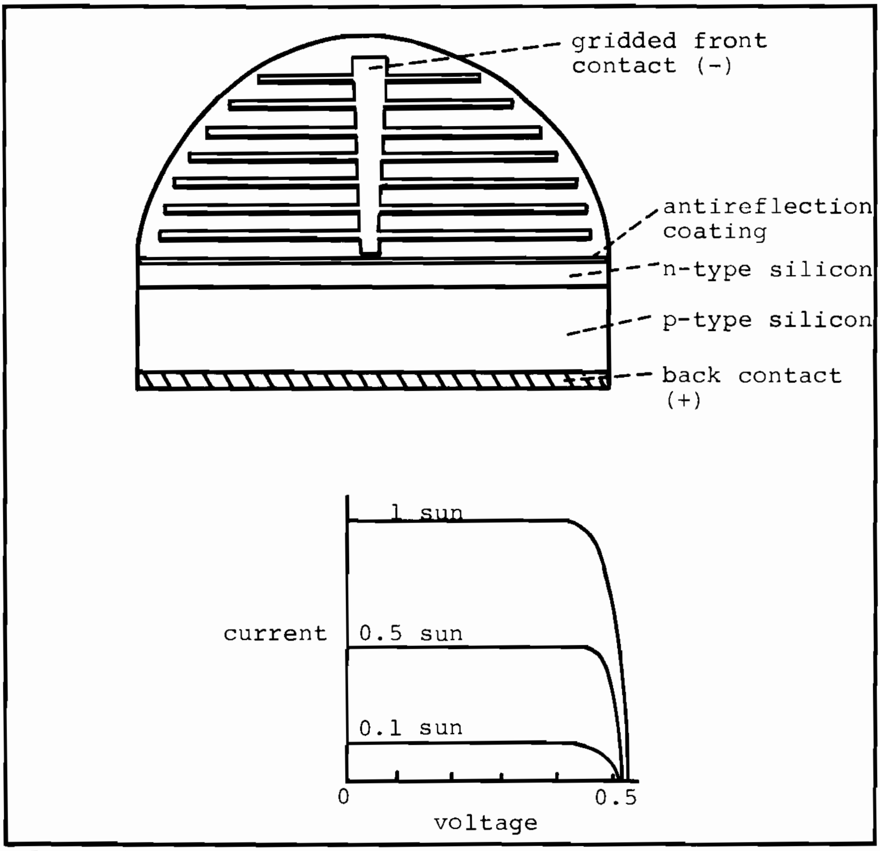



FIGURE 4A. Schematic cross-section of a p-n junction silicon solar cell. The silicon wafer is 0.3-0.5 mm thick, with a diameter of 75-100 mm.
FIGURE 4B. Typical current-voltage characteristics of these cells under different solar irradiances

damage, or it can be connected to a resistive load to operate at up to its open-circuit voltage. A single silicon cell will deliver ~30 mA $cm^{-2}$ short-circuited, under AM1 illumination, or 0.55 V open-circuited, with a maximum power output between these points when a matched load is connected. Higher voltages and currents are obtained by series/parallel combinations of cells. Unavoidable energy losses occur through incomplete use of the solar spectrum: firstly, all photons of energy below a threshold "energy gap" of the semiconductor are not absorbed, and secondly, those much above the energy gap each contribute only an amount equal to the energy gap. Even those photons which are absorbed may not produce electrical charges close to the built-in field, and the magnitude of this field, which sets an upper limit on the voltage delivered, is never as great as the maximum theoretical value (the energy gap). Other losses may be reduced by design and careful processing, with some additional cost.

Other semiconductors may be used in place of silicon, but are less well-advanced in technology, and less abundant. One way of reducing cell costs, and decreasing the energy payback period with some sacrifice of performance, (11,12) is to use thin-films, but only one such cell has reached pilot production stage - the cadmium sulphide-copper sulphide heterojunction cell. This has suffered from degradation losses and a short life-time, but recent developments show that 10% efficient cells may yet be commercially available. An alternative route is to use small 20% efficient gallium arsenide cells with lenses or mirrors to concentrate the sun up to 1000 times, together with active cooling which provides a second energy supply. In order to reach the cost targets set by the U.S. Department of Energy for its solar cell programme it will eventually be necessary to develop new thin-film cells, such as amorphous silicon cells, although intermediate targets may be reached by automated production of cells based on polycrystalline, "solar-grade" silicon (13).

Despite the present high cost of solar cells (from U.S.$5 to U.S.$20 per watt of generating capacity, for a panel of cells, in AM1 sunlight) there are already some applications where they are the best economic choice. Their main advantage over, say, diesel generators is that they can operate unattended for long periods, and will last for 20 years. Some arrays in excess of 200 kW are currently under construction in the U.S.A., and the total world production of solar cells now amounts to some 2 MW per year.

## APPLICATIONS

Most of the current applications of solar energy are on a small scale, and will remain so in the near future. However, they can make an important contribution to local requirements. Water heaters have already been mentioned, but have a poor payback period in high latitudes where they are perhaps most needed! There are various industrial requirements for water at up to 100°C, and in some places these are being satisfied by large arrays of flat-plate solar collectors: for example, wool is washed, milk is pasteurised, food cans are washed, and paper is made using solar-heated water. Large quantities of hot water may be more reliably provided by a "solar pond", as developed in Israel (14). These ponds, about one metre deep, have a dissolved salt concentration gradient which increases towards the bottom. The dense brine remains at the bottom of the pond, even when it is heated by absorption of solar radiation at the blackened bottom, and so is prevented from losing heat by conduction or evaporation to the atmosphere. (These collectors are thus a type of flat-plate collector with suppressed convection losses). Bottom temperatures can exceed 100°C, and heat is extracted by withdrawing liquid from the bottom layers and returning it after passage through a heat exchanger. Vertical walls prevent wind and wave agitation, and the vertical concentration gradient is maintained by adding the required water or salt. Large ponds will store thermal energy over periods of weeks, and operate on a seasonal cycle rather than a diurnal one.

Another application which can use low temperatures is the cooking of food, and many solar cookers have been designed and tested, especially in India where important gains are to be made in conserving dung for a fertiliser rather than using it for a fuel. While small parabolic reflectors will boil water and cook food rapidly, they must be constantly adjusted to face the sun, and are liable either to scorch the food or to let it cool down by winds around the exposed cooking vessel. A simpler construction is the solar oven (Figure 5) - an insulated enclosure with one or more glass covers, and perhaps with added reflectors. This does not need constant attention, although it cannot be sited inside a building. Some modified flat-plate collectors are capable of producing small quantities of steam which can then be circulated around a cooking vessel inside a building, but these have not been widely tested.

A major contribution to an arid region's requirements may be made by solar energy in supplying and purifying water. The relative simplicity and low cost of solar distillation compared with other methods of water purification makes it very attractive (15,16). To vaporise each kilogram of water at 100°C requires at least 2.25 MJ.

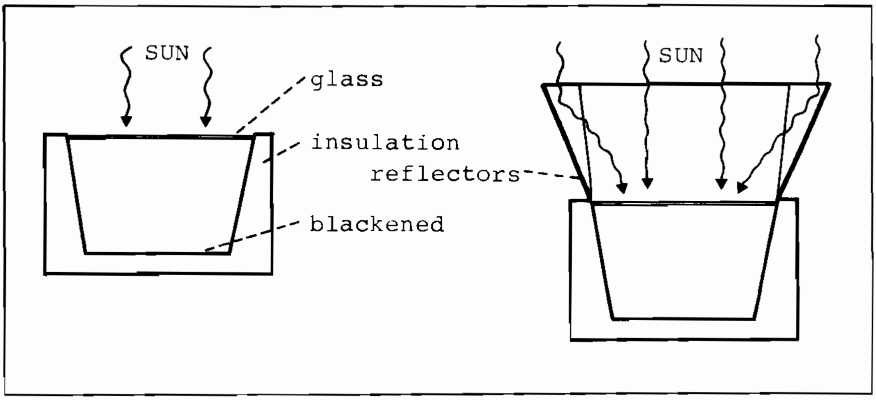



FIGURE 5. Simple solar ovens

Simply-constructed solar stills, (Figure 6A) such as have been used for over one hundred years, can yield 2-5 l $m^{-2}$ $day^{-1}$ of pure water, but these have high energy losses: reflection of solar radiation from the cover, convection and radiation from the impure water to the cover, and rejection of the heat of condensation when pure vapour is liquefied. Their efficiency is only about 30%, compared with over 60% for more complicated stills which reclaim the heat of condensation to pre-heat the incoming impure water (Figure 6B). "Multiple-effect" stills aim to reject the waste liquid at almost the same temperature as it entered (the pilot plant constructed at Sonora, Mexico, in the 1960s yielded 19 l $m^{-2}$ $day^{-1}$), and may even use reduced pressures to improve efficiency. To ensure that even the simple basin stills operate at their maximum efficiency, it is important to avoid dry patches on the floor of the still while using only a thin layer of liquid, and to prevent salt deposits and algae growth. Wick stills, which have enhanced solar absorptance at the absorber-liquid interface by flowing the brine through a fibrous mat, are particularly prone to these difficulties although they are otherwise very efficient. The cost of single-effect solar stills depends on the cost of land and on the availability of local labour and materials: it has been variously estimated at U.S.\$14 $m^{-2}$ (India), U.S.\$35 $m^{-2}$ (Greece).

A greater return for the capital investment is given when stills are hybridised with another application. Although the heated liquid could be used to vaporise a low boiling point organic fluid which could drive a heat engine, the overall efficiency of still and engine would be very low. The Carnot efficiency of an engine operating from a source at 400 K into a sink at 300 K is 25%, and the Rankine cycle efficiency would be even lower. A simpler system which has been on trial for over two and a

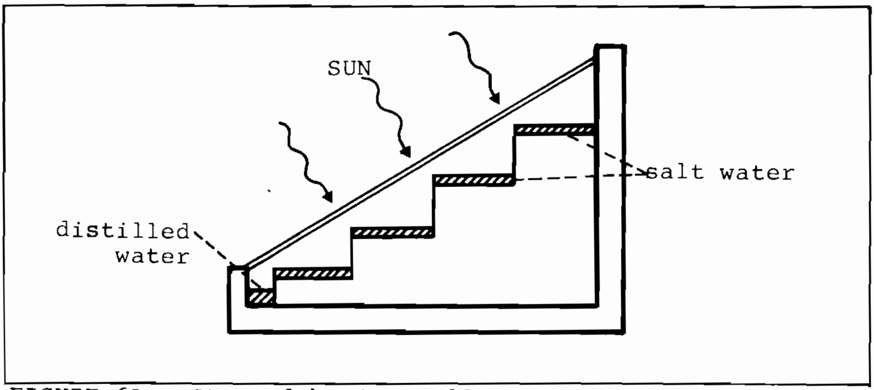



FIGURE 6A. Stepped basin still

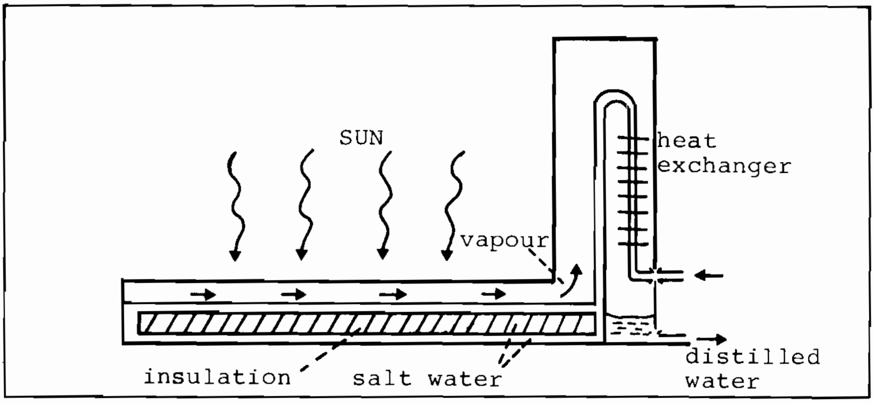



FIGURE 6B. Chimney still

half years is to incorporate the still into the roof of a greenhouse (Figure 7) (17). This has two benefits: the water film filters the solar radiation so that the temperature within the house is reduced, and water is conserved when the growing crops transpire, allowing it to be recycled.

Water pumping in many countries has traditionally been powered by windmills, which use a form of solar energy, but it is equally possible to use radiant solar energy (18,19). The first efforts of engineers to use solar-powered heat engines were in irrigation and well-pumping. Several pioneers in the nineteenth century developed solar hot air or steam engines of a few horsepower (i.e. a few kW), but the first large-scale demonstration was probably the irrigation system of Shuman and Boys in Egypt in 1913 (73 hp, or 54 kW), which used a series of parabolic trough

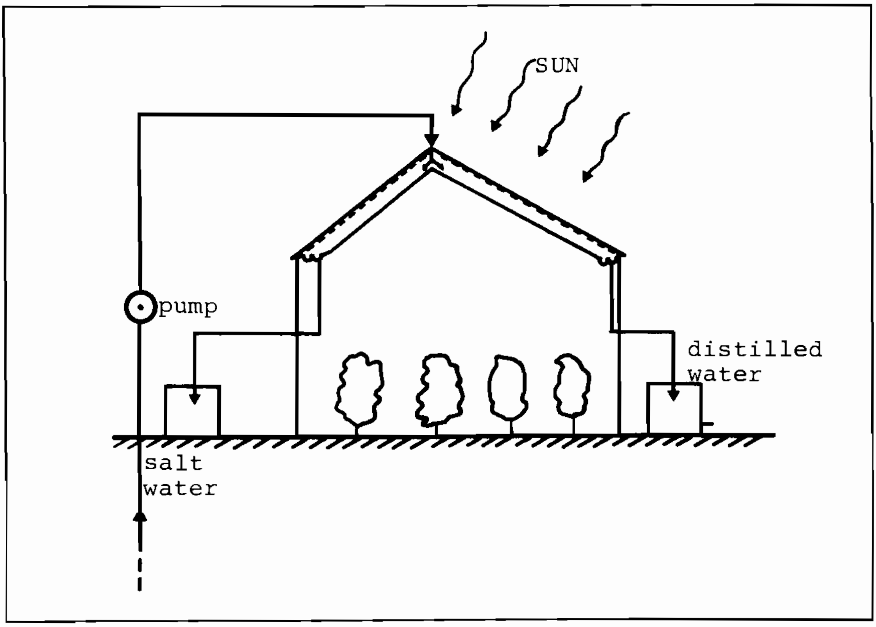



FIGURE 7. Solar still and greenhouse combined

concentrators to produce steam in absorber tubes. In recent years a number of commercial solar pumps have been offered, using either solar cells to drive an electrical pump, or photothermal collectors (flat-plate or concentrator) to drive a reciprocating engine or turbine. The working fluid in the second type is generally an organic compound, although it may be vaporised by water heated in the solar collectors rather than by a direct system. Figure 8 shows the common elements of an indirect system. The organic fluid is vaporised by hot water, flows through a turbine or piston engine, is liquefied, and returns to the evaporator via a re-generator which preheats it from vapour which has yet to be condensed, so preventing too much heat rejection at the condenser. Thus we need a cold sink as well as a hot source. Some designs use intermittent cycling of the working fluid, with radiative cooling at night, but they suffer from low efficiency (20). An important feature of heat-engine pumps is their need for regular maintenance, but if several smaller units are coupled together there is less inconvenience. Two of the biggest installations are in the U.S.A.: the one at Mead, Nebraska, is a 50 kW flat-plate array of photovoltaic cells which drives a 10 hp (7.5 kW) motor to pump 3.8 $m^3$ per minute, with storage cells for a back-up supply; the other near Phoenix, Arizona, uses parabolic trough collectors to vaporise an organic fluid (R - 113) which drives

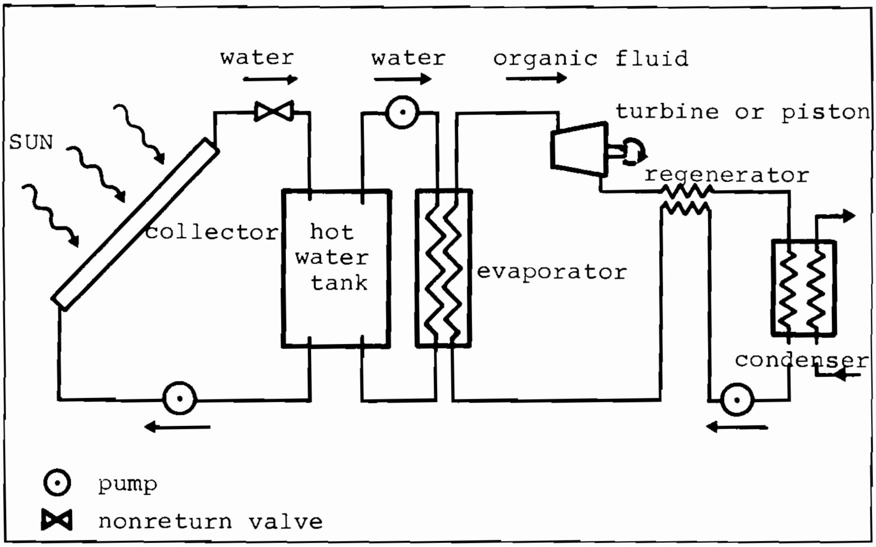



FIGURE 8. The fluid cycles for driving a heat-engine with solar energy. (Evaporator and hot water storage tank may be combined, and the organic fluid may even circulate through the collector to eliminate some heat exchangers).

a Rankine-cycle power unit capable of pumping 38 $m^3$ per minute (50 hp, or 37 kW, pump). Neither system has to pump water through a great height. Smaller units are sold by the French companies, Sofretes, Pumpes Gruinard, and Briau. The latter two companies have installed photovoltaic cell arrays of a few hundred watts to pump water with a head of ~20 m, at a rate of 15-40 $m^3$ per day. The first company, Sofretes, has already installed electrical pumps in Mexico, operated by an organic fluid turbine-generator (the fluid being vaporised by hot water from flat-plate collectors). Finally, there is still some research effort being expended on developing novel, cheap, low efficiency pumps, like the Fluidyne engine (a liquid piston Stirling cycle engine using hot air), the Banks engine (using "nitinol" alloy, which if distorted returns to its original shape on heating above 65°C), and various forms of balanced rotors (which are unbalanced by liquid vaporising and moving from one end to the other). None of these has yet been realised on a useful scale.

On a less sophisticated level, solar heating can be used in a direct application - that of drying crops for storage. Fruit, leaves, grain, and fibres have all relied on "natural" solar drying, but this exposes them to spoilage and animals. Since even grain requires 300-700 kJ $kg^{-1}$ to reduce its moisture content to less than 25%, conventional-fuel-fired heating is very expensive. (One possible way to reduce the capital investment in a solar irrigation plant is to use it later in the year to drive a drying fan). Another situation which calls for a low input of conventional fuel is the production of alcohol fuel from vegetation (e.g. cassava), where the high moisture content can be reduced by solar heating so that there is no net consumption of fuel. Even air of 60% relative humidity can still be used to dry crops spread on a blackened floor. Most designs use a simple tunnel collector to heat air, which is then blown through a cabinet by a fan. Minerals have also been dried by solar heat, an updated version of the old salt-pans used in many countries for hundreds of years.

But apart from heating, solar energy can more appropriately be used for cooling and refrigerating (21). Refrigeration, which can be used either for air conditioning or for food storage, relies on one of four methods:

1. radiation cooling;
2. evaporative cooling;
3. absorption cooling;
4. compression cycle cooling.

Radiative cooling uses a glossy "flat-plate collector" to radiate energy at night through a selective transmitting cover (22,23). Since there is very little radiation <u>from</u> the atmosphere between 8 and 13 μm, it is possible to design an emitter with a selective transparent cover which radiates preferentially in this region, but which will not transmit incoming energy at other wave-bands. No commercial systems are available, but experiments with certain plastic films have shown this technique to be practical. Evaporative cooling is not dissimilar: water is evaporated into the atmosphere, allowing an air-stream to be cooled as it flows into the building. In order to reach the lower temperatures required for food storage, one of the two other processes listed above must be used. They are also able to be used intermittently or continuously, and the absorption cycle does not necessarily need a pump because a solid system is available. The vapour compression system is the most widely used in conventional refrigerators: vapour is expanded through a valve, during which it cools, and is then compressed again before passing through a condenser for the next cycle. The compressor may be driven by a Rankine cycle heat-engine (requiring a high solar collector temperature for high efficiency, as noted previously), but a heat store will be needed if night-time operation is required; alternatively a photovoltaic array and storage battery may be used with an electric compressor. The absorption system is not as mechanically complex, and was the basis of the "Electrolux" system. Figure 9 shows the essential features of this arrangement, when a pump is included. The refrigerant vapour flows from the evaporator (i.e. the chamber which is

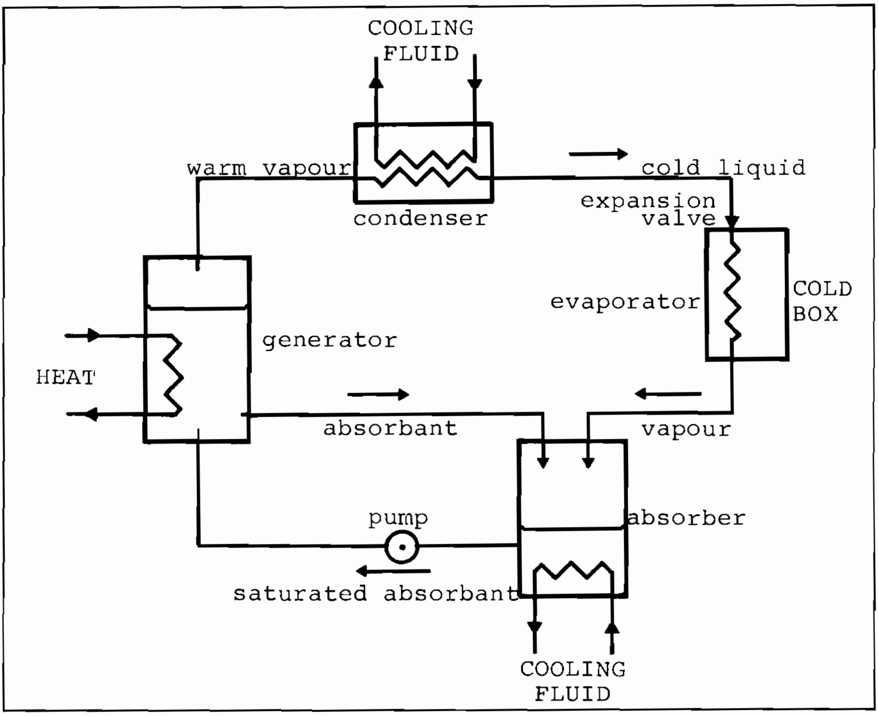



FIGURE 9. Continuous cycle refrigeration system using the absorption method. If heat is provided at 80°C and cooling fluid at 30°C, then 0°C can be produced in the cold box with a coefficient of performance of 0.3

to be cooled) to a chamber where it is absorbed by the second fluid; from here the mixture passes to a heated chamber where the refrigerant vapour is released ("generated"), and from which it returns to the evaporator after being cooled in a condenser and expanded through a valve. The absorbant material is separately returned to the absorbing chamber. Two liquid systems have been widely examined: lithium bromide with water as the refrigerant (needing a generator temperature of 70-90°C), and water with ammonia as the refrigerant (needing a generator temperature of 90-180°C, depending on operating pressure). The solid system of calcium chloride with ammonia as refrigerant operates at ~110°C and allows the generator and absorber chambers to be combined, alternating between night-time absorption and solar generation. It is also less sensitive than the ammonia/water system to changes in generator and condenser temperatures. The coefficient of performance of a well-designed continuous absorption system can be 0.3 to 0.5 (i.e. the net cooling divided by the heat input) but, when combined with the efficiency of flat-plate solar collectors, this falls to 0.1 or less. (This is equivalent to a yield of 6 kg of ice per day per square metre of collector). Intermittent cycles are less efficient, although simpler, because they must reject the heat used to generate the vapour from the absorbant, instead of using it to preheat the next quantity of solution.

It is worth noting that "passive" heating and cooling of buildings can considerably reduce the demands made on these "active" systems. By using earth walls as thermal insulation, overhanging eaves to shade the sun when it is high in the sky, and internal walls with high heat capacity, it is possible to avoid large diurnal temperature fluctuations. Natural convection can also be encouraged by well-sited air passages and double roofs. Trombe walls, and similar structures, are effective in a range of climates. They use a massive vertical wall to absorb the solar radiation which passes through a parallel vertical glass wall. Heat is then passed to the room behind through a series of controlled apertures, often without the need for fans to circulate the air.

When fans are required for air-conditioning it is possible to run them from batteries charged by solar cells. Other electrical requirements are even more suited to solar cell supplies. Telecommunications equipment, which now uses less power than was foreseen during the days of valves (vacuum tubes), often operates for only part of the day. Television receivers for educational services in West Africa (24), telephones (25), VHF direction-beacons, and remote instrument stations have all been powered by small solar cell panels. There have been demonstation installations in some countries for powering whole villages, but while this can be competitive with a diesel generator electrical supply, it is a very large capital project at present day solar cell prices.

## SUMMARY AND CONCLUSIONS

Although improvements are anxiously sought in photochemistry and photobiology, the collection of solar thermal energy and the photovoltaic collector are already highly developed. I have not discussed the types of energy storage which are available, but it is quite possible to store thermal or electrical energy for periods of days. Longer terms are costly for an individual. The technology already exists for the application of solar energy to a range of requirements, and the main problem is the capital cost. Much of present research is into reducing the materials and construction cost of collectors, not necessarily into improving their efficiency. The best systems are those which can be manufactured locally, for they are then more easily repaired than a complex mechanical item imported from another country. No solar energy system will be used despite government incentives unless it is culturally and socially acceptable.

If there is no attractive alternative to solar energy for a particular site, especially with regard to the future when conventional fuels are limited or even more costly than now, then a time-scale must be decided for the various applications. The first priority is to provide the basic requirements of water, cooking, lighting and communication (>1 kWh per person per day), then to use solar energy for food processing, and finally to apply it on a community (e.g. hospitals) or an industrial scale.

Solar energy is not a "second best" resource, and there is already some international prestige in the extent to which it is used in each country. Solar energy can be used today for space- and water-heating, refrigeration and air conditioning, water pumping and purifying, and remote telecommunications.

## ACKNOWLEDGMENTS

I am grateful to Fiona Riddoch and other members of the Heriot-Watt solar cell group for their assistance and for supplying information used here.

## REFERENCES

1. Duffie, J.A. and Beckman, W.A., Solar Energy Thermal Processes, Wiley, New York, (1974).
2. Meinel, A.B. and Meinel, M.P., Applied Solar Energy - An Introduction, Chapter 9, Addison-Wesley, Reading, Massachusetts, (1976).
3. Winston, R., Solar Energy, 16, 89, (1974).
4. Rabl, A., Solar Energy, 18, 93, (1976).
5. Kemper, J.P., Sunworld, 5, 17, (1977) (Pergamon Press for ISES).
6. Hall, D.O., Solar Energy, 22, 307, (1979).
7. Weaver, P.F., Lien, S. and Seibert, M., Solar Energy, 24, 3, (1980).
8. Maruska, H.P. and Ghosh, A.K., Solar Energy, 20, 443, (1978).
9. Hovel, H.J., Solar Energy, 19, 605, (1977).
10. Hovel, H.J., Solar Cells, Vol. II of Semiconductors and Semimetals, Beer, A.C. and Willardson, R.K., (eds) Academic Press, New York, (1976).
11. Harrison, R., Jenkins, G. and Hall, R., Solar Cells, 1, 55, (1979/1980).
12. Riddoch, R. and Wilson, J.I.B., Solar Cells, to be published (1980).
13. Forney, R.G., Conference on Photovoltaic Solar Energy Conversion (C21), 81(UK Section of the Int. Solar Energy Society, London, 1979).

14. Weinberger, H., Solar Energy, 8, 45, (1964).
15. Moustafa, S.M.A., Brusewitz, G.H. and Farmer, D.M., Solar Energy, 22, 141, (1979).
16. Ali Kettani, M., Sunworld, 3, 76, (1979).
17. Bettaque, R., Sun - Mankinds' Future Source of Energy, Proceedings of the ISES Congress, New Delhi, India, Pergamon Press, (1978).
18. Pytlinski, J.T., Solar Energy, 21, 255, (1978).
19. Bahadori, M.N., Solar Energy, 21, 307, (1978).
20. Soin, R.S., Prasad, I.M., Rao, D.P. and Rao, K.S., see Ref. 17.
21. See Ref. 17.
22. Catalanotti, S., Cuomo, V., Pino, G., Ruggi, D., Silvestrini, V. and Troise, G., Solar Energy, 17, 83 (1975).
23. Johnson, T.E., Solar Energy, 17, 173, (1975).
24. Polgar, S., Solar Energy, 19, 201, (1977).
25. Perez, E.J., Del Valle Padilla, J.L., Urbano, A., Servin, E., Romero, H., Proc. 13th IEEE Photovoltaic Specialists' Conference, Washington, D.C., (1978).

# Part IV

# Assessing Technologies and Interdisciplinary Research

# 18
# The Management of Technology: Old and New Perspectives

*Harold A. Linstone*

## I. INTRODUCTION

I will examine fundamental problems which have arisen in the necessary linking of technology with management, i.e., in relating artifact-focused with people-focused activities. It is my theme that these two foci not only use different models, but require different paradigms and perspectives. This does not imply that the technical perspective is of no value in looking at management problems. Rather, it means that this perspective is inherently blind to certain important social and human signals and indicators. The capable manager intuitively knows this and places only modest reliance on such technically oriented input in the decision making process. Here are the words of two effective managers (1):

> R. P. Jensen, Chairman of General Cable Corp.: "On each decision, the mathematical analysis only got me to the point where my intuition had to take over"
>
> J. Fetzer, Chairman of Fetzer Broadcasting Co.: "Walk through an office, and intuition tells you if things are going well."

Further evidence of the inadequacy of the technical perspective is provided by two studies. Green, Newsom, and Jones (2) surveyed the FORTUNE 500 companies to determine the extent of use of nineteen operations research techniques. They included simulation, queuing theory, network analysis, linear programming, factor analysis, statistical sampling, inventory models, Markov chains, regression and correlation, etc. It was found that nine of the techniques were not used at all by 60% or more of the responding organizations and only seven were of frequent use by 25% or more of the respondents.

Balachandra (3) surveyed 103 U.S. firms which emphasize R&D (using R&D expenditures as a criterion) concerning their use of technological forecasting models. The ten techniques listed included simulation, cross-impact analysis, relevance trees, morphological analysis, signal monitoring, trend extrapolation, Delphi, scenarios, expert opinion, and brainstorming. The technique rated "very useful" by the largest number of firms was expert opinion (26%). Brainstorming was second with 14% and the other eight each were less than 7%! For seven of the techniques at least 45% of the firms said they never use them. Of the three most widely used methods - expert opinion, brainstorming, and trend extrapolation - two have a very strong intuitive component.

These findings strongly suggest that improvement in the state-of-the-art is not to be sought along the lines of bigger and better planning models and computer simulations. History provides some hints. For example, as Jay (4) has observed, Machiavelli had a superb appreciation of management. In his book "Management and Machiavelli", he writes:

> "Machiavelli... is bursting with urgent advice and acute observations for top management of the great private and public corporations all over the world".

The point he would make is that Machiavelli uses different paradigms; his perspective of organizational behavior is not at all that of modern organization theorists. The successful manager probably is, and has always been, far ahead of the theorist, uninhibited by scientific rigor and analytic precision.

And, as we shall see, some of our best systems thinkers are also aware of the situation.

## II. WHAT IS WRONG?

Science and technology represent the most successful religion of modern times. From Galileo to the Apollo lunar landing, from Darwin to recombinant DNA, the paradigms of science and technology have yielded dazzling triumphs.

These paradigms include the following:

1. The definition of "problems" abstracted from the world around us and the implicit assumptions that problems can be "solved";
2. Optimization or the search for a "best" solution;
3. Reductionism, i.e., study of a system in terms of a limited number of elements (or variables) and interactions among them;
4. Reliance on data and models, and combinations thereof, as modes of inquiry;
5. Quantification of information;
6. Objectivity, i.e., the assumption that the scientist is an unbiased observer outside of the system he or she is studying;

7. Ignoring the individual, a consequence of reductionism and quantification (e.g., use of averages) as well as non-human objectivity;
8. Time movement seen as linear, i.e., at a universally accepted pace reckoned by precise physical measurement.

A technology and its environment are typically viewed as a system. Systems analysis tools are considered appropriate and the traditional guidelines for analysis apply. Technical impacts are carefully described and where possible, quantified. Benefits and costs are calculated. Frequently, cause and effect modeling is carried out to study the static and dynamic behavior of the variables which describe the system and its environment. Structural models are illustrative of such tools (5). System dynamics modeling and decision tree analysis provide other examples (6:370). At times the models may drive the analysis, i.e., the analyst's modeling background and experience may be instrumental in determining what is analyzed and how. Strong reliance is placed on technical experts as well as technical reports containing empirical data or theoretical models and data. Rationality is assumed to determine decisions, e.g., the alternative with the most favorable benefit-cost relationship will be selected. Figure 1a schematically summarizes the general approach.

The success of this mode of thought and its paradigms has led very naturally to increasing pressure to extend its use beyond science and technology, i.e., to society and all its systems. Organizations become cybernetic systems, utility theory determines preferences, decision analysis provides the key to decision making, policy analysis selects strategies. There is a mathematical theory of war and, of course, "management science". Figure 1b portrays the situation.

Without question the technical perspective is ideal for well-structured problems in science and technology. Why, then, is there deep trouble in relying on it in managing technology or anything else? To answer this question - we examine the eight paradigms listed above in more detail.

## The Problem-Solution View

When we talk about a "problem" we assume there exists a solution. We have been brainwashed in school: a text book presents a problem only if there is a solution (often in the back of the book). It is not pointed out that in the living world every new solution provided by a technology creates new problems. Public health measures cut the death rate but have led to a global population explosion. Introduction of European agricultural techniques in Africa produces food in the short term and desertification in the

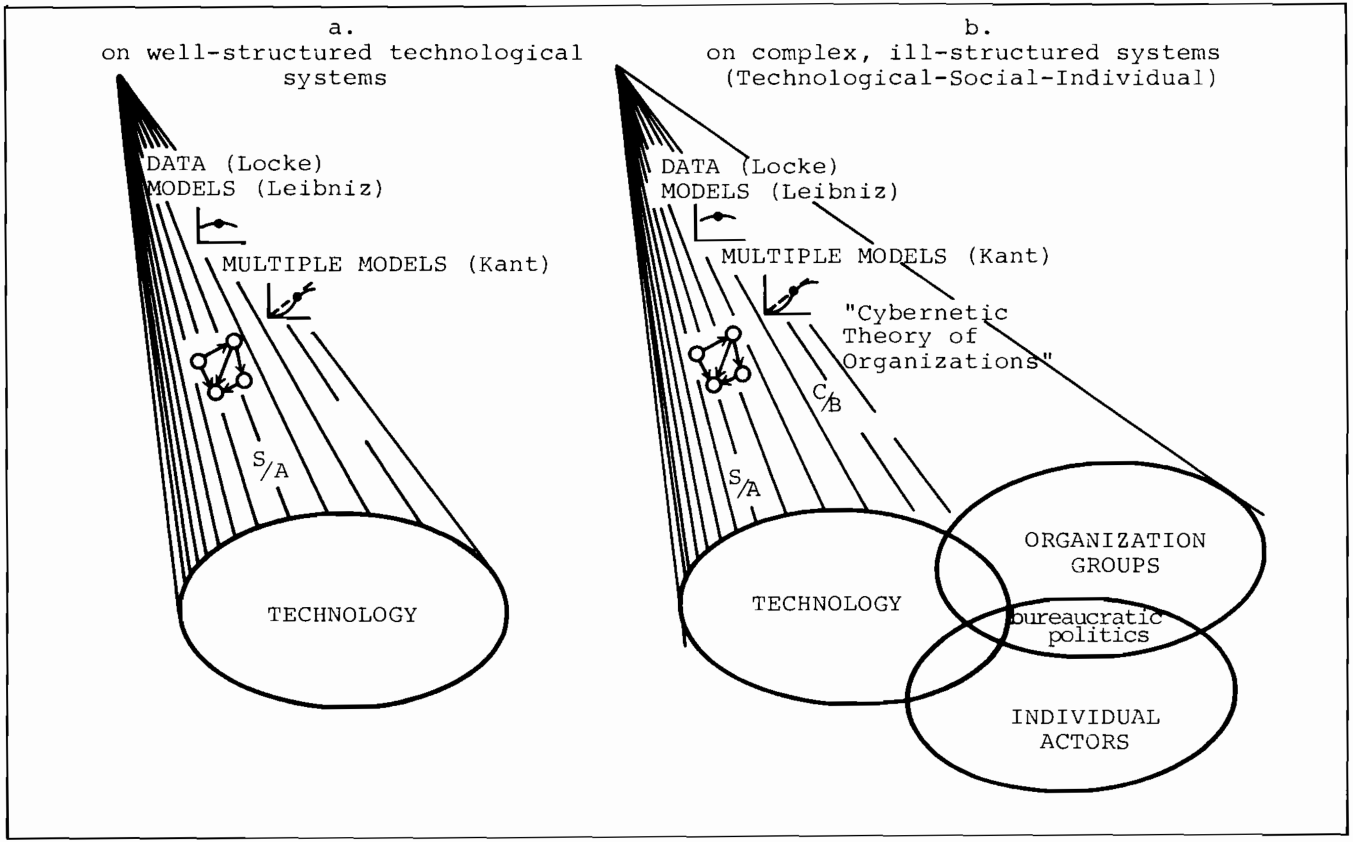



FIGURE 1. The technical perspective

long term (7). It would be more correct to state that we shift problems rather than solve them.

## The "Best" Solution Search

Cost-benefit analysis and linear programming are typical of the search for the optimal solution. It comes as a shock to those nurtured on this perspective that complex living systems have not organized themselves in accordance with this principle. As Holling (8) notes, ecological systems sacrifice efficiency for resilience, or avoidance of failure (the fail-safe strategy familiar to engineers) for survival over failure (a safe-fail strategy). They strive to maximize their options, rather than confine them by selection of the "best" one. They do not "manage" themselves by manacling themselves. Evolution shows that their safe-fail strategy is eminently suited to a world which is inherently unpredictable at certain times.

## Reductionism

Von Foerster's First Law (9) expresses the reductionist process rather well:

> "The more complex the problem which is being ignored the greater are the chances for fame and success."

If a system is complex we simplify it by dividing it into subsystems. If we still cannot handle the subsystems we reduce it further. Finally we arrive at problems we can solve. Fame and success come with publishing: there is a plethora of papers which deal elegantly with unimportant, even trivial, problems. The use of averages (e.g., statistical mechanics in physics, per capita GNP in economics) and probabilities (e.g., cross-impact analysis) has permitted treatment of systems with a very large number of elements, each behaving in a unique way. In technological forecasting there is talk of a "most probable" scenario. Either it comprises so few elements (events and trends) that it is meaningless or so many that, even if each has a 90% chance of occurrence (or non-occurrence), the product has a very low likelihood. For example, for 20 elements each with 90% probability, the scenario has only 12% likelihood. If all alternative scenarios have a lower probability, does this make the 12% scenario a "most probable" one? History is strewn with events which had a powerful impact but were calculated to have a very low probability (e.g., Three Mile Island accident). The clients of technology assessment are less interested in probabilities than in circumventing catastrophe and moderating effects of failure.

Another example of the simplifications common in modeling is the representation of a system as a set of elements with pairwise relationships denoting the interactions.

If there are three elements (A,B, and C), there are six possible relations (e.g., A-B, C-B). If the pairwise qualification is removed, there are at least 49 interactions (e.g., AB-ABC, B-B, BC-A). Anyone with a family or corporation knows that there are numerous non-pair relationships (e.g., father to children). For a system of 10 elements this number rises to over 1 million. (The formula is $(2^n-1)^2$).

Modeling often becomes an end rather than a means. The dedicated modeler reminds one of Pygmalion, the sculptor of Greek methology. He fashioned a beautiful statue of a girl and fell in love with it. Responding to his plea the goddess Aphrodite brought her to life and he married his model. Today's modelers, blessed with vast computer capacity, also become wedded to their creations: the model becomes reality. In a recent survey of structural modeling techniques, Linstone et al. (5) found over one hundred types in this very limited area. Clearly it seems to be fun for the modelers, but it also is a nightmare for the real world problem solver.

A recent fashion in reductionism is the transfer of entire theories from one field to another (often fallaciously presented as an example of interdisciplinarity). One case is the adoption of thermodynamics by some economists, e.g., the "entropy state" of Georgescu-Roegen (10). It is tempting in the context of the science-technology world view to reduce complexity by taking an existing law, albeit derived for closed physical systems, and apply it to open social systems. But the Second Law of Thermodynamics simply does not apply to the evolution of living systems from single cells to *homo sapiens*. Such systems are becoming increasingly organized, oblivious to the running down postulated by the Law. In human beings each fertilized egg recreates potential (i.e., negentropy) and the transfer of information about technology among different cultures has a similar effect.

## Data and Models

Another characteristic of the science-technology world view is the use of certain modes in inquiry (11) (Table 1):

1. Lockean - empirical; agreement on observations or data; truth is experimental and does not rest on any theoretical considerations.
2. Leibnizian - formal model; theoretical explanation; truth is analytic and does not rest on raw data of an external world.
3. Kantian - theoretical model and empirical data complement each other and are inseparable; truth is a synthesis; multiple models provide synergism (e.g., particle and wave theories in physics).

TABLE 1.
Typical Questions Posed by Inquiring Systems. Source (12)

Suppose we are given a set of technology assessment statements. Our Inquiring Systems can be simply differentiated from one another in terms of the kind of characteristic questions each of them would address to the assessor or to his set of statements. Each question in effect embodies the major philosophical criterion that would have to be met before that inquirer would accept the statement.

- The Lockean analyst or Inquiring System would ask something like:

  "Since data is always prior to the development of theory, how can one independent of any formal TA model justify the assessment by means of some objective data or the consensus of some group of expert judges that bears on the assessment? What are the statistics? What is the probability you are wrong? Is that a good estimate?

- The Leibnizian analyst or IS might ask:

  "How can one independent of any empirical considerations give a rational justification of the assessment? What is the model you are using? How was the result deduced and is it precise and certain?"

- The Kantian analyst or IS would ask:

  "Since data and theory always exist side by side, does there exist some combination of data or expert judgement plus underlying theoretical justification for the data that would justify the assessment? What alternative assessments exist? Which of these satisfies my objectives?

- The Hegelian analyst or IS might ask:

  "Since every assessment is a reflection of more general theory or plan about the nature of the world as a whole system, i.e., a world view, does there exist some alternative sharply differing world view that would permit the serious consideration of a completely opposite assessment? What if the reverse happens and why wouldn't that be more reasonable?"

- The Merleau-Ponty analyst or IS might ask:

  "What is the shared reality? How does it facilitate the generation of policy options? How does the assessment create an impetus for desirable action? What kind of reality is most effectively negotiated by the parties at interest?"

- The Singerian analyst or IS would ask:

  "Have we taken a broad enough perspective of the basic assessment? Would other perspectives help? Have we from the very beginning asked the right question? To what extent are the questions and models of each inquirer a reflection of the unique personality of each inquirer as much as they are felt to be a "natural" characteristic or property of the "real" world?"

In this world view it is difficult to realize that, as we move beyond the pure science-technology domain, other systems of inquiry may prove more fruitful. Following are several candidates:

4. Hegelian - dialectic confrontation between opposing models or plans leading to resolution; truth is conflictual as typified in a courtroom trial.
5. Merleau-Ponty - reality as currently shared assumptions about a specific situation; acceptance of a new reality is negotiated out of our experience; truth is agreement which permits action.
6. Singerian - pragmatic meta-inquiring system which includes application of the other systems as needed; the designer's psychology and sociology inseparable from the physical system representation; ethics swept into design.

If we concentrate on the individual we should also mention Kant's noumena:

7. Noumena - reality beyond the perception of our senses, a world which we can only intuit, to which we are linked through our unconscious mind. in such a world there is no temporal distinction of past, present and future.

Thus we see that there is much out there beyond data-based, model-based, and complementary multimodel systems of inquiry. As Plamenatz writes in his work on Machiavelli (13),

> "The ideas about the great man and his role in history of a sometimes careless historian may be more perceptive and realistic than those of the most scrupulous recorder of facts."

The science-technology world view also places great stress on cause and effect relationships. But pause to consider a comment of Toynbee:

> "In my search to the present point, I have been experimenting with the play of soul-less forces...and I have been thinking in deterministic terms of cause and effect... Have I not erred in applying to historical thought which is a study of living creatures, a scientific method of thought which has been devised for thinking about inanimate nature? And have I not also erred further in treating the outcomes of encounters between persons as cases of the operation of cause-and-effect? The effect of a cause is inevitable, invariable, predictable. But the initiative that is taken by one or the other of the live parties to an encounter is not a cause; it is a challenge. Its consequence is not an effect; it is a response. Challenge-and-response resembles cause-and-effect only in standing for a sequence of events. The charac-

> ter of the sequence is not the same. Unlike the effect of a cause, the response to a challenge is not predetermined... and is therefore intrinsically unpredictable." (14)

Prigogine's (15) concept of "order through fluctuation" posits another source of unpredictability: the phase when a system becomes unstable and experiences temporary "macroscopic indeterminacy" before reaching a new stability state. The new state may depend on one fluctuation which is itself of no significance.

Quantification

In ancient Greece the Pythagoreans already attempted to preserve the purity of their mathematical expressions by putting to death the man who discovered incommensurables. Today the computer has become the ideal instrument to fuel the drive for quantification. A new version of Gresham's Law states that "quantitative analyses tend to drive out qualitative analyses". Zadeh's "fuzzy set theory" has even been developed to quantify qualitative terms, and, in the manner of a shoehorn, squeeze them into the computer input format.

The developed nations are, culturally speaking, measuring societies. In the words of Yankelovich (16),

> "The first step is to measure whatever can be easily measured. This is OK as far as it goes.
>
> The second step is to disregard that which can't be measured or give it an arbitrary quantitative value. This is artificial and misleading.
>
> The third step is to presume that what can't be measured easily really isn't very important. This is blindness.
>
> The fourth step is to say that what can't be easily measured really doesn't exist. This is suicide."

Compare this attitude with that of another culture, Papua, New Guinea. Fuglesang (17) writes:

> "In many villages they do not use measures, because people's life style is such that they have no need for it. In other villages people may measure the size of houses, fields or gardens in 'paces', which are sometimes called 'feet'...(The technical expert) will be disenchanted by the fact that a 'pace' is not a fixed standard measure. It will vary with the man who is doing the pacing. In villages I lived in in Zambia, people were perfectly happy with that, because they knew the man."

Quantification engenders self-delusion. For example, Tversky and Kahneman (18) have found that

> "People tend to overestimate the probability of conjunctive events and to underestimate the probability of disjunctive events...(such biases) are particularly significant in the context of planning. The successful completion of an undertaking, such as the development of a new product, typically has a conjunctive character; for the undertaking to succeed, each of a series of events must occur. (This leads) to unwarranted optimism in the evaluation of the likelihood that a plan will succeed or that a project will be completed on time. Conversely, disjunctive structures are typically encountered in the evaluation of risks. A complex system, such as a nuclear reactor or a human body, will malfunction if any of its essential components fails. Even when the likelihood of failure is slight, the probability of an overall failure can be high if many components are involved ...people will tend to underestimate the probabilities of failure in complex systems."

Objectivity

The traditional assumption of objectivity on the part of scientists and technologists is revealed more and more frequently as a myth. Churchman writes of the social sciences:

> "One of the most absurd myths of the social sciences is the 'objectivity' that is alleged to occur in the relation between the scientist-as-observer and the people he observes. He really thinks he can stand apart and objectively observe how people behave, what their attitudes are, how they think, how they decide ...(it is a) silly and empty claim that an observation is objective if it resides in the brain of an unbiased observer." (19:86)

Mitroff lays to rest objectivity in its traditional meaning in the physical sciences with his study of Apollo moon scientists:

> "It is humanly impossible to eliminate all bias and commitment from science...(we cannot) pin our hopes for the existence of an objective science on the existence of passionless unbiased individuals." (20: 248)

Von Foerster, himself a cyberneticist, insists that it is humanly impossible to eliminate all bias and commitment from science. Objectivity cannot occur in the relation between the scientist as observer and the people he observes. The claim that the properties of an observer must not enter into the description of his observations is nonsense, because without the observer there are no descriptions; the observer's faculty of describing enters, by necessity, into his descriptions (21).

If the objectivity cannot be assumed for the scientist in his proverbial ivory tower, it would seem foolhardy indeed to carry this assumption over to technology management in a "real world" setting. The real world is a complex system in which virtually "everything interacts with everything" - and this includes the manager. That being the case, the choice of model and data, of problem definition and boundaries, is always partly subjective.

## Avoiding the Individual

From Adam Smith to West Churchman there have been expressions of concern with the danger of ignoring the individual, losing him in the aggregate view. Smith said 200 years ago:

> "The man of system...seems to imagine that he can arrange the different members of a great society with as much ease as the hand arranges the difficult pieces upon a chessboard. He does not consider that the pieces upon the chessboard have no other principle of motion beside that which the hand impresses upon them; but that, in the great chessboard of human society, every single piece has a principle of motion of its own altogether different from that which the legislature might choose to impress upon it."

Churchman in his inimitable way makes the following observations:

> "Economic models have to aggregate a number of things, and one of the things they aggregate is you! In great globs you are aggregated into statistical classes....
>
> Jung says that, until you have gone through the process of individuation...you will not be able to face the social problems. You will not be able to build your models and tell the world what to do...
>
> From the perspective of the unique individual, it is not counting up how many people on this side and how many on that side. All the global systems things go out: there are no trade-offs in this world, in this immense world of the inner self...All our concepts that work so well in the global world do not work in the inner world...We have great trouble describing it very well in scientific language, but it is there, and is important...

> To be able to see the world globally, which you are going to have to be able to do, and to see it as a world of unique individuals...(that is, the ability to) hold conflicting world views together at the same time (and be) enriched by that capability - not weakened by it...that is really complexity." (22:88)

In retrospect we encounter instance after instance where individuals were crucial in the interaction of a technology with the society: Wernher Von Braun's leadership in rocket and space vehicle development, Dr. Rachel Carson's book "The Silent Spring". In these cases we have an impact of individuals on technology. Conversely, technology may have a tremendous impact on the individual. Television ended the career of Senator Joseph McCarthy, radio (e.g. the fireside chats) worked powerfully for President Franklin Roosevelt, and the space program created the astronaut as a folk hero.

But even aside from the case of individuals who play a central role in the interaction between a technology and a society, there are other interesting arguments in support of inclusion of the individual:

1. An appreciation of individual attitudes can facilitate our understanding of collective attitudes subsequently, i.e., the organizational perspective.
2. It brings us closer to the way we usually obtain information and insights in any situation which is not purely technological.

Why does playwright Arthur Miller use Willie Loman to describe the middle American urge to be popular? Why does George Bernard Shaw use Liza Doolittle and her father to portray class problems in England? Why does historian Barbara Tuchman use a single person, Enguerrand de Coucy as the focal point of her sweeping survey of 14th century Europe? Why does General Sir John Hackett in his NATO scenario "The Third World War: August 1985" focus on an Italian cameraman, a submarine commander, and a young American serviceman at crucial points of his narrative?

I believe the answer in each case is that there is a recognition of the power of communication afforded by the use of the individual. Each one of us operates at this level and it should not be surprising that we receive input particularly well at this level. In our normal activities we receive input by a mix of both form and content. We read and converse; we interact with experts and laymen, with varying degrees of subjectivity, with varying personalities and focus of expression. The use of multiple perspectives resembles the use of two eyes. Confining ourselves to a two dimensional image we find one eye adequate; a technological problem can be viewed adequately from a technical perspective. However, proper perception of a three-dimensional object, i.e., depth, requires two eyes (stereoscopic vision). Analogously, a sociotechnological problem requires more than the technical perspective.

In the case of Guayule, for example, unique individuals such as Assistant Secretary of Agriculture Alex Mercure, California's Isi Siddiqui and Ed Flynn help to create a three-dimensional image of the strategic options for its development.

Finally, we note a striking limitation in the generally accepted view of technology assessment: like its intellectual precursors, operations analysis and systems analysis, it reaches the domain of policy and decision making (often just barely) and almost never deals with the toughest phase - implementation. It is precisely there that the individual becomes most central - and the potential value of the tools is most severely tested.

## The Linearity of Time

The science-technology world view is concerned with physical space-time, i.e., with time as a dimension or variable essential in grasping the dynamics of a complex system. Distortions intrude through relativity theory, e.g., perceptions of time vary with movement speed in an Einsteinian universe. Economists apply a discount rate to future dollars to determine their present value; the basis is traditionally the cost of capital. Aside from such rather mechanistic alterations, this perspective sees time as moving linearly, at a universally accepted pace determined by precise physical measurement. Thus Forrester, Meadows, Mesarovic, and Pestel may exercise their system dynamic models over 50 or 130 year periods, but the computational time increment $\Delta t$ is independent of society and individuals, geographical locale, and era. We shall use the term technological time for this case.

By contrast every individual has a very personal conception of time. Dominated by biological time and needs, a person's time horizon is dictated by the expected life span and position in Maslow's hierarchy of needs.

The individual applies a psychological discount rate to his perception of future problems and opportunities which is totally distinct from the businessman's dollar discount rate based on cost of capital. The psychological discount rate means in effect that the individual looks at the future as if through the wrong end of a telescope (23:5-6). Distant objects appear smaller than they really are. The highest discounting occurs where personal survival is the prime concern; a low rate in an affluent well-educated family in a Western setting. Time discounting varies with age and with psychological type. Table 2 suggests the Jung typology and related time orientations. As the Marschallin in "Der Rosenkavalier" observes, "Die Zeit, die ist ein sonderbar Ding" (Time is a strange thing).

TABLE 2.
Jung's Typology and Time Orientations

| Jung Type | Time Focus | Discounting |
|---|---|---|
| Sensation | Present | Highest |
| Feeling | Past | Selective bias (high/moderate) |
| Intuition | Future | Selective bias (high/moderate) |
| Thinking | Past-Present-Future | Moderate |

Source: (23:10)

Even our daily newspaper raises the subject:

> "The dimension of time has become a great paradox of the modern world. Words and images are transmitted instantly, people almost as fast. But the context and the meaning do not come through the blur of impression which seems to make adjustment slower and more difficult." (24)

The experiments of Tversky and Kahneman demonstrate how human beings apply a discount rate to their own past and thus distort the integration of their personal experience (18). Recent events are overstressed in comparison to more remote ones.

The importance of such discounting in the technology management context can hardly be overestimated. As shown in connection with the world dynamics modeling (Figure 2), decisions are drastically altered as the discount rate varies.

Let us turn from the individual to organizations or social entities. Neither technological time nor biological time prevails.

Organizations have a longer time horizon than individuals; they do not expect to die like human beings. This does not mean they use a zero discount rate, merely a lower one than individuals. Social time is multigenerational. Organizations are, in fact, a curious blend of long and short term horizons. There is the motivation of perpetuation and the pressure of meeting next month's payroll and protecting next year's budget. As in the case of individuals, organizations have a spectrum of time horizons. Small companies contrast with large ones, medieval Christian with modern American societies, rich European states contrast with poor African governments.

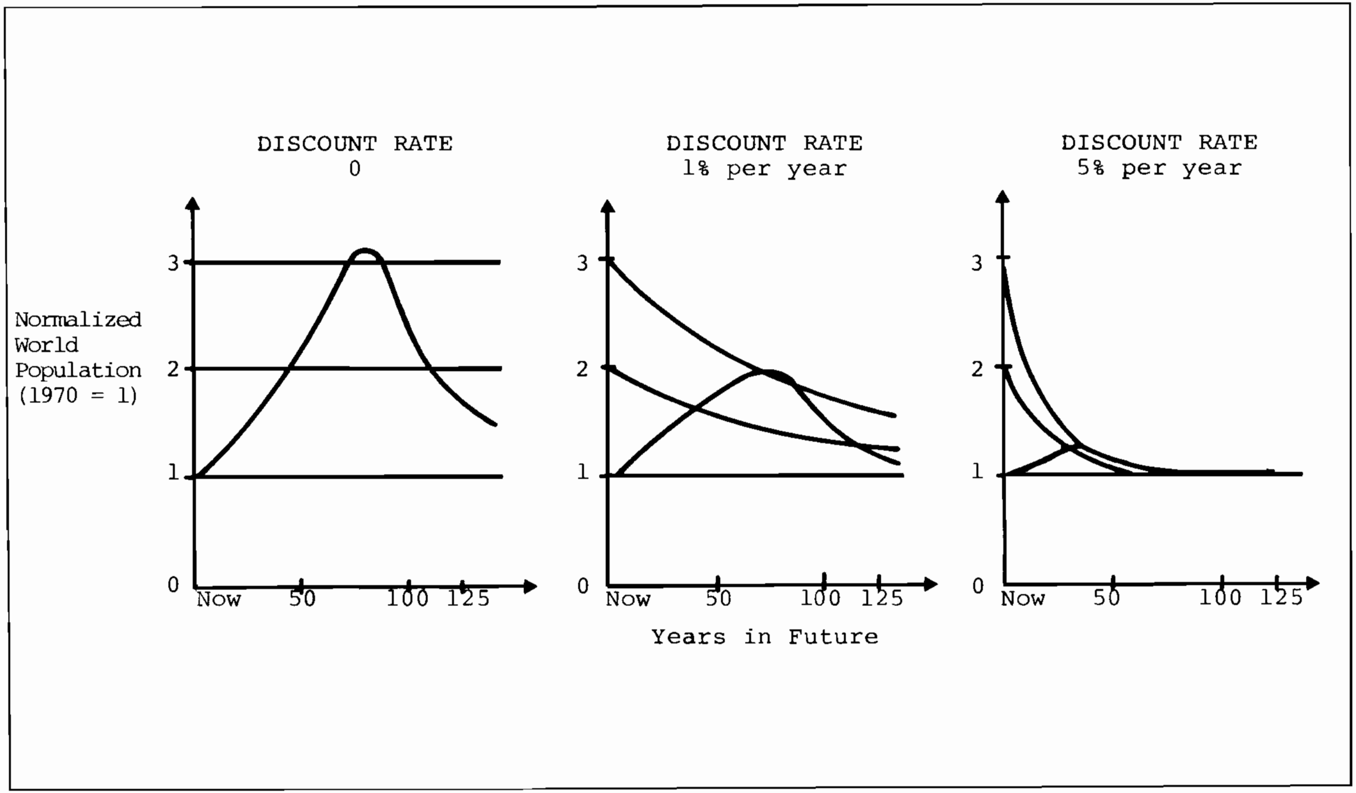



FIGURE 2. The discounting phenomenon: World population crisis
Zero discount rate case based on Meadows' "Limits to Growth" standard run (25:24)

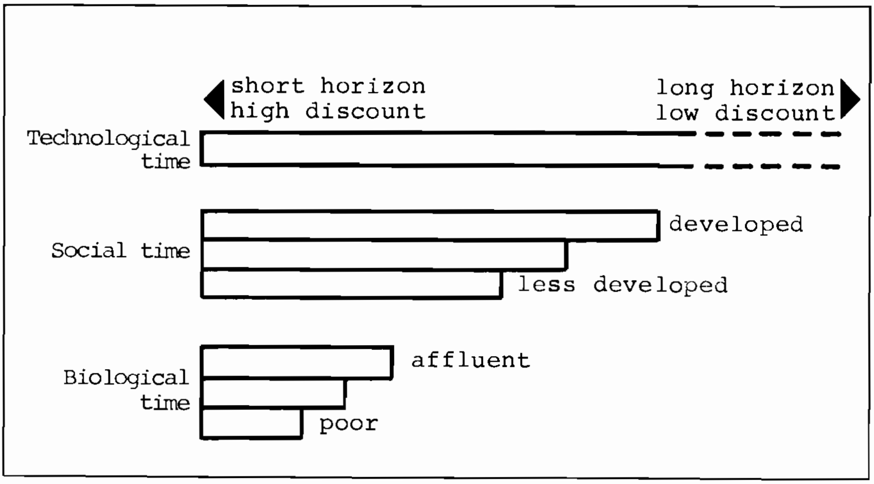



FIGURE 3. Relative time horizons - A schematic

Consider once more the case of Papua New Guinea (17):

"There is something we could call 'village time'. It is not measured in hours, minutes or seconds, but in seasons or moons...Women would tend to measure the time by the chores of the day, which are very regular in a village setting. There is the time for gathering firewood or making the fire. There is the time for weeding the garden and the time for preparing the big meal of the day."

Figure 3 summarizes this discussion of time.

## III. MULTIPLE PERSPECTIVES

It has been shown that the technical perspective, so successful in addressing purely technical problems, is very inadequate in dealing with sociotechnical and other problems. It is well suited to design a highly sophisticated technological system but ill suited to deal with the assessment or implementation. In this technology management phase the system can no longer be viewed as a purely technological one. Organizations and individuals play important roles and it is suggested that other perspectives with different paradigms must augment the technical perspective. In other words, multiple perspectives are needed.

Let us first make clear what we do not mean by multiple perspectives:

First, we refer to the use of multiple models simultaneously, not sequentially. The latter use is exemplified by the Copernican and Ptolemaic models, one replacing the other as the "correct" view of the world. Religions, like early science, depended strongly on one "Weltanschauung" as a base for authority. The fear of unsettling alternative views is reflected in inquisitions, witch hunts, ostracism by colleagues, and other techniques of persecution.

Second, we do not imply that a technological aspect must be viewed by a technological perspective (Figure 1a) and an organizational aspect by an organizational perspective. The technological, social, and individual aspects are interrelated and it is the hypothesis of this paper that multiple perspectives should be considered in looking at all aspects. Acceptance of multiple models simultaneously requires a considerable degree of intellectual sophistication or maturity. In mathematics the nineteenth century challenged us with the Euclidean, Riemannian, and Lobachevskian geometries, while physics offered the wave and particle theories as simultaneously valid. Anthropologists have used the triad of culture, society, and personality (26). In the social sciences Etzioni bases his model of "mixed scanning" on political and systems approaches to decision making (27). Multiple perspectives are most familiar to the trial lawyer (he expects each witness to bring forth a different perspective) and have also been used as literary devices. "Rashomon" is a classic example.

The three perspectives proposed by Linstone et al. (28) are based on the earlier work of Allison (29), Steinbruner (30), and Andersen (31). Figure 4 is a schematic showing the relationships. Allison was the pioneer in this area; his case study of the Cuban missile crisis was published in 1971. His models I and II were built on a solid base of 1950s and 1960s scholarship. The "RAND school" and its disciples produced a plethora of rational actor guidelines. The organizational process model was drawn largely from the Simon-March "school" of organizational decision making (32,33). Many of Allison's propositions are taken from Cyert and March (34). Allison's model III is weaker than models I and II; it recognizes that two models could not encompass all the crucial aspects of the decision making process. He notes that "Model III tells a fascinating story, but is enormously complex. The information requirements are often overwhelming". (29:274)

The main descriptors of the Allison models are shown in Table 3.

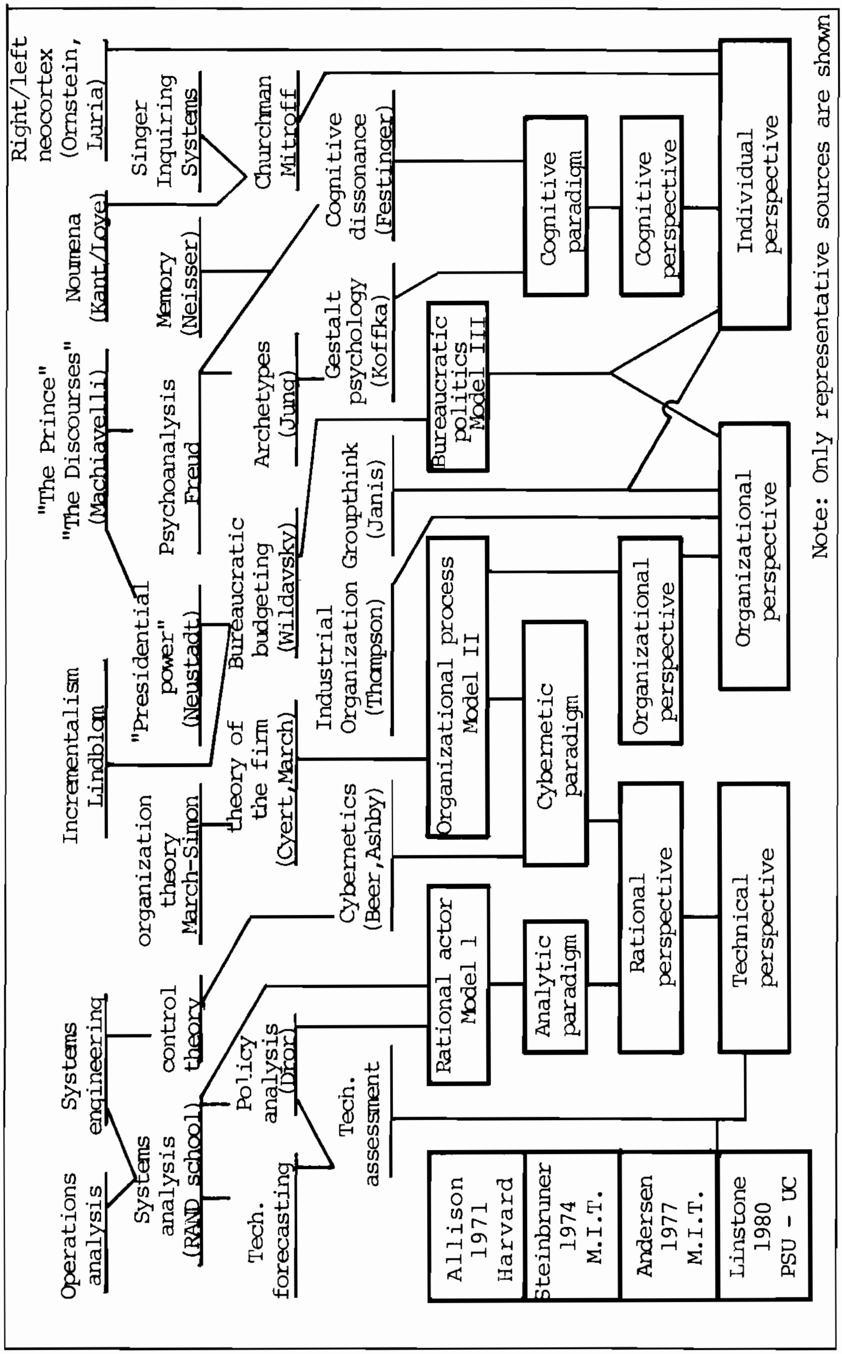



FIGURE 4. A comparison of the multiple perspectives and their sources

Building on the work of Allison, Steinbruner, and Andersen, we are currently experimenting with the application of our own version of these multiple perspectives to the area of technology assessment (28). Figure 4 shows that it is close to Andersen's set, differing significantly only in the individual perspective. Table 4 describes our perspectives in summary form and Figure 5 relates these multiple perspectives to our discussion in Section II (Figure 1).

We do not suggest that each perspective is equally significant in any technology assessment. The status of the technology - emerging, existing - as well as the type - small or large scale, centralized or diffuse - makes a difference in the balance among perspectives.

## The Guayule Case

Our current National Science Foundation project is considering three applications to technology assessments: electronic funds transfer, on-site solid waste management, and commercialization of Guayule. Here we will concretize our ideas by using Guayule as an illustration. The name refers to a plant which grows wild in northern Mexico and could be planted in the southwestern U.S. It is of interest in its role as a potential substitute for natural rubber (Hevea). The technology assessment was performed by the Office of Arid Lands at the University of Arizona with Midwest Research Institute as subcontractor. Principal investigator of this NSF-sponsored project was Dr. Kennith Foster.

The technical perspective samples in Table 5 are drawn from that excellent effort (35). The other samples in this Table reflect the insights which may be swept in by the organizational and individual perspectives.

A very important lesson learned in our project is the need for a talent quite distinct from that normally drawn into technology forecast, assessment, or transfer studies. The person who is excellent in using the technical perspective is likely to be unsuitable in applying the other perspectives, and vice versa. Thus science-trained analysts or engineers are accustomed to the technical perspective, have problems with the organizational, and are completely stymied by the individual perspective. It should be emphasized that the answer is not to staff the team with experts from a variety of disciplines (e.g. economics, agriculture, civil engineering) or with interdisciplinary types (e.g. systems analysis, operations research, environmental science). All of these types are (hard or soft) science-trained. Rather, the second and third perspectives require individuals from very different backgrounds (e.g., lawyer, politician, career bureaucrat, investigative reporter, writer). It is even

TABLE 3.
Allison's Three Models

| | Rational Actor | Organizational Process | Bureaucratic Politics |
|---|---|---|---|
| Basic Unit of Analysis | Action as choice of total system | Action as organizational output in framework of present capabilities & constraints | Action as political resultant (bargaining, compromise) |
| Organizing concepts | Unitary decision maker (e.g. government) | Constellation of loosely allied units topped by leaders | Players ("where you stand depends on where you sit") |
| | One set of goals (e.g. national) | Problems factored; power fractionated | Parochial priorities and perceptions |
| | Problem as seen by unitary decision maker | Parochial priorities | Goals include personal interests |
| | Solution a steady-state choice among alternatives | Goals are constraints defining acceptable performance of organization | Players' impact based on relative power |
| | Action a rational choice based on goals/objectives, alternatives/options, consequences, and value maximizing selection | Sequential attention to goals | Action channels structure the game |
| | | Standard operating procedures (SOP) | Rules sanction some tactics (bargaining, coalitions, bluff) but not others |
| | | Programs and repertoires | |
| | | Avoidance of uncertainty | |
| | | Problem-directed search | |
| | | Central coordination and control | |
| Dominant Inference Pattern | Actions are maximizing means to achieve ends | Behavior of organization at time $t$ similar to $t-1$, at $t+1$ similar to $t$ | Action resultant of bargaining game among individuals, groups |

| | | | |
|---|---|---|---|
| General Propositions | Likelihood of any action results from a combination of relevant values and objectives, perceived alternative courses of action, estimates of various sets of consequences, and net valuation of each set of consequences | Standard routines: program is a cluster of SOPs satisfying rather than maximizing (first acceptable rather than best alternative) | Peculiar preferences and stands of individual players |
| | | | Styles of play vary |
| | | Long-range planning institutionalized then disregarded | Face of issue differs from seat to seat |
| | Increase in costs of an alternative reduces likelihood of its selection | Incremental change | Fuzziness useful to get agreement |
| | | Trade-offs neglected | Focus on immediate decision rather than on doctrine |
| | Decrease in costs of an alternative increases likelihood of its selection | Organizational health implies growth, imperialism | Views: |
| | | Administrative feasibility a major dimension | Looking down - options<br>Looking sideways - commitment<br>Looking up - show of confidence |
| | | Directed change possible when organization is in crisis | Frequent misperception<br>Misexpectations<br>Miscommunications |

Source: (29)

TABLE 4.
Linstone Perspectives

| | TECHNICAL (T) | ORGANIZATION (O) | INDIVIDUAL (P) |
|---|---|---|---|
| WELT-ANSCHAUUNG | Science-technology | Organization | Psychology-behavior |
| CHARACTER-ISTICS | Cause-effect | Cause-effect & challenge-response | Challenge-response |
| | Objective | Objective & subjective | Subjective |
| | Problem solving | Problem avoidance/delegation | Leaders and followers game-in-process for most |
| | Analysis | Analysis and synthesis | Intuition |
| | Prediction | Recognition of partial unpredictability<br>Action/implementation | Fear of change and unknown |
| | Optimization | Satisficing | Creativity & vision by few - "the yogi" |
| | Complete rationality | Parochial priorities<br>Incremental change | Partial rationality<br>Inner world/self<br>Maslow hierarchy of needs |
| | Use of averages, probabilities<br>Trade-offs | Standard operating procedures<br>Factoring/fractionating problems | Learning<br>Power/influence/dominance - "the commissar" |
| | Left neocortex | Left and right neocortex | Left and right neocortex |
| PREFERRED INQUIRING SYSTEM | Lockean-data<br>Leibnizian-model<br>Kantian-multimodel | Hegelian-dialectic<br>Merleau-Ponty-negotiated reality | Intuition-noumena<br>Individual reality |
| TIME CONCEPT | Technological time<br>Zero discounting | Social time<br>Moderate discounting | Biological time<br>High discounting |

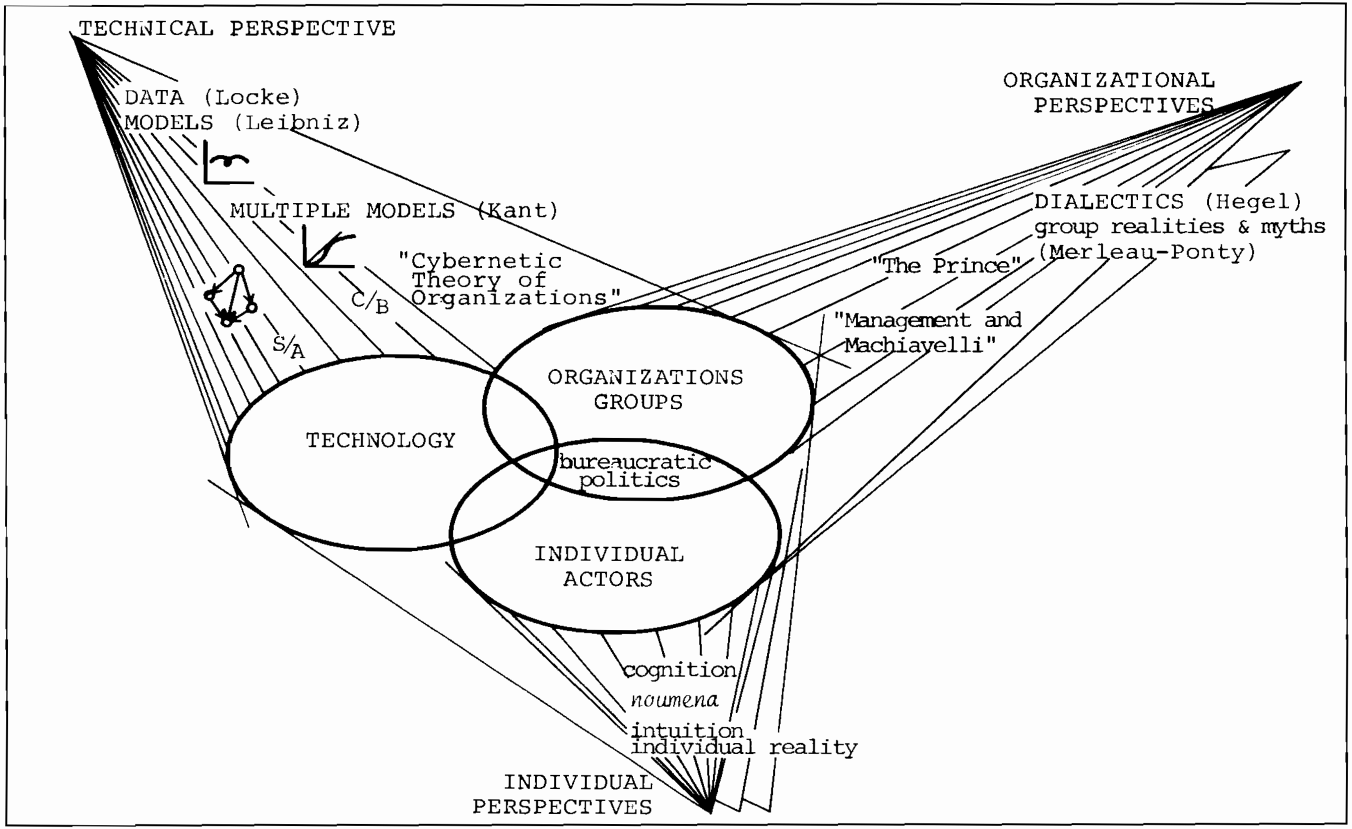



FIGURE 5. Multiple perspectives - a Singerian Inquiring System

TABLE 5.
Examples of the Use of Multiple Perspectives on the Guayule/Hevea Rubber Substitution

Technical Perspective

- Tests have shown Guayule to be a satisfactory substitute for Hevea in automobile and aircraft tires (the primary use of natural rubber)
- In view of the 300% price increase of natural rubber since 1972, Guayule is becoming competitive
- Guayule development can meet 100% of the projected natural rubber shortfall by 1991
- Yield per acre is expected to double between 1985 & 2000
- Research needs to be done on the use of Guayule to retard desertification
- The established view on economics of scale is open to question

Organizational Perspective

- Mexico has had a long history of interest in Guayule (wild natural growth, research institute in Saltillo, pilot processing plant), but motivations not readily grasped by U.S. interests due to cultural differences.
- Research is not the key issue; rather, production start-up raises the question of assumption of financial risk between the tire and rubber companies and the government (Federal and California).
- The Department of Agriculture has not been aggressive. If implementation succeeds it may act as an agent of change with the Department.
- Inbreeding appears to be a problem in tire and rubber industry management. Organizational inertia may offer an opening to industry outsiders to jump at Guayule commercialization opportunities. The point where control is likely to be exercised is at the processing stage.
- A number of groups are not represented in the dialog and decision process (e.g. farmers, Indian tribes, and farm workers).
- The Guayule commission could become the lead group but has not achieved much to date (lack of appropriate funds).
- National security considerations may act as the decisive catalyst; fear of increased Asian turbulence is spurred by events in Iran and Afghanistan. The Department of Defense and Federal Emergency Management Agency would then become key elements.

TABLE 5 (cont'd)

Individual Perspective

- Ed Flynn ("Mr. Guayule Rubber News") is a determined promoter.
- Effective leadership of, and cooperation between, Alex Mercure, Chairman of the Federal Guayule Commission, and Isi Siddiqui of the California Department of Food and Agriculture may spark implementation action.
- Representative George Brown (D. California) has been a most effective advocate in the Congress and has been joined more recently by Senator Peter Domenici (R. N.M.) Texas is lacking a strong Congressional supporter.
- Each actor tends to perceive his own perspective behavior quite differently than the others perceive it. Each sees the others' perceptions as distorted. Each therefore interprets a given act differently. This situation discourages formation of coalitions.
- None of the present actors yet sees enough in it for him to have a feasible action strategy. Personal changes must be watched for indications.
- There is a crucial difference between those whose careers and fortune are tied to a Guayule development and those who must make the commercialization decisions (advocates vs. judges).

---

desirable to present the results of the second and third perspective in a different format from that of the first. We are still experimenting to combine different formats in the referenced project (28).

## IV. CONCLUSION

In regional development we never deal with a well-structured, purely technological system. Yet the files are full of impressive technical studies which artificially assume that regional development is such a system. In the case of Guayule, the perspective of the migrant worker and Southwest Indian in the U.S. as well as the Northwest Mexican rural population can be modeled or simulated neither by sociologists and agricultural scientists from academe nor by bureaucrats in agency offices. And tire and rubber company perspectives cannot be understood from their experts' technical talks or their public relations films.

We have by now ample evidence of the subtlety in the impacts of introducing a technology into a physical-social setting. The substitution of the chimney for the central hall fire in medieval European castles hastened social stratification; the substitution of the spinning wheel for manual weaving during the same period made the mass production of books practical and thus revolutionized Western societies. We still are uncertain of the impact of television on children and on national politics. And we are just beginning to consider the potential of automated information processing as a prosthesis of the human brain imbalancing our left-right neocortex capacities (36). We have therefore learned a new appreciation of system complexity and of the limits of technical tools. In this paper we have posited the hypothesis that multiple perspectives offer a means to enhance technology forecasts, assessments, and transfer studies. It is not a hypothesis which can be "proven" in the scientific sense; such proofs are themselves inherently constrained to the technical perspective. But the applications to date appear quite promising, i.e., the use of multiple perspectives is adding valuable insights which may enhance the decision making process in regional development.

## REFERENCES


1. Rowan, R., Those Business Hunches are more than Blind Faith", Fortune, April 23, (1979), p.112.
2. Green, T.B., Newson, W.B. and Jones, R.S.,"Research Notes", Academy of Management Journal, 20, 4, (1977) p.669.
3. Balachandra, R., Perceived Usefulness of Technological Forecasting Techniques", Technological Forecasting and Social Change, 16, 2, February (1980), p.157.
4. Jay, Anthony, Management and Machiavelli, Holt, Rinehard and Winston, Inc., New York, (1968).
5. Linstone, H.A. et al., The Use of Structural Modeling for Technology Assessment, Technological Forecasting and Social Change, 14, 4, September (1979), pp. 291-328.
6. Porter, A.L. et al., A Guidebook for Technology Assessment and Impact Analysis, North Holland, New York, (1980).
7. Hopcraft, D., Nature's Technology, Technological Forecasting and Social Change, to be published 1980-1981.
8. Holling, C.S., The Curious Behavior of Complex Systems: Lessons from Ecology, in H.A. Linstone and W.H.C. Simmonds' Futures Research: New Directions, Addison-Wesley Pub. Co., Reading, MA, (1977) p. 129.
9. Von Foerster, H., Responsibilities of Competence, Journal of Cybernetics, 2, 2, (1972), p.l.
10. Georgescu-Roegen, N., The Entropy Law and the Economic Process, Harvard Univ. Press, Cambridge, MA, (1972).

11. Churchman, C.W., The Design of Inquiring Systems, Basic Books, Inc., New York, (1971).
12. Mitroff, I.I. and Turoff, M., Technological Forecasting and Assessment: Science and/or Mythology?, Technological Forecasting and Social Change, 5, (1973), pp. 113-134.
13. Plamenatz, J. (ed.), Machiavelli, Fontana/Collins, Great Britain, (1972).
14. Toynbee, A., quoted in Prigogine, I., Allen, P.M. and Herman, R., Long Term Trends and the Evolution of Complexity, in E. Laszlo and J. Bierman (eds.), Goals in a Global Community, 1, Pergamon Press, New York, (1977), pp.57-58.
15. Prigogine, I., Allen, P.M. and Herman, R., Long Term Trends and the Evolution of Complexity, in E. Laszlo and J. Bierman (eds.), Goals in a Global Community, 1, Pergamon Press, New York, (1977), p. 57.
16. Yankelovich, D., quoted in Smith, A., Supermoney, Random House, New York, (1972), pp. 271-272.
17. Fuglesang, A., Doing Things...Together: Report of an Experience in Communicating Appropriate Technology, The Dag Hammarskjold Foundation, Uppsala, (1977),p.96.
18. Tversky, A. and Kahneman, D., Judgment Under Uncertainty: Heuristics and Biases, Science, September 27, (1974), pp. 1124-1131.
19. Churchman, C.W., Challenge to Reason, McGraw Hill, New York, (1968), p.86.
20. Mitroff, I.I., The Subjective Side of Science, Elsevier-North Holland, New York, (1974), p.248.
21. Von Foerster, H., The Curious Behavior of Complex Systems: Lessons from Biology, In H. Linstone and W.H.C. Simmonds, Futures Research: New Directions, Addison-Wesley Pub. Co., Reading, MA, (1977),pp.107-108.
22. Churchman, C.W., A Philosophy for Planning, in H.A. Linstone and W.H.C. Simmonds, Futures Research: New Directions, Addison-Wesley Pub. Co., Reading, MA, (1977).
23. Linstone, H.A. and Simmonds, W.H.C., Futures Research: New Directions, Addison-Wesley Pub. Co., Reading, MA, (1977).
24. New York Times, December 28, (1979), p. A-6.
25. Meadows, D. et al., The Limits to Growth, Universe Books, New York, (1972), p.124, Fig. 35.
26. Kluckhorn, C. and Mowrer, O.H., Culture and Personality: A Conceptual Framework, American Anthropologist, 46, (1944), pp.1-29.
27. Etzioni, A., Mixed Scanning: Third Approach to Decision Making, Public Administration Review, 27, Dec. (1967), pp.385-392.
28. Linstone, H.A. et al., The Use of Alternative Decision Models for Technology Assessment, NSF Project, Future Research Inst., Portland State Univ., Portland, OR, (1980).

29. Allison, G.T., Essence of Decision, Little, Brown & Co., Boston, MA, (1971).
30. Steinbruner, J.D., The Cybernetic Theory of Decision, Princeton University Press, Princeton, (1974).
31. Andersen, D.F., Mathematical Models and Decision Making in Bureaucracies: A Case Story Told from Three Points of View, Ph.D. Dissertation, M.I.T., Aug.(1977)
32. March, J.G. and Simon, H., Organization, Wiley, New York, (1958).
33. Simon, H., Administrative Behavior, MacMillan, New York, (1957).
34. Cyert, R.M. and March, J.G., A Behavioral Theory of the Firm, Prentice-Hall, Englewood Cliffs, NJ,(1963).
35. Foster, K. et al., A Technology Assessment for Guayule Rubber Commercialization, Office of Arid Lands Studies, University of Arizona and Midwest Research Institute, May (1980).
36. Linstone, H.A., Automated Information Processing: Extending or Imbalancing Human Capacity?, Discoveries Symposium, Honda Foundation, Stockholm, August 1979.

# 19 Social Assessment of Technology

*Francois Hetman**

## SOCIAL RELEVANCE OF SCIENCE AND TECHNOLOGY

New national needs call into being new science and technology policy mechanisms. This demonstrates a need for means whereby scientific and technological effort can be brought and kept within a more coherent and purposive relationship, in line with the way international goals and objectives are selected and pursued.

In most countries there is a tendency to strengthen the role played by R&D activities in tackling problems raised by industrial, energy, business, monetary, socio-cultural, international and other uncertainties that the world is currently having to contend with. The main economic strategies that are likely to call for an increased contribution of S&T are:

1. Sustaining the rate of economic growth;
2. limiting dependence on external sources of energy, raw materials and manufacturers;
3. strengthening competitive advantages on foreign markets;
4. shifting priorities to more socially oriented goals.

It can be observed in this connection that many countries take measures:

1. To strengthen links between basic research, applied research and experimental development in order to take systematic advantage of ideas which can give rise to new processes and products;

*The opinions expressed by the author are his own and do not commit the organisation to which he belongs.

2. to encourage research aimed at adapting domestically produced processes used in one sector for use in another (horizontal transfer of technology);
3. to enhance the value of domestic and foreign R&D findings by means of S&T information policy integrated with S&T policy.

Another important issue is the demand for greater social relevance and for a societally more useful R&D. This had so far led to only a slight shifting of research priorities. A somewhat larger share of public R&D expenditure has been allocated to sectors which may stand under the heading of quality of life: health, protection of the environment, town and country planning, social development and welfare services.

The problem of generating research of societal relevance raises the question of available methods which can be applied to the identification, selection and design of research. Now, this is basically a question of human and societal values and of the corresponding political concern to put S&T effort to new uses.

An increased attention is paid to the effectiveness of all components of the S&T system. Problems of evaluation gain in importance since in many countries the resources available to the R&D system have come to a standstill or have even decreased relatively to the gross national product. Therefore, national authorities count on an effort to optimise the allocation of resources through sounder programme management, stricter control of means and a more radical use of research findings.

A new phenomenon is the public concern about science and technology. Various social groups are now claiming social and political competence to evaluate the acceptability of science and technology and are wanting to have their say on policies which traditionally have been regarded as the exclusive province of scientific and technological expertise or wise entrepreneurship. Such challenges are expressed, in particular, in the technology assessment movement.

## BEYOND TECHNOLOGICAL DETERMINISM

The concept of technology assessment leads to a reappraisal of the role of science and technology in contemporary society, both with deeper understanding of the nature of technology and of the innovation process, as well as consideration of the consequences of alternative technological decisions and a new approach to a better informed decision-making.

Scientific research and technological innovation are basic factors of the socio-economic development. Factors of change, they are also causes of destabilisation. They create new areas of uncertainty. They make obsolete whole categories of knowledge, technologies and professional skills.

They are also looked upon as the main source of remedial action. Science is viewed as a rational process. The development of R&D activities on a large scale, the establishment of institutions for science policy raise hopes that the rationality of the scientific method can be transposed into governmental policy-making processes.

Science and research-fuelled technological change continuously reveal incompatibility or conflict between old objectives, routine decision patterns and new issues. This raises the need for a new attitude towards relationships between research, technological innovation and decision-making which takes into account not only technical and economic performance parameters, but also the societal dimension of impacts of new technological developments.

Mankind is being faced with new risks and challenges. These are man-made. No external or supra-natural correcting mechanisms will be available. From now on, men will have to come to new terms with technology-induced human systems. This implies devising new ways of bringing technological innovation and proliferation of technologies under some kind of social control.

This runs counter to a broadly accepted view that technology is a self-enhancing factor which acts upon society in an irresistible way. According to this "technological determinism", technology is advancing autonomously whereas human adaptability and social structures in general are stagnating if not actually regressing. This discrepancy ends by provoking a feeling of frustration and growing alienation which further accentuates the lack of confidence in existing social institutions.

Consequently, new tools for decision-making in the field of technology are needed. Since it has been recognised that technology can be the source of both benefits and undesirable effects, a drastic change in thinking and general attitude towards technological change is now taking place.

## TECHNOLOGY ASSESSMENT MOVEMENT

Technology assessment can be defined as a process of analysis, forecasting and assessment of technological futures and their impacts on society resulting in action options for decision-makers. The term "technology assessment" was coined in the late 1960s by the Science, Research and Development Sub-Committee of the U.S. Congress. It was then defined as a form of policy research, a method of analysis that systematically appraises the nature, significance, status and merit of technological progress with a view to identifying policy issues, assessing the impact of alternative courses of action and presenting findings.

On the analyst's side, it encompasses the study of technological parameters, the elaboration of technological forecasts, the analysis of social, environmental, cultural and political factors, a general assessment of all relevant effects and possible consequences of a technology and an evaluation of alternatives.

On the decision-maker's side, it implies appropriate institutional mechanisms which make it possible to: identify demands for technological change; gear scientific and technological knowledge to societal needs; make the choice of socially acceptable technologies; determine suitable means of action; plan the appropriate phases of implementation.

Since the beginning there have been two tendencies diverging in approach and philosophy.

The first tendency can be called the technologist's approach. It considers that technology assessment examines the impacts of all alternative policies which can be followed, but does not come out with a specific recommendation involving value systems. Assessment ends at the frontiers of the broadened technological analysis, leaving the rest to traditional, existing, social and political processes.

The second tendency, on the contrary, regards management of technology as a part of overall planning or "social engineering". In its extreme formulation, it starts by spelling out values, social policies and objectives and works down to technology assessment in order to clarify the most appropriate technical options.

These two points of view may be considered as extremes between which social assessment of technology can take a great variety of forms. They are not mutually exclusive but rather complementary. They address themselves to the same cluster of problems, but from different angles and at different levels of the decision-making process. At the present stage, both challenge scientists and engineers to develop a better understanding of inter-relationships between technology and society. They also challenge decision-makers, from individual organisations to central governments, to evolve new procedures and institutional forms which can help to build a firmer basis for technology policies.

Theoretically, six main areas can be identified as starting points for technology assessment studies: technology, economy, society, the individual, the environment and value systems. However, for some of these and particularly for society, environment, the individual and value systems, there is as yet little knowledge available on relationships with technology. Most frequently, therefore, technology assessment studies are merely divided into two broad categories:

1. technology-initiated, and
2. problem-initiated

Available examples of technology assessment studies are mostly of the technology-initiated type. This can easily be explained by the fact that the first generation of assessment took place in direct response to questions concerning the particular environmental impacts of selected technologies.

## SIMILAR CONCEPTS

In a way, environmental impact statements can be considered as precursors of TA studies. They are sometimes qualified as limited TAs centred on one category of impacts: on the environment. They represent a form of assessment institutionalised in the United States with the enactment of the "National Environmental Policy Act". This Act requires that all Federal agencies include in every proposal for legislation or actions affecting the quality of the human environment a detailed statement on the impacts of the proposed action. Similar legislation and procedures have been adopted in a number of other countries together with the establishment of government mechanisms for environmental protection.

To convey the idea that technology assessment involves an important change in attitude, a certain number of other terms were suggested, such as "study of impacts", "analysis of social impacts" and "social management of technology". The same concern has led OECD to adopt the expression "social assessment of technology" to point out that the main thrust is on comprehensive and systematic analysis of technological developments on society.

According to one school of thought this concern with "societal aspects" should lead to a much more normative concept of TA. Such a concept would imply the establishment of an "early warning system" applied to new technological developments with a view to maximising their advantages and minimising the risks. Its main purpose would be to trace future developments so as to analyse their possible impacts on society and consequences of available choices (1). The system would define new technological priorities and indicate new directions for allocation of R&D resources.

Another current of thought dedicates particular attention to the "TA system" which means a political process within which the interested parties, "the actors", are involved in a conflictual situation. To evaluate possible consequences of a given political choice, it is necessary to know their motives, scales of values and objectives.

Here the emphasis is put on the study of the decision-making process which can be applied not only to new technologies but also to other political issues(2,3).

Analysis of the various citizen's groups claiming social or political competence to evaluate the acceptability of science and technology leads to the concept of "participatory TA". This would include a comprehensive study in which would be involved all social groups and all parties likely to be affected by decisions in the area of technology. TA would thus be the concern of the public at large, involving all informed citizens and not only technologists (4).

The concept of "systems assessment of new technology" (SANT) has been outlined within IIASA as a part of its investigations in the fields of systems analysis and technology management. It is presented as a framework for comprehensive study embracing the whole range of analytical issues, ranging from technological forecasting, to technology assessment, alternative technologies, evaluation of R&D and science-technology potential. The object of SANT is organised technology, in other words both technical and organisational and managerial innovation (5).

In 1977, the U.S. Energy Research and Development Administration (ERDA) (Now part of the Department of Energy) launched an important programme on "integrated assessment" which is expected to shed light on impacts of new technologies developed by ERDA both from the point of view of society and the environment. The definition of an integrated assessment is almost identical with that of a comprehensive TA or social assessment of technology. It does not include the term "technology" which seems to imply that the emphasis is on the analysis of impacts and consequences of a given political choice and that the concept is applicable to decision-making in general.

## TECHNOLOGY TRANSFER

Recently, an increasing amount of attention has been paid to "technology transfer", a catch-all concept which is given a range of interpretations, from specific phases of diffusion to an all-embracing notion of technology as prime mover of world trade and economic development.

The international transfer of technology has a different meaning for the industrialised countries and developing countries. The rate and direction of technological advance are determined by industrialised countries and in particular by few of them which can devote considerable resources to R&D and a systematic exploitation of new findings. For these countries technology transfer is just a logical step in the search of new outlets and profitable diffusion of goods with high science and technology contents.

For developing countries, technology transfer is a decisive factor in their industrial and economic development. However, they have but a little control over it and often come to consider it as a highly unbalanced flow bringing a cumulative advantage to industrialised countries. Another argument is that imported technologies are frequently not adapted to the situation of developing countries. Generous ideas have been launched calling for "specific", "intermediate" or "appropriate" technologies. But in a world of increasing interdependence, the real choice is constrained by competitive advantage, which favours more advanced technologies.

Since technology transfer is hardly amenable to transnational monitoring, each country must define a mix of policies bearing in mind the choice of imported technologies and their optimal utilisation with respect to national needs and available skills. Social assessment of technology can be instrumental in formulating such policies and in providing an informed guidance for such a choice. It has been put on the agenda of the United Nations in the hope that it will help developing countries to concentrate on the optimising aspects of the TA approach (6).

## SOCIAL ASSESSMENT OF TECHNOLOGY

Ideally, social assessment of technology should examine closely all eventual outcomes of adoption of a technology. This implies that analysts are able to consider and evaluate all possibilities both as to their beneficial and negative effects. However, any new technological development entails an infinite number of unpremeditated consequences. There is no scientist or technologist who can take into account all of these consequences, which go far beyond the capability of any group of people to understand and to draw the "social path" of a given technological event.

These are important and sobering limitations. It is obvious that social assessment of technology is not a technical device but rather a change in attitude towards technology and a new approach to a better informed decision-making in this field. It is not concerned with technical expertise _per se_, but mainly with socio-political answers to the impacts of technology. If the analysts are to provide useful information, their involvement, assumptions, sources of data and methods of reporting to decision-makers must be made clear so as to set workable boundaries on their effort.

There is a close and permanent interplay between an assessment study and decision-making. It takes the form of convergent iterations which are necessary to evaluate the consequences of technological change on society and to determine the channels through which societal objectives can influence the future course of technological development.

This can be represented as a systemic approach which integrates the processes of analysis, of decision-making, and of information into one dynamic continuum - as illustrated in Figure 1. The analysis process itself is a multi-iterative feedback process which combines forecasting and evaluation methods to explore relevant societal aspects of a given technological development, and to evaluate their impacts and consequences.

## BRIDGE TO TECHNOLOGY POLICY?

As a new concept and a new approach to technological change and social policy in general, TA still has to find its place within institutional set-up and decision-making mechanisms.

What can be the institutional status of technology assessment? Is it an outgrowth of science and technology policy? Or is it a new branch of general policy stemming from the reaction to the "disenchantment" with science and technology and the subsequent questioning of the ends of scientific activity and passive acceptance of technological developments?

One would expect that it should be closely linked to technology policy. However, there has not been such a thing so far. From the institutional point of view, technology has no place of its own. Both in national governmental agencies and relevant committees of the international organisations, the word technology was only recently added to that of science. Although this marks an increased concern for questions of technology, the couple, science and technology, remains ill-matched. While government agencies for science policy are now established with reasonably well-defined responsibilities, this is not the case for technology. Deep investigations are still necessary to understand the mechanisms of technological advance and of the interplay between technology and society before technology policy can be outlined in relevant operational terms.

With the exception of the United States and its Office of Technology Assessment, there are no special institutions for TA. As is illustrated hereafter by the experience of OECD, the major obstacles to TA, both within nations and at the international level, is the absence of technology policy and a government body responsible for it.

In the present situation, it is extremely difficult to find for any candidate technology for a TA, the appropriate institution which is willing, able and authorised to undertake such assessment studies. There is a wide dispersion of competences among the various ministries and agencies.

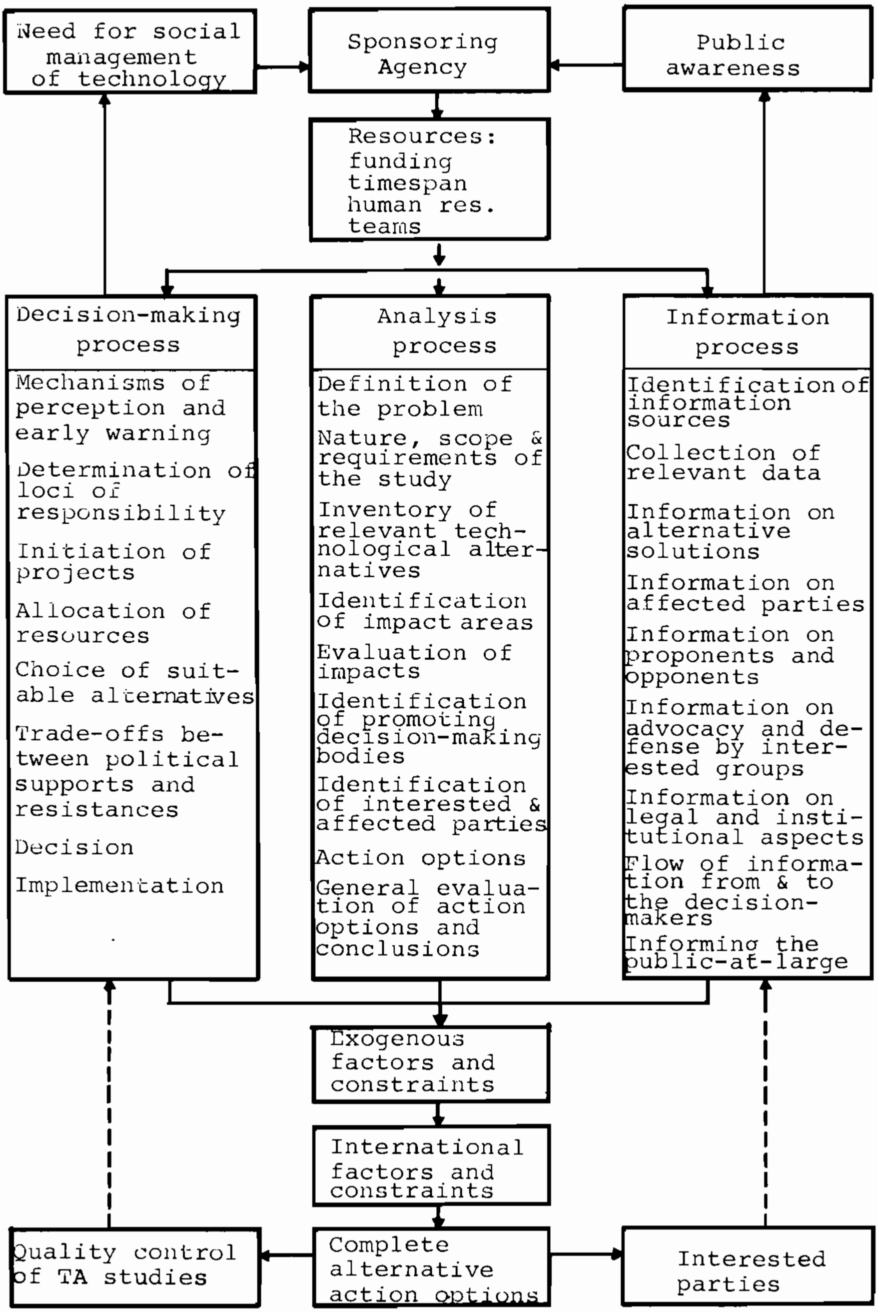

Need for social management of technology
Sponsoring Agency
Public awareness
Resources: funding timespan human res. teams
Decision-making process
Mechanisms of perception and early warning
Determination of loci of responsibility
Initiation of projects
Allocation of resources
Choice of suitable alternatives
Trade-offs between political supports and resistances
Decision
Implementation
Analysis process
Definition of the problem
Nature, scope & requirements of the study
Inventory of relevant technological alternatives
Identification of impact areas
Evaluation of impacts
Identification of promoting decision-making bodies
Identification of interested & affected parties
Action options
General evaluation of action options and conclusions
Information process
Identification of information sources
Collection of relevant data
Information on alternative solutions
Information on affected parties
Information on proponents and opponents
Information on advocacy and defense by interested groups
Information on legal and institutional aspects
Flow of information from & to the decision-makers
Informing the public-at-large
Exogenous factors and constraints
International factors and constraints
Quality control of TA studies
Complete alternative action options
Interested parties

FIGURE 1.

Furthermore, institutions which show an interest in TA - and there are often several of them, each responsible for only one aspect of a given technology - are hampered by their narrowly defined responsibilities; they have the greatest difficulty in modifying their programmes in order to devote some resources to TA.

In addition to these well-known phenomena of structural rigidity and institutional inertia, there is the fact that the concept of TA is still badly understood and hardly established. For all these reasons, its usefulness is minimised and its implementation resisted.

As a rule, technology is developed as a trial and error process, with opportunities for feedback from social, economic and legal institutions. Such a feedback should allow technologists to modify and reshape a technology and to adapt it better to social objectives. In reality, there is little adaptation because the social consequences are difficult to clarify and impossible to attest objectively, and because practical and political involvements make it generally difficult to modify the course of action. This makes decision-makers hesitant and ready to justify ongoing technological trends, rather than to challenge them.

## OECD PROGRAMME ON SOCIAL ASSESSMENT OF TECHNOLOGY

These various difficulties were encountered by OECD in launching and carrying out its programme on social assessment of technology. As a first phase of this programme OECD undertook an in-depth exploration of the state-of-the-art which led to the publication of "Society and the Assessment of Technology", a comprehensive OECD report, examining the general philosophy of social assessment of technology, conceptual starting points and methodological frameworks, reviewing the available experience, establishing a general typology of assessment of studies, expositing the methods of cost/benefit analysis, outlining the possible areas for use of assessment studies and examining the institutional problems and relationships between analysts and decision-makers (7).

The need to set up guidelines which might be used by the Member countries and the international community at large led to a follow-up publication "Methodological Guidelines for Social Assessment of Technology". This publication set forth a general framework attempting to reconcile comprehensiveness with practical usefulness (8).

As a second phase, an activity was started which was intended to test the social assessment approach by applying it to real problems of the interested Member countries. From a great number of topics suggested by national authorities, a number of subjects were selected for common comparative studies.

Finally, a sufficient commitment could be secured for one subject only: New Urban Transportation Systems. The project was carried out within the timespan of about two years, following the first exploratory stage, devoted mainly to defining the practicability and operational steps of the methodological approach and to identification of national studies which could be retained in the framework of the project.

The succeeding meetings of the national project leaders made it clear that none of the national organisations involved were ready, or had the opportunity to devote a sufficient part of their resources to a specifically designed social assessment study. Instead, proposals were made to base some kind of contribution from ongoing work. In order to obtain at least some degree of similarity with respect to the format, a list of 12 "common points" was drawn up as a guide, in the hope that all participating research teams would be able to contribute to these items and, if not, to bring out explicitly the difficulties of assessment.

As a result, even if compared with an extremely limited common frame of reference, the national contributions received could hardly be considered as fully-fledged social assessment studies of technology. Most often they were parts of broader projects undertaken within the current programme and responsibility of the respective research organisations. Frequently, they were merely derived from an already completed work which had been carried out with a quite different objective in mind. Each of them was thus devoted to a particular aspect or point of interest on which a meaningful comparison could be made (9).

In general, however, a certain effort was made to introduce the idea of social assessment of technology either as an additional category of conceptualisation or, more whole-heartedly, as a promising methodological tool, allowing for exploration of aspects often neglected in traditional technical feasibility studies.

This is not a negligible result if one considers that the main thrust of the OECD programme must have been to draw attention to the ideas and methodology of the social assessment of technology with a view to making both researchers and decision-makers aware of its potential value to policy-making.

## POTENTIAL AREAS OF APPLICATION

The main potential areas of application of social assessment of technology are the following, in order of increasing difficulty:

## Monitoring of Negative Effects of Existing Technologies

Undesired effects of a technology are frequently of a non-linear type. They appear in a cumulative way and create a new collective need to abate and to master them. There is a "threshold effect" both in physical terms and in the degree of public awareness. Social assessment of technology should therefore not only map out the future development of a technology, but also identify the thresholds under which undesirable effects should be kept. Though this sounds relatively easy, it may be extremely difficult to detect phases of expansion and break points which lead to new unexpected branchings.

## Quality of the Environment

In a sense, social assessment of technology relative to the environment is the reverse of the evaluation of a nascent technology. Instead of starting from a technology and looking after its effects and impacts, one begins with a stocktaking of impacts and proceeds then to causes of technological nature to show processes which end up in having unfavourable consequences.

Government decision-makers look for criteria which would enable them to optimise the well-being of society after having taken into account the effects of the various socio-economic activities on the environment. They tend to break down the quality of the environment, considered as a whole, into a series of specific questions. Courses of action are established for each case and advantages or disadvantages of each course of action are examined with regard to an optimal solution.

## Recycling and Re-use of Resources

Recycling of natural resources is desirable both to facilitate conservation of raw materials and to improve the quality of the environment. This requires quite a new approach of a more global type than simple techniques of recovery of scrap or re-usable waste. Management of natural resources brings with it new constraints for manufacturing and production processes. New technological solutions will be necessary and above all a new philosophy of production and utilisation of material goods.

## Screening and Selecting of New Technologies

Such a screening includes:

1. Identification of research areas most likely to generate technological breakthroughs;
2. detection of those technological developments which are likely to lead to important innovations;

3. identification of possible innovations which seem more efficient and desirable on social grounds than existing technologies;
4. definition of criteria for evaluation of the desirability of such possible innovations.

Screening of potential new technologies will require a particularly imaginative approach since it is supposed to take into account a large amount of huge and hardly reducible uncertainties. It should be envisaged as a continuous process within a social system represented by a model which can be run with different sets of criteria to shed light on each new technological option.

## Research on New Socially Desirable Technologies

Both the final ends of economic growth and the self-justifying nature of technological change are increasingly questioned. Policy-making bodies are called upon to put first criteria for desirable societal initiatives and then look for a specific role which can be played by new technologies.

This involves conversion of societal aspirations and discernible needs into operational objectives and a workable consensus on such objectives. These conditions are hardly met in the real world. Society is still ill-equipped to handle conflicting interests and to decide what kinds of technological developments would lead to the achievement of certain objectives. A genuinely innovative approach is necessary to tackle problems arising from a new dimension and complexity of socio-economic phenomena.

## AMBITION AND CONSTRAINTS OF REALITY

The need to assess the technology assessment movement and studies completed over the last years stimulated a number of analyses. The most comprehensive ones are the review and evaluation of TA by Stanford University on behalf of the U.S. National Science Foundation, the synthesis of a series of public hearings by the U.S. Office of Technology Assessment and a detailed examination of fifteen existing studies by the OECD (10,11,12).

Based on these analyses and evaluations, an attempt can be made to draw some general remarks on two points of fundamental importance: the definition of the technology under study and the evaluation of impacts and formulation of action options.

Critics of TA contend that, so far, there hardly has been any comprehensive study whose findings would approximate the initial ambition or expectation. There are several reasons for this and one of them is the unrealistic delineation of the study in comparison with constraints of time, money and available skills.

Scope of the Assessment

Contrary to what such a criticism may imply, experience shows that it is extremely difficult to define a new technological development in accessible operational terms as a conceptual whole and subject for a TA study. Most studies are started with a theme defined only in vague terms. The usual justification is a lack of data. It is not always understood that the definition of the technology is decisive for the scope and structuring of the study. Only an iterative process of narrowing the limits of the technology can lead progressively to an outline of a workable "assessment system" and its variables.

In most cases the scope of the study is too broad even in terms of technical feasibility and the main technical variants. This makes it necessary to concentrate major efforts on collecting such a range of technical data that it is impossible, within reasonable limits, to give sufficient consideration to alternative technologies and, even less, to ascertain all relevant impact areas.

The experience available suggests that a full assessment of technology can be carried out only when the analysis is limited to a narrow and carefully defined technological development, so that the analysts are able to consider in sufficient depth all the constitutive categories of the assessment. However, to limit the scope of the technology studied may run counter to another - fairly contradictory - requirement, which is, to situate this technology with regard to alternative systems, alternative technologies, and competing and supporting technologies. All this cannot be covered to the same degree of pertinence and detail. It is obvious that superficial and arbitrary assumptions would be misleading. On the other hand, a reasonably creditable and documented survey of this kind is necessarily a costly task both in terms of funds and talents.

Stumbling-block of Social Impacts

By definition, identification and evaluation of impacts is the central part of social assessment of technology. It should therefore be the most accomplished part of the study. In reality, it seems to be the most elusive, in spite of many-faceted and often enlightened efforts to supply relevant information on possible effects of a technology.

In most studies only the identification of non-technical impacts is undertaken, generally in breadth rather than in depth. Frequently, impact areas are identified on a conceptually pre-selected basis inferring by analogy with past examples the effects expected from a technological development. The result is that some categories of effect receive particularly insistent attention whereas whole categories of other impacts are ignored. Since no explanation is given in the studies of the reasons for selecting a given category of impacts rather than another, the general impression is that the coverage of impact areas is highly intuitive and often dictated either by a personal scale of preferences or by the degree of accessibility to readily usable data.

To ascertain those societal areas which are likely to be influenced by the application of a given technology is an important step provided that it is followed by an evaluation of impacts. This is the hard core and the most difficult part of the analysis. In many studies there is a tendency to be as comprehensive as possible in the logical or imaginative inference of eventual impacts. However, such an extensive listing of a great number of impacts runs a risk of being merely a formal brain-storming exercise if it is not accompanied by an effort to determine their probable magnitude and intensity.

In general, evaluation concentrates mainly on technical and economic factors and aspects. Other categories of impacts are treated in descriptive and more or less peripheral terms. There is a clear-cut methodological break between the former group of effects - deemed amenable to statistical and numerical evaluation - and the latter, considered as being of a distinct "qualitative nature".

The final outcome is thus heavily unbalanced. Given the inherent or supposed difficulties of quantification, the attention is focussed on quantifiable elements while the puzzling problem of attaching some commensurable value to social aspects is pushed yet farther away into the realm of analytical intractables.

This makes it almost impossible to think of drawing together the various impact categories into an integrated overall balance sheet of societal advantages and costs. Such a failure is a major drawback, throwing some doubt on the realistic character of the social assessment of technology and the usefulness of its resulting findings to the decision-maker.

## Policy Options

Considerable attention is devoted to the formulation of action options or suggestions for policy measures. Such extensive treatment may be surprising when one considers the rather inconclusive analysis of societal categories of impacts. This may reflect a more or less conscious effort to compensate for the somewhat frustrating part of the analysis dealing with evaluation of impacts. In many cases, an impressive list of suggestions is drawn up like an inventory of things that should be done, rather than a truly rigorous definition of action options derived as closely as possible from the results of the assessment of impacts.

There is a general tendency to give as many suggestions or recommendations as possible, as if they were generated in a brain-storming session. These suggestions frequently resemble an enumeration of desiderata formulated without any attempt to establish a hierarchy or to order them by some rating based on a set of criteria of internal coherence and political feasibility.

The type of action most often investigated is reform of legal norms and regulations. This is presumably because these are reputed to have the most general validity and because it is believed that they can be most easily acted upon by the public decision-maker.

Though some attention is given to issues which may arise as a consequence of actions or behavioural attitudes of the interested social groups on the one hand and the affected parties on the other, the general tendency is to avoid these questions in final suggestions or policy recommendations.

In summary, it appears extremely difficult to formulate a range of action options set in a coherent political framework so that they could impose themselves on the attention of decision-makers. There is little evidence that recommendations resulting from TA studies have facilitated or simplified the decision-making process. Their main contribution may be a more systematic structuring of uncertainty and above all an awakening of more intense awareness on the part of decision-makers of often neglected or unnoticed impact areas.

## TOWARDS A CREATIVE SOCIAL ASSESSMENT OF TECHNOLOGY

All the various pieces of experience suggest that the fundamental rationale of SAT is to map out consequences of new technological developments in order to monitor technology for the benefit of society. There may still be many shadings in the definition of technology assessment or description of its conceptual framework. But beyond these differences it is now possible to distinguish the basic characteristics of comprehensive technology assessment or social assessment of technology which make it potentially far-reaching in shaping the decision-making process:

1. Comprehensive or social assessment of technology must be conducted in a "systemic way", i.e. the problem under consideration is studied as a system, as a dynamic whole whose components are defined both _per se_ and through the mutual relationships.

2. Its central part is a systematic inventory of the possible impacts on society, both direct and indirect, short and long-term.
3. The crucial phase is the attempt to evaluate all of these impacts including, in addition to the usual technical and economic ones, the impacts on individuals, social groups, social structures, the environment and value systems.
4. Not only promoters and interested parties have to be taken into account. In particular, the options and socio-political weight of those social groups who have previously been considered as external to the decision-making process must enter into the analysis of impacts and especially into the formulation of policy.
5. The expected outcome of genuine assessment of technology is to present an array of coherent action options to the decision-maker.

Ideally, SAT should be considered from the very beginning of a new technology development. Concern for societal relevance of technology should be integrated into evaluation criteria for research findings. To establish such a set of criteria presupposes a very high degree of societal consensus on basic common values. However, achievement *ex ante* of societal consensus is the most difficult and evasive problem of the decision-making process.

As a matter of fact, the nature, size and growth rate of indirect effects of a new technology are unknown. Reducing this uncertainty implies establishing some meaningful links between changes observed in the past and application of a new technology. This is a long endeavour which requires pluri-disciplinary research and important human and financial resources. Prior to undertaking such an effort, government must be convinced that the new technological development is likely to have considerable impacts on society.

Now, it is extremely difficult to determine, prior to the outburst of a crisis, which of the governmental mechanisms is supposed to foresee technology impacts on society. In certain sectors management of technology is inherent in the operational activities of the responsible governmental departments. In most cases however no governmental agency will be charged with new responsibilities as long as it is not quite clear whether a new technology is likely to be prejudicial to human health or to have harmful effects on national economy.

Most of the assessment studies realised by governmental agencies bear on specific techniques or issues closely related to their administrative responsibilities. Strictly speaking, no governmental agency can avail itself of budgetary appropriations for problems which lie outside its official sphere of responsibility. Consequently, it is in the nature of the governmental apparatus to tackle problems in a way that is likely to discourage launching of the most important or needed assessment studies which would best serve the public interest.

The private sector tends to look at SAT as an additional and particularly insidious intrusion into the domain of free enterprise which threatens to stifle innovation at its very source. As long as SAT encounters this attitude of apprehension, if not overt hostility, there is little chance of making it a central piece of the decision-making process in matters of technology. The only means to overcome this difficulty is to emphasise the "creative" role of TA, that is to orientate it mainly towards desirable transformation of existing technologies and development of new technologies more in line with societal concerns, so as to help find a new ground for relating innovators' interests to the pursuit of social objectives.

To become an effective tool for exploring and evaluating societal impacts of new or alternative technological developments, SAT must be a specific and continuous process. Neither analysts nor public decision-makers can perform satisfactorily without a continuous analysis of the social phenomena at issue. Consequently, technology assessment requires a permanent monitoring activity based on a continuous evaluation of the states of society so as to establish an organic link between technological change and social and economic trends and aspirations.

## REFERENCES


1. Wenk, Edward, Hearings, Committee on Science and Astronautics, U.S. House of Representatives, Washington, D.C., (1971).
2. Gibbons, Michael, Technology Assessment: Objectivity or Utopia, Prometheus, August 1976.
3. Schuman, Jack N., Assessing Technology Assessment, Futures, August 1976.
4. Henderson, Hazel, Philosophical Conflict: Reexaming the Goals of Knowledge, Technology Assessment, Public Administration Review, Jan-Feb 1975.
5. Dobrov, G.M., A Strategy for Organised Technology in Systems Assessment of New Technology: International Perspectives, IIASA Workshop, Laxenburg, (1978).
6. United Nations, Technology Assessment for Development, Report of the United Nations Seminar on Technology Assessment for Development, Bangalore, India, New York, (1979).
7. Hetman, Francois, Society and the Assessment of Technology, OECD, Paris, (1973).
8. Methodological Guidelines for Social Assessment of Technology, OECD, Paris, (1975).

9. Social Assessment of Technology in the Field of New Urban Transportation Systems, OECD, Paris, (1978).
10. Office of Technology Assessment, Technology Assessment in Business and Government, Congress of the United States, January (1977).
11. Stanford University, Dept. of Engineering-Economic Systems, Strategies for Conducting Technology Assessment, Conducted by Joe E. Armstrong and Willis W. Harman, Stanford, December (1977).
12. OECD, Social Assessment of Technology, Review of Selected Studies, In print.

# 20
# Technology Assessment in Arid Land Renewable Resource Development: Guayule in Mexico*

*E. Campos, J. García,*
*E. Neavez, K. E. Foster,*
*B. K. Mortensen, and J. Taylor*

## INTRODUCTION

Guayule (Parthenium argentatum) is a rubber-producing shrub native to the Chihuahuan Desert. It has constituted one of the most important projects of CONACYT (National Council for Science and Technology) and CONAZA (National Commission for Arid Zones) and these two organizations have financed Guayule research and development activities in Mexico since 1973.

The Guayule Project began in an historic era. The world fuel crisis, experienced since 1973, became an important driving force; the situation in the natural rubber market began to recuperate after almost three decades of depression and uncertainty; interest arose in alternative sources of energy and materials; and from numerous laboratories and experimental fields throughout the world potential hydrocarbon- or oil-producing crops emerged.

In Mexico the Guayule Project was being structured and around 1977 it became a Research and Development Project, integrating pilot and product development activities. The first steps towards implementation were taken in 1980, although some attempts had previously been made.

It began to appear obvious that the public sector agencies were too weak to integrally evaluate technologies which, like the Guayule one, imply not only the handling of abundant information from diverse and numerous scientific fields, but also the management of the values and political criteria of various federal dependencies with regional responsibilities, the political organizations, the rubber industry, the "beneficiaries" and the role of the governors. All this complex framework of interests

---

* This is an abbreviated version, translated from Spanish, of a Research Report entitled "Evaluación de los Impactos de la Comercialización de Guayule en México", presented by CIQA to CONACYT and CONAZA in 1982.

gradually surrounded the Guayule Project before the impotence of the traditional schemes of technical-economic evaluation which were insufficient for such a changing situation - between 1979 and 1982 alone the price of rubber fluctuated from U.S. 40 cents to 90 cents and fell again to 40 cents per pound. If the inflation and devaluation of the Mexican peso during this same period is considered, the infeasibility of economic evaluation as the only criterion can be understood. How could the criteria of analysis and decision-making be based upon this uncertainty?

The current serious limitations of the public sector agencies in charge of the diffusion of innovation in arid zones have been put to the test by the Guayule Project and the need for new interactive, systemic, systematic and prospective procedures for the analysis of the numerous technological options available for the development of arid zones has been shown up.

This Technology Assessment (TA) emerged as part of this process and it integrates the path followed by the Applied Research and Experimental Development Project, the relevant factors which have favoured it and the constraints against its conversion into a Regional Development Project. Based on the state of society, it presents alternative development scenarios and has eminently practical aims oriented towards recommendations and decision-making. It is one of the first efforts made in Mexico to apply this type of methodology in the integral analysis of the numerous technology options which will be required in regions which, like the arid ones, have natural constraints on their development. The sustainability of the resources for development will be one of the principal challenges for the coming decades and will demand the trying out of new methodological approaches which, like TA, take science and technology into the sphere of public policies and decisions.

In the Mexican Guayule Project, the criteria of technical effectiveness began to be replaced by those of economic feasibility, followed by the considerations of a social nature and, finally, those of political, institutional and organizational feasibility. The assessment of a technology involves not only the analysis of the desired effects, but also of the less obvious second order consequences of the innumerable "trans-scientific" questions which are more difficult to resolve in a "scientific way". Each perspective provides its own perceptions of the uncertainties and risks which accompany the decisions. Guayule was transformed from a multi-objective project into an even more complex one which involves various groups and institutions (1).

Majone (2) states that no technology exists which is institutionally and distributionally neutral; its impacts depend upon the institutional framework through which it is transferred and utilized. The operators and beneficiaries - individuals or institutions - will always try to achieve a less restricted use. On assessing a technology and its impacts, we are really assessing the institutional framework.

## WHAT IS TECHNOLOGY ASSESSMENT?

Technology Assessment has gradually evolved from simple cost/benefit analyses to sophisticated means for policy analysis. TA is a consequence of the technological development of the increasingly rapid incorporation of new technologies into society and of the direct and indirect impacts which this causes. Some authors (3) identify up to four stages in its evolution. One of the fundamental studies was that carried out by the National Academy of Sciences of the United States of America and entitled "Technology: Processes of Assessment and Choice" (4). This was submitted to the Commission for Science and Technology of the U.S. Chamber of Representatives on 19th July 1969 and later gave rise to the creation of the Office of Technology Assessment of the U.S. Congress.

Some relevant definitions of TA are:

> Technology assessment is a class of policy studies which systematically examine the effects on society that may occur when a technology is introduced, extended or modified. It emphasizes those consequences that are unintended, indirect, or delayed (5).

> Technology assessment is a deliberate search for the consequences of a given technology in order to determine whether the intended benefits are sufficient to offset its costs (6).

> TA is an attempt systematically to identify, analyze, and evaluate the potential environmental, legal/political, and other social impacts of a technology. TA is being developed as a policy-making tool for alerting public and private decision makers to the likely consequences of making a decision either to employ a particular technology or to choose among alternate technologies...assessors assume that unanticipated impacts can be as powerful, pervasive, and durable as the anticipated impacts (7).

> Technology assessment can be defined as a process of analysis, forecasting and assessment of technological futures and their impacts on society resulting in action options for the decision-makers (8).

TA has emerged, to a great extent, due to the increase in the society-technology-environment interactions. It is in the developed countries where more emphasis has been put on its application; a large part of the directing forces originated from the preoccupation of the deterioration of the environment produced by technologies and by the uncontrolled induction which these cause in the flows of energy and materials within the environment. TA is also linked to the planning of the economy and technology, presenting different approaches depending on the country concerned:

- In the developed countries with a free market economy, the development of TA has been fundamentally oriented towards problems of an environmental nature (9).
- In the developed countries with centrally-planned economies, TA is an instrument immersed within the social system of technology. It is oriented more towards technical and economic aspects. Some authors (10) consider it as a field of "science of science". As an example of the importance of TA techniques, it is interesting to note that in the USSR alone 150 different forecasting methods were applied in various fields of technology (11).
- In the developing countries, the low flow of technology has demanded slight needs in terms of assessment. Brazil is one of the countries which has begun to carry out this type of study and the National Council for Research (CNPq) has had an office of TA studies since 1978 (12). In Mexico, the National System for Technological Forecasting was founded within the Ministry of Patrimony and Industrial Promotion (SEPAFIN) in 1982 (13). During a UN meeting held in 1978 in Bangalore, India (6), the need to promote the carrying out of TA was mentioned, with emphasis not only on environmental impacts but also as strategic studies which induce the transfer of technologies and improve the capacity for selection based on regional and sectorial factors. Some of the first attempts to apply TA have been in appropriate technologies, but these have diminished due to lack of confidence in these technologies which have often been considered as second order ones; fortunately TA is a methodology which can be used at any level of technology. TA could be an important instrument of methodological support for the planning of R&D projects and in the identification of "holes" of critical information.

## How is it Structured?

A TA is a systematic study of the interactions between a specific technology and society. It is not an engineering study, nor an economic, legal or operational research one, but it can incorporate part of these. It is fundamentally based on systems analysis and accepts flexibility starting from the fact that the technology cases surrounding it can be very diverse. Table 1 identifies some components of a TA.

## Tools

For the integration of these components, a "tool-kit" exists, as mentioned by Coates (5), which ranges from the Delphi techniques, dynamic modeling , KSIM (Kane Structural Interpretative Modeling), input-output analysis, cost-benefit analysis, etc., as well as procedures which include workshops, interviews, hearings, etc. Each one of these tools is utilized, according to the problem and the criteria of the analysts, in one of the various stages of the study. Figure 1 shows how some of these study techniques can be incorporated in the various components of the TA and which were used during the Guayule TA.

TABLE 1.
Components of a TA

| According to Coates (5) | According to Porter (14) |
|---|---|
| 1. Examine the components of the problem | 1. Definition of the problem |
| 2. Specify systemic alternatives | 2. Description of the technology |
| 3. Identify possible impacts | 3. Technological forecasting |
| 4. Evaluate impacts | 4. Social description |
| 5. Identify the decision apparatus | 5. Social forecasting |
| 6. Identify the action options for (5) | 6. Identification of impacts |
| 7. Identify the parties-at-interest | 7. Analysis of impacts |
| 8. Identify the macro-system | 8. Impact evaluation |
| 9. Identify exogenous variables or possible events which could affect (1) to (8) | 9. Policy analysis |
| 10. Conclusions and recommendations | 10. Communication of results |

| Study techniques | Structuring the problem | The systems alternatives | Possible impacts | Evaluating impacts | Identifying decision makers | Identifying possible action options for decision makers | Parties at interest | Macro systems alternatives | Exogenous variables State of society | Conclusions and Recommendations | Participation of parties at interest | Presentation of results |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Historical surveys | ● ○ | ● ○ | ● ○ | | ● ○ | ● ○ | ● ○ | ● ○ | ● ○ | ● ○ | | |
| Input/output | ● ○ | | | ● ○ | ● ○ | | ● | | | | | ● ○ |
| Compilation of prior work | ● ○ | ● ○ | ● ○ | ● ○ | | ● ○ | ● ○ | ● ○ | ● ○ | ● ○ | ● ○ | |
| Cost-benefit | ● ○ | | | ● ○ | | | ● ○ | | | | | ● |
| Systems analysis | ● ○ | ● ○ | ● ○ | ● ○ | | ● ○ | | ● ○ | | | | |
| Risk-benefit | ● | | | ● | | | ● | | | | | ● |
| Systems engineering | ● | ● | ● | ● | | | | ● | | | | |
| Simulation | ● ○ | ● ○ | ● ○ | ● ○ | | | ● ○ | | ● ○ | | ● ○ | ● ○ |
| Expert panels, workshops | ● ○ | ● ○ | ● ○ | ● ○ | ● ○ | ● ○ | ● ○ | ● ○ | ● ○ | | ● ○ | ● ○ |
| Modeling | ● | ● | ● | ● | | | ● | | ● | | ● | ● |
| Hearings | ● ○ | ● ○ | ● ○ | | ● ○ | ● ○ | ● ○ | ● ○ | ● ○ | ● | ● | ● |
| Interpretive struct. mod. | ● | | | | ● | | ● | | | ● | ● | ● |
| Field or on-site research | ● ○ | | ● ○ | ● ○ | ● ○ | | ● ○ | | | | ● ○ | |
| Signed digraph | ● ○ | | ● ○ | ● ○ | ● ○ | ● ○ | | | | | | ● ○ |
| Trend extrap. & analysis | | | ● | ● | | | | | ● | | | |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Physical models | | | ● | ● | ● | ● | ● | ● | ● | | ● | |
| Delphi | ● ○ | ● ○ | ● ○ | ● ○ | ● ○ | ● ○ | ● ○ | ● ○ | ● ○ | ● ○ | ● ○ | ● ○ |
| Scenarios/games | ● ○ | ● ○ | ● ○ | ● | | ● | | | ● ○ | | ● ○ | |
| Cross impact | ● | ● | ● | ● | ● | ● | ● | | | ● | ● | ● |
| Survey techniques | | | | ● ○ | | | ● ○ | | ● ○ | ● ○ | ● ○ | ● ○ |
| Decision/relevance tree | ● | ● | ● | ● | ● | ● | | | | | | ● |
| Ballots | | | | ● ○ | | | ● ○ | | ● ○ | ● ○ | ● ○ | ● ○ |
| Fault tree | ● | | ● | ● | | | | | | | | ● |
| Decision theory | | | | ● | | ● | | | | | | ● |
| Scaling | | | | ● ○ | | | | | ● ○ | ● ○ | | ● ○ |
| Brainstorming | ● ○ | ● ○ | ● ○ | | | | ● ○ | ● ○ | ● ○ | ● ○ | ● ○ | |
| Graphics | | | | ● ○ | ● ○ | ● ○ | | | | | ● ○ | ● ○ |
| Judgement theory | | | | ● | | ● | | | | ● | | |
| Dynamic modeling | ● | ● | ● | ● | | | | | ● | ● | | ● |
| KSIM | ● ○ | ● ○ | ● ○ | ● ○ | | | | ● ○ | ● ○ | ● ○ | ● ○ | ● ○ |
| Check lists | ● ○ | ● ○ | ● ○ | | ● ○ | ● ○ | ● ○ | | | | | ● ○ |
| Telecommunication participation | | | ● | ● | ● | ● | ● | | ● | ● | ● | ● |
| Morphological analysis | ● | ● | | | | | | ● | | | | |
| Historical analogy | ● ○ | | ● ○ | ● ○ | ● ○ | ● ○ | ● ○ | | ● ○ | ● ○ | | |

● Original table

○ Techniques used in the Guayule TA

FIGURE 1. Elements in a comprehensive technology assessment (5).

## Consequences

Some of the most important consequences of a successful TA study are:

- Stimulation of research and development (reduce risks, alternative technologies, corrective measures);
- Identification of regulatory needs;
- Promotion of legislation development in new areas;
- Identification of institutional changes;
- Support of innovation strategies;
- "Culturalization" of the parties at interest with regard to the technology;
- Support of planning and implementation;
- Modification or delay of the project to reduce or avoid negative consequences;
- Render the technology operational.

Some of the most recent applications are found in such important fields as energy, genetic engineering, new crops, electronics, forestry activities, hydraulic projects, communications, etc.

## THE GUAYULE TA

During the carrying out of the Guayule TA, extensive interaction among the participants was sought. To this end some adaptive approaches were employed: using some of the experiences reported by Holling (15,16), emphasis was placed on the organization of three structured workshops in which the technology and the scenarios were presented, the critical questions discussed, the impacts assessed and the policy analysis begun. The study lasted 18 months and was financed by the National Council for Science and Technology (CONACYT), the National Commission for Arid Zones (CONAZA), the Applied Chemistry Research Centre (CIQA) and the National Science Foundation of the United States of America. The central working group was made up by investigators of CIQA and of the Office of Arid Lands Studies of the University of Arizona. The principal agencies, industries and local groups interested in the exploitation of Guayule participated throughout the study.

Through the workshops, important experiences were gained from the various participants and from the discussion on the technology-related problems. In all of the workshops, two types of document were utilized: 1) a working document and 2) the summary of the previous workshop. During the last two workshops, "in situ" computer facilities were available for the application of KSIM in impact evaluation exercises and Delphi.

The most important results of the study are presented in the following sections in the same order as that followed during the study.

## The Rubber Market

In 1980 each Mexican consumed an average of approximately 0.6 kilograms (kg) of natural rubber and by the year 1995 this figure could rise to approximately 1.5 kg (7% annual increase in consumption). Natural and synthetic rubbers are strategic materials in the economy of every country. The relationship between economic growth and the consumption of energy is manifested as a secondary but inevitable impact on the consumption of rubber articles (tyres, seals, etc.). Despite the explosive substitution of natural rubber for synthetic rubber after the Second World War, the crisis of 1973 reduced this process. From then on the natural rubber market began to stabilize and its prices to improve, although these have again been very erratic during the last three years. The existing studies on the future natural rubber market differ with regard to numbers (17) but coincide on trends:

- Natural rubber will conserve its competitiveness and its share in the international market of around 30% of the total rubber consumed by mankind;
- The prices of natural rubber will be related to the prices of synthetic rubbers and fuels;
- The capacity to produce natural rubber is not sufficiently dynamic to satisfy the demand and there will be shortages;
- The development of new tyre technologies (principally radials) has had a positive impact on the demand for natural rubber.

In Mexico the situation is similar. The demand for natural rubber is related to the economic development; supposing a 7% increase in the demand, at the end of the years 1995 and 2000 there will be serious deficits of 155 and 219 thousand tons respectively (Figure 2). There is an "almost unlimited" market for natural rubber which could be produced in Mexico. If this were to happen, it would improve the balance of trade and reduce the dependence on imports. The supply of polyisoprene rubbers, natural and synthetic, requires a formal policy which still does not exist, although its design has been attempted (18). The production of non-isoprene synthetic rubber is increasing rapidly to satisfy part of the demand for domestic consumption, but the production of natural rubber requires longer-term plans due to the prolonged length of time needed for the establishment of the crop and development of the organization. The Rubber Trust (Fidhule) has expressed the intention of incrementing the production

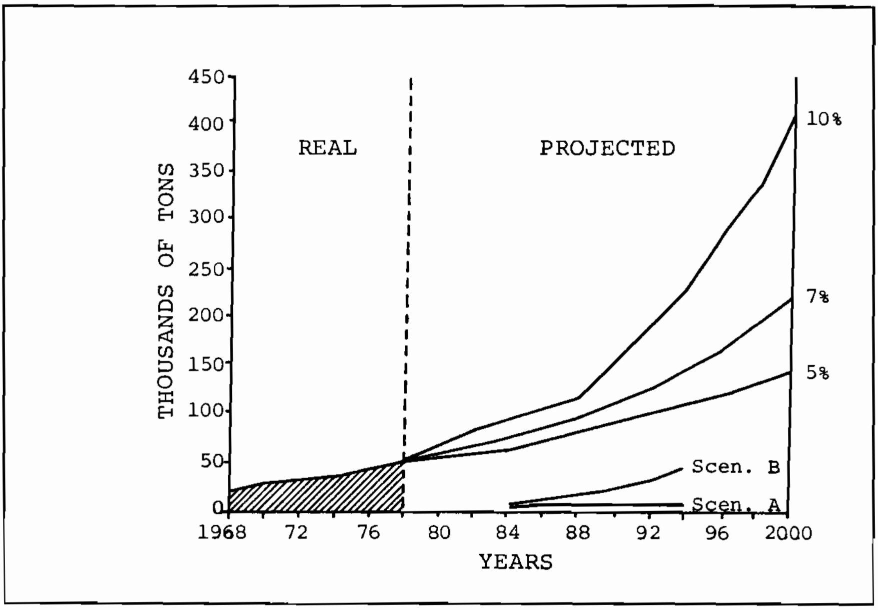



FIGURE 2. National consumption of natural rubber

of natural rubber from Hevea brasiliensis in Mexico, which in 1980 only supplied 10% of the demand.

## Guayule: The State of the Art

Perhaps no other arid zone plant exists which has been studied with the thoroughness and depth dedicated to Guayule. The scientific knowledge and technology currently available originates from three stages:

- Until the 1930s, studies were carried out by companies, mainly from the USA, oriented towards the study of the shrub, its inventory, physiology and botany and the development of industrialization methods, many of which were put into practice in the various industrial plants which were established during this time (19). These technologies did not produce high-quality rubber but, for the needs of those days, it penetrated the market.
- The Emergency Rubber Program (ERP), supported by the government of the United States of America, began before the First World War and terminated at the beginning of the 1950s. It put emphasis on the domestication of the shrub and originated a large part of the current agronomic know-how. It

also went more deeply into the development of industrialization processes and paid some attention to the use of the sub-products - especially the resin. During this same era, other countries, such as Italy, Argentina and Spain, carried out research on this shrub.

- The third stage began in the 1970s in Mexico with the establishment of CONACYT and CONAZA. The Program, utilizer of new technical and scientific elements and tools, supported by these dependencies was first oriented towards the satisfaction of basic Guayule information needs (microstructure, molecular weights, branching, etc.)(20). Special emphasis was put on the development of industrialization processes, pilot experimentation, product development, ecological studies, inventories, etc. From 1976 onwards, other countries, especially the USA, were incorporated into the agronomic studies. Later other countries, such as Australia, Israel and some African countries, became interested.

The utilization of Guayule presents numerous alternatives. In Mexico it can range from a silvicultural system with slight technological advances, to a highly technified, irrigated agronomic operation. This wide spectrum of options is due to Guayule's characteristic physiology and the fact that its rubber is not an annual product but is accumulated as the plant grows and advances in its interaction with the "stress" of the environment. Its genetic potential is immense and its photosynthesis is carried out via a C3 mechanism (21).

The current advances in agronomy make it possible to design cultivation strategies which, utilizing the previously-mentioned characteristics and with adequate handling of water and soil allows a crop harvest within a time period of 4 to 2 years.

Abundant information is currently available with regards to agronomic aspects, the industrialization process, the basic knowledge about its rubber and the development of technical products from this rubber. This information has been classified utilizing a CIQA methodology (22) which divides the R&D activities into 5 levels: 1) the resource, 2) agricultural or silvicultural practices, 3) the process, 4) the product and 5) the sub-products, around the three stages of an agroindustrial system - supply, transformation and distribution. This information is presented in Figure 3 which uses these concepts and some others (23).

There is a huge amount of information still to be obtained, but much of this, especially the agronomic information, requires levels of financing and organization which this project in Mexico never had; therefore policy decisions are essential.

| | Known/ Operational | Needs refinement | In Development: Lab. | In Development: Pilot | Idea planned | Unknown | CIQA | CONAZA | OTHERS | ERP USA 1942-1946 | OTHER USA |
|---|---|---|---|---|---|---|---|---|---|---|---|
| RESOURCE BASE | | | | | | | | | | | |
| -Abundance/existence | ● | ● | | | | | ● | ● | | | |
| -Ecology/habitat | ● | | | | | | ● | | 1,2 | ● | |
| -Physiology | | | ● | | | | ● | | 1,2 | ● | ● |
| -Genetics | | ● | ● | | | | | | ● | ● | ● |
| -Biochemistry | | ● | ● | | | | ● | | ● 3 | ● | ● |
| -Cytology & anatomy | ● | | | | | | | | ● | ● | ● |
| SUPPLY | | | | | | | | | | | |
| -Alternative propagation | | ● | | ● | | | ● | | 1,2 | ● | |
| -Reforestation/forestation[a] | | | | ● | | | ● | | ● | | |
| -Dryland cultivation | | ● | | | | | ● | | 1,2 | ● | ● |
| -Cultivation under irrigation | ● | ● | | | | | | | 1,2 | ● | ● |
| -Germination methods | ● | | | | | | ● | | 1,2 | ● | ● |
| -Seedling production | ● | | | | | | ● | | 1,2 | ● | ● |
| -Direct seeding | | ● | | ● | | | ● | | 1,2 | ● | ● |
| -Site selection | | ● | | | | | ● | | 1,2 | | ● |
| -Water consumption | | ● | | | | | ● | | 1,2 | ● | ● |
| -Equipment required | | ● | | | | | | | 1,2 | ● | ● |
| -Pest control | | | | ● | | | | | 1,2,3 | ● | ● |
| -Bioinduction | | ● | | | | | ● | | 3 | | ● |
| -Harvesting methods | ● | ● | | | | | | | 1,2 | ● | ● |
| TRANSFORMATION - CIQA Process/Aqueous System | | | | | | | | | | | |
| -Transport of Guayule | | ● | | | | | ● | | | | |
| -Storage | | ● | | | | | ● | | | | |
| -Grinding | ● | | | | | | ● | | | | |
| -Pulping and separation of rubber | ● | | | | | | ● | | | | |
| -Deresination | ● | | | | | | ● | | | | |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| -Rubber purification & stabilization | ● | | | | | | ● | | | | |
| -Solvent recuperation | ● | | | | | | ● | | | | |
| -Drying and standardization | ● | | | | | | ● | | | | |
| -Use of sub-products | ● | | | | | | ● | | | | |
| -Water recirculation & residue elimination | ● | | | | | | ● | | | | |
| -Basic engineering | ● | | | | | | ● | | | | |
| -Detailed engineering | ● | | | | | | ● | ● | | | |
| -Energy and materials balance | ● | | | | | | ● | | | | |
| THE RUBBER | | | | | | | | | | | |
| -Chemical structure | ● | | | | | | ● | | | | ● |
| -Phys./Chem., Phys./Mech. & Ecol. prop. | ● | | ● | | | | ● | | | | ● |
| -Use evaluation (tyres, seals, pipes, etc.) | ● | ● | | | | | ● | | | | ● |
| -Dev. of derivated prods. (thermoplastics) | | | ● | | | | ● | | | | |
| -Quality standardization | ● | | | | | | ● | | | | |
| SUB-PRODUCTS | | | | | | | | | | | |
| Resin - characterization and uses | ● | | | | | | ● | | | | ● |
| - extraction and purification proc. | ● | | | | | | ● | | | | |
| - economic feasibility | | | | | | ● | | | | | |
| Bagasse - application alternatives | ● | | | | | | ● | | ● 1 | | ● |
| - forrage production process | | ● | | | | | ● | | | | |
| - assessment as fuel | ● | | | | | | ● | | | | ● |
| - assessment as forrage | | ● | | | | | ● | | | | |
| - economic feasibility | | | | | ● | | ● | | | | |
| GENERAL | | | | | | | | | | | |
| -Site of processing plant | ● | | | | | | ● | | | | |
| -Technical & economic prefeasibility | ● | | | | | | ● | | ● | | |
| -Socio-economic state of the region | ● | | | | | | ● | | | | |
| -Guayule TA | ● | | | | | | ● | | ● | | |
| -Planning of project implementation | | | ● | | | | | | | | |
| -Policy analysis for Guayule Ag./Ind. Syst. | | | ● | | | | ● | | ● | | |

[a]The maximum sustained yield of wild Guayule stands is still to be determined.

KEY: 1 = Agronomic University "Antonio Narro", 2 = Agricultural School "Hermanos Escobar"
3 = National Autonomous University of Mexico.

FIGURE 3. State of development of Guayule technology

Nearly all the elements of the technology of Guayule production and its rubber are at the stage where they need to be refined and tested through large demonstration projects - the first stage could consist of a small-scale operation (<10,000 tons of rubber per annum).

## Scenarios

Quade (24) mentions that the development of implementation scenarios is one of the most useful methods for anticipating the future when the uncertainty is great; this is the case of projects such as the Guayule one. Scenario exercises are needed which allow the decision-maker to see alternative courses of action and the uncertainty and risks involved in each one.

What is a Scenario? Innumerable definitions of scenarios exist - two appropriate to the aims of this study are:

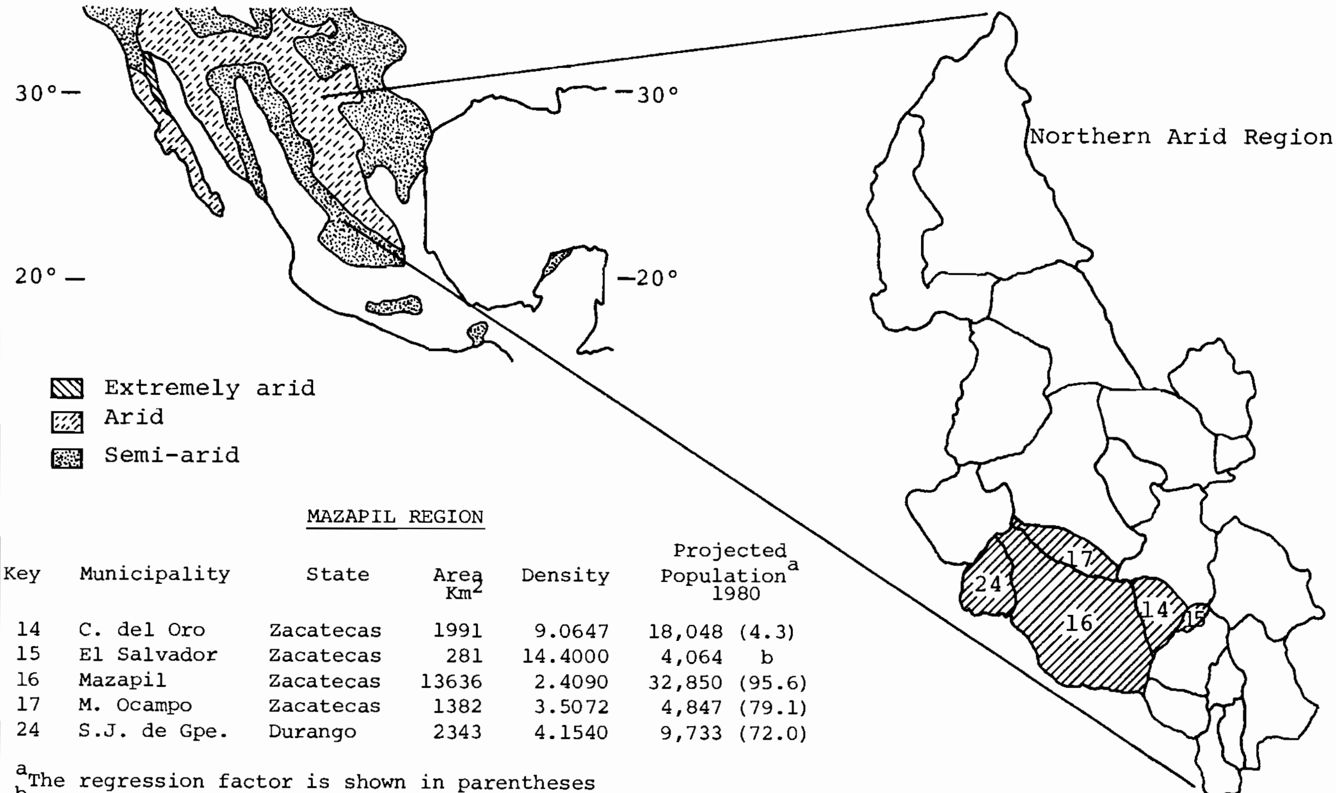
- A scenario is a logically consistent statement or characterization of a possible future state of the world. Often the scenario statement also specifies a logical sequence of events that could transform the reference or base year state into the postulated future state. The postulated future state can represent the consensus of many experts or be outrageously absurd, provided that it is internally consistent and follows from the assumptions made. A scenario, therefore, is not a prediction, but simply one of infinitely many future states that might happen. Scenario development and analysis can serve many varied purposes...for example in contingency planning or developing emergency preparedness. In contrast...scenarios are used to provide synthesis for conceptions and projections about a wide variety of issues in the long term. This is above all a learning process...(25).
- It is the description of a future situation together with the succession of events which led up to it.
- A scenario is a set of input data for a simulation model which reflects the actions of the decision-maker and the output of which presents the decision-maker with the system behaviour (26).

The two scenarios of this study are development ones and were improved upon through the workshops.

The Mazapil Region. Mexico has two vast desert systems - the Chihuahuan Desert and the Sonoran Desert (27). Historically, a large part of the commercial exploitation activities have been carried out in the former and this is the natural habitat of Guayule. The Northern Arid Region (28) is part of the Chihuahuan Desert and coincides, to a great extent, with the marginal region denominated by COPLAMAR (Coordination of the National Plan for Depressed Zones and Marginal Groups) as "Ixtlera-Candelillera" due to the activities of ixtle fibre and candelilla wax exploitation. Within this Northern Arid Region (Figure 4), some regionalization exercises have been carried out which have permitted the identification of some "sub-regions" such as the Mazapil one (referred to from now on as a region) which is made up of four municipalities in the state of Zacatecas - Concepción del Oro, Salvador, Mazapil and Melchor - and one in the state of Durango - San Juan de Guadalupe. These five municipalities cover an area of 20,000 $km^2$ and had an estimated population of 81,563 in 1980. In 1970, 170 localities existed, of which only one was urban. Mazapil is an arid marginal region with the following characteristics:

Economic. The principal activity is represented by mining (80%), then follows goat husbandry (15%) and finally agriculture (4%) and forestry activities (1%). Since 1960, as a consequence of migration, the economically active population has been substantially reduced, equally in the prime sector as in the secondary and tertiary ones. Their principal occupations are mining, goat and cattle husbandry, dryland agriculture (corn and beans), the obtention of ixtle fibres and the extraction of wax from candelilla.

Social. The total regional population, both rural and urban, has been stable since 1960. Migration is a characteristic of the Mazapil region and especially of the municipalities of Mazapil and Concepción del Oro. In 1970, 60% of its 62,000 inhabitants lived in localities of less than 999 inhabitants. In 1978, of these localities, 9 were dedicated to candelilla harvesting, 91 (49 registered cooperatives and 42 unregistered) to ixtle harvesting and approximately 25 were supported by COPLAMAR programs - a figure which has certainly risen by now. Twenty-eight percent of the total number of localities have electricity. In 1970, 30% of the economically active population earned less than 200 pesos per month and 65% less than 500 pesos (in 1970 the official minimum daily wage was 60 pesos). In all of the Mazapil municipalities, the minimum standards of well-being - food, education, health, and housing - are less than the state averages and are among the lowest in the country (29). The average illiteracy rate for people over 15 years of age was approximately 25% in 1974. Seventy-three percent of the houses




MAZAPIL REGION

| Key | Municipality | State | Area Km$^2$ | Density | Projected Population[a] 1980 |
|---|---|---|---|---|---|
| 14 | C. del Oro | Zacatecas | 1991 | 9.0647 | 18,048 (4.3) |
| 15 | El Salvador | Zacatecas | 281 | 14.4000 | 4,064 b |
| 16 | Mazapil | Zacatecas | 13636 | 2.4090 | 32,850 (95.6) |
| 17 | M. Ocampo | Zacatecas | 1382 | 3.5072 | 4,847 (79.1) |
| 24 | S.J. de Gpe. | Durango | 2343 | 4.1540 | 9,733 (72.0) |

[a]The regression factor is shown in parentheses
[b]1970 population. This municipality was created in the 1970s.

FIGURE 4. Arid regions of Mexico (30)

do not have electricity and approximately 60% of the population do not have potable water services. There are 13 government-subsidized food shops in the region (SAHOP-Forestal). Since 1977, an intense social program has been carried out by COPLAMAR and its agreements (29) but the results of these were not available for integration into this TA study.

Political. Due to the economic and social marginality, to a great extent the development policies for this region have been established during the last few years by the COPLAMAR programs and the participation of the ixtle and candelilla workers' organizations has been of special importance. The social dispersion and low incomes causes the capacity for organization to be extremely reduced (31).

Climate and Environment. Arid climates predominate in the region; the northern part is a zone with a very dry desertic climate (BW) and the south a zone with a dry climate (BS). Hot summers and winter rains predominate - conditions which restrict the development of prosperous agriculture and added to this is the high risk of drought and the poor soils. Bushes with small leaves, and fleshy and thorny plants such as the maguey, sotol and lechuguilla dominate.

Water, Energy, Soil, Guayule and Manpower. The annual rainfall oscillates between 300 and 400 mm. There is potential for the obtention of underground water, however the existing infrastructure for agriculture is weak.

There are two electricity sub-stations and lines of 115 Kv to the principal population centres of San Tiburcio, Concepción del Oro, Mazapil, Cedros, M. Ocampo y Camacho, with around 16 electricity lines. The predominant solar energy incidence in the region is between 400 and 450 Langleys and in the rural areas firewood is still the most common source of energy (firewood 86%, electricity 9% and kerosene 5%) (32).

Around 16,000 "ejidatarios" (peasants who live on communal ranches) each have available on average a workable area of 1.33 hectares and 69.7 hectares of rough pasture. There are 1,600 smallholders, each with an average of 3.47 hectares of workable land and 218 hectares of pasture.

The majority of soils are alluvial, products of the erosion of the layer which covers the mountains; they are dry and poor in humus and very inapt for agriculture. In the greater part of the region, there are lithosols in association with regosols and calcic xerosols. Saline soils also exist in areas of San Juan de Guadalupe.

According to the inventories - satellite and field - carried out in the last few years (33,34), there are approximately 150,000 hectares with 485,000 tons (dry) of unexploited Guayule. The principal identified Guayule areas are found to the south of Mazapil and in Melchor Ocampo, with potential for reforestation of Guayule in a large part of the region.

Recent industrialization in neighbouring cities, particularly Saltillo, has demonstrated the great capacity for mobility of the work force in this region and, of course, migration to the USA is important. The lack of constancy in the social-economic programs, the lack of integral planning with frequent political conflicts and the aleatory nature of the primary economic activities, have also caused a large part of this mobility.

The Development Scenarios. Due to this "physiological capacity" of Guayule to be converted from a wild system (scarce technology, organization, social and environmental risks) to an agronomic system (highly technified under irrigation), there exist numerous options for development. The decision is, of course, a policy one and has to seek, among the various alternatives, that which is most appropriate to the social, economic, political and environmental needs. The decision is not simple and cannot be based on only one option.

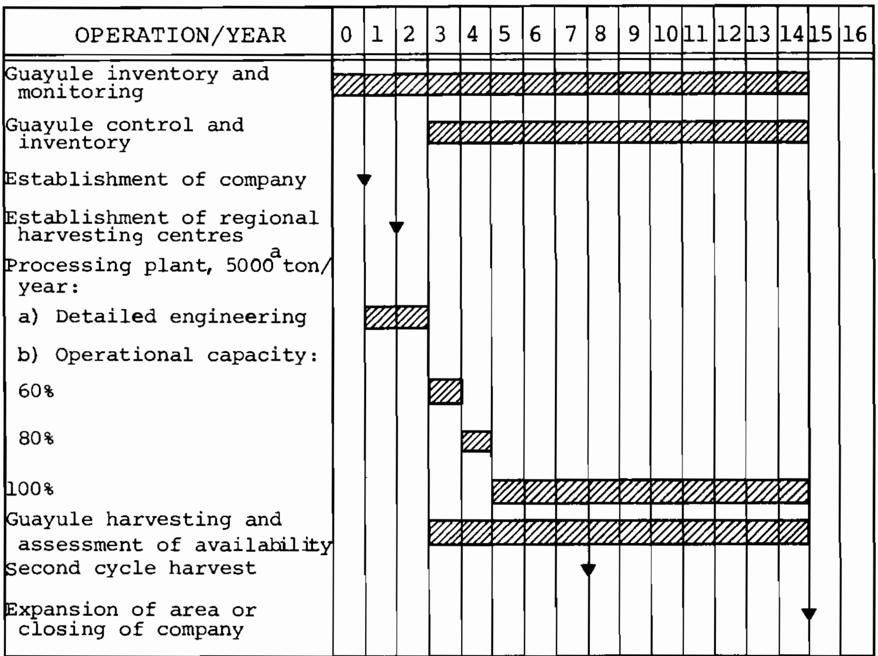
The problem is not so much the assessment of a technology of Guayule industrialization, but a whole system and strategy of implementation and operation. As it is impossible to study "all" of the options, two scenarios were elaborated which are more oriented towards the "wild-dryland" alternatives.

The two scenarios utilized for the evaluation of the impacts of a possible development of the Guayule agro-industry in Mazapil are:

- Scenario A, "Slow Growth" - based on the collection of wild Guayule motivated by social and regional needs.
- Scenario B, "Regional Potential" - supposes cultivation under dryland conditions, motivated by national economic needs oriented towards the satisfaction in 1995 of one third of the national demand for natural rubber.

Both scenarios are located in the Mazapil Region and take place between 1982 and 2000 (Figures 5 and 6). They are, for the purposes of analysis, intentionally restrictive, given that Guayule can be harvested or cultivated in a much bigger area than that of Mazapil, which was selected as being one of the most economically depressed and marginal in the arid north of Mexico and of course as presenting agroecological advantages for Guayule.

The two scenarios are based on the basic assumptions of the State of Society and of the market which are described in Table 2. Tables 3 and 4 show the specific aspects of each one of the scenarios.




[a]Rubber production could be reduced

FIGURE 5. Scenario A - "Slow Growth"

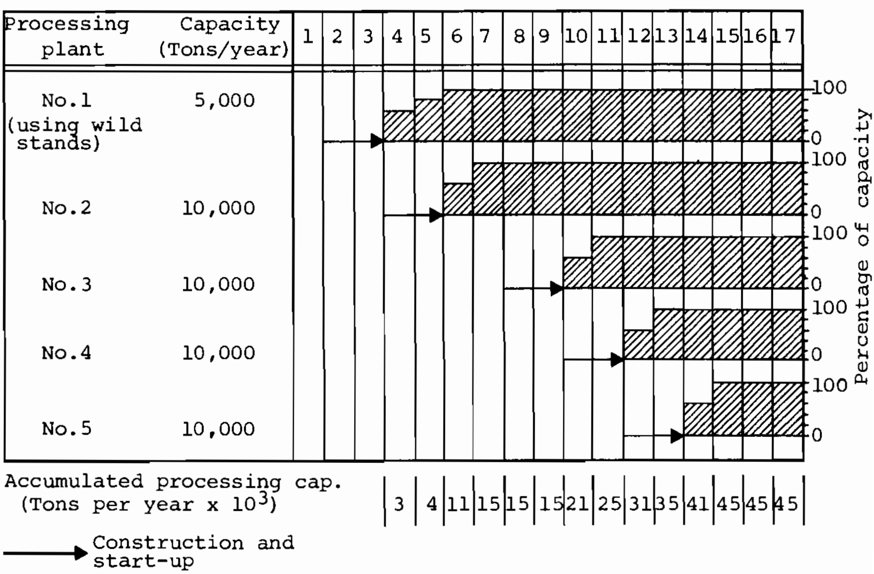



FIGURE 6. Scenario B - "Regional Potential"

TABLE 2.
State-of-Society and Rubber Market Assumptions

State-of-Society Assumptions

- No natural disasters of wars of worldwide dimensions
- Political instability in rubber-producing regions of South East Asia will continue
- The pressures of population growth and dwindling natural resources will continue to challenge capabilities
- Self-sufficiency in food is a long-term goal for Mexico
- Mexico will remain a net energy exporter
- Mexico will work toward a more favourable balance of trade
- OPEC will continue to be a dominant factor in the world economy
- The price of Mexican oil will be pegged to world prices
- Unemployment and underemployment rates will remain high
- The Mexican government and its institutions will not change dramatically
- Growth of the Gross Internal Product in Mexico is not more than 7%
- Inflation will continue
- The Mexican population growth rate will be about 2.9%
- In the arid zones, urbanization will continue

Rubber Market Assumptions

- World elastomer demand will increase at an average annual rate of 3.6% during the 1980-2000 period
- Mexican elastomer demand will increase at an average annual rate of 7% during the 1980-2000 period
- The relative consumption of natural rubber to synthetic will decrease from 29% to 27% by the year 2000. It will constitute 32% of the Mexican elastomer demand in 1980, declining to 28% by 1990
- World production of *Hevea* rubber will increase at an average annual rate of 3.2% during the period 1980-2000
- The world natural rubber shortfall will be 0.2 million metric tons by 1985, 0.3 by 1990 and 0.8 by 2000
- Mexico consumed around 1.5% of the world natural rubber in 1980 and will consume 2.8% by the year 2000
- The Mexican production of *Hevea* rubber will not surpass 10-15,000 tons per year by the year 1995
- The Mexican demand for natural rubber in 1995 will be 140-160,000 metric tons
- Natural rubber prices will roughly parallel world oil prices
- The price and quality of Guayule rubber will be competitive with *Hevea* rubber.

TABLE 3.
Assumptions for Scenario A

Basic Assumptions

- Motivated by social needs
- A modest set of social and economic betterment goals
- A low improvement level in the regional organizative and administrative capacity
- Requires modest market expansion to accommodate the product
- The quantity of rubber produced (5,000 tons) represents a fraction of the national demand
- Does not require intense research and development activity
- It is a regional impact strategy

Socio-Political Assumptions

- Federal financing for Guayule R&D remains moderate
- Guayule development is consistent with government plans (Global Development Plan, National Plan for Agroindustrial Development, National Employment Plan)
- The Guayule project is oriented to increasing productivity and employment and thus the well-being of the Mazapil region
- Article 32 of the Agricultural Promotion Law eliminates restrictions on the use of ejido land. Edidatarios and small-holders can unite in productive units for Guayule exploitation

Technological Assumptions

- 75,000 tons of shrub (30% humidity) should be harvested annually in the Mazapil region, producing one ton of rubber for every 14.28 tons of dry shrub
- The harvesting assumes a shrub regeneration cycle of 10 years
- To supply the processing plant with 275 tons of shrub per day, a minimum of 450 harvesters and 200-500 donkeys are required
- The daily processing capacity of the plant is 52 tons of dry shrub in a 24-hour day, for 300 days a year and the hourly production is 0.69 tons of rubber
- The shrub is harvested from 5-10 collection centres

TABLE 3. (cont'd)

Regional Assumptions

- The ejidatarios agree with Guayule harvesting and there are sufficient workers to harvest the quantities necessary for the processing plant
- The existing conflicts between institutions such as La Forestal and Fondo Candelillero are resolved by means of policy decisions which form one organization for the planning and management of renewable resources

Organization Alternatives

- The ejido community and the industrial organization work together in the development and operation of the Guayule industry, contract the supply with the ejidos and give support in the coordination of harvesting activities. The ejido community would be responsible for the harvesting details and the industrial organization for the processing and commercialization aspects

- The industrial organization contracts the workers and organizes all aspects of the harvesting, transport and processing. This alternative appears improbable due to the difficulty of recruiting and organizing the workers without the cooperation of the ejido organization, but offers advantages in terms of shrub control, programming of harvesting, control of salaries and negotiation with small-holders

- Organization and supervision of the workers, the harvest, transport and the processing activities are carried out through the establishment of an inter-ejido cooperative. This alternative appears unlikely given the degree of cooperation necessary for the management of all the above-mentioned aspects, particularly the processing which would be a completely new activity for the ejido.

TABLE 4.
Assumptions for Scenario B

Basic Assumptions

- Supposes an important governmental assistance
- Requires a high level of improvement in the regional organizative and administrative capacity
- Requires an intense R&D activity in the processing of primary and secondary products
- Guayule production is intended to supply one third of the national demand
- It is a strategy with impacts at a national level

Socio-Political Assumptions

- The Guayule Project is oriented to a relatively high production of rubber and increases productivity and employment at a regional level
- The Guayule Project is part of a program to reduce rubber imports and therefore improve the balance of trade
- The production of Guayule rubber is initially based on the wild stands already existing in the Mazapil region and subsequently on 5 zones of dryland cultivation in an area north of Zacatecas
- The utilization of the wild resource requires reforestation and management to guarantee the continued and sustained supply for a plant which produces 5,000 tons of rubber per year

Technological Assumptions

- The average rubber production is 10% of the shrub on a dry weight basis
- Seed should initially be collected from existing wild stands but in the third year seed from the plantations will be used
- 5 processing plants are required, one in Cedros with a capacity of 5,000 tons of rubber per year, using the wild stands and 4 each with a capacity of 10,000 tons in each of the remaining zones of the Mazapil region
- The subproducts of Guayule processing should include the purification of the resins, food for cattle and fuels from the bagasse

Regional Assumptions

- The ejidatarios agree to harvest Guayule and there are sufficient workers to harvest the quantities necessary for the processing plant
- The salaries for non- and semi-qualified workers will not increase rapidly in the surrounding region (Saltillo and Monterrey) compared to the inflation rate
- The Mexican Food System (SAM) begins the development of food production in dryland regions in the north of Zacatecas

## Impact Evaluation

Once the scenarios and the state of the art of Guayule were presented, the integration of the impact issues was proceeded with in order to predict the most important ones for each scenario. The collaboration of the workshop participants permited the following:

- identification of the critical questions of the scenarios and of the technology;
- their structurization in preoccupation issues;
- evaluation of the probable impacts of each scenario.

Some Models. There are numerous techniques and mathematical models for the integration of the perceptions of a group of experts on the impacts of technology. Some of the most frequently used are:

ELECTRE - An analytical tool for use with multiple criteria. It permits the optimization of decision-making when the data are not comparable among themselves and when different scales and measurements exist (35).
SPIN - A method of analysis using digraph models. It provides behaviour over time and information which describes the structure of the model (36).
KSIM - A type of model which permits the structurization and analysis of relationships between variables which are not well-defined in large and complex systems (37).
QSIM - Permits the obtention of a rapid dynamic simulation (38).
IMPACT - A method which puts special emphasis on the determination of whether or not there is a relationship among the variables and the relative importance of this relationship (39).
CROSS-IMPACT - A technique which considers the probabilities of events and permits forecasting (40).

The elaboration of the corresponding graphs permits a visual presentation of the direct and transitive impacts and promotes discussion and analysis.

The critical questions collected during the workshops fall within the following general headings at the percentage indicated in brackets:

- TECHNOLOGY AND ORGANIZATION (36%). Administrative structure, yield, Guayule ownership, infrastructure, design engineering, rubber commercialization, organisms involved, organizative structure.
- RESOURCES (22%). Water, Guayule available, jobs generated, sustainability of the resource, energy.

- POLICIES (14%). Organization, legal support, labour conflicts, smallholders, organisms involved, national and regional plans, regional leaders, participation.
- ECONOMICS (10%). Profitability criteria, role of private enterprise, financing, taxes, distribution of the economic benefits, rubber market, regional product, jobs and salaries.
- CLIMATE AND ENVIRONMENT (9%). Other species, aquifers, erosion, pollution, organisms involved.
- SOCIAL (9%). Beneficiaries, cultural impact, public services, intermediarism, new human settlements, income.

The impact issues were then integrated with these critical questions. The issues constitute, as mentioned by Coates (41), important public and social policy issues - areas of permanent conflict with which Guayule could be associated. The principal issues for Scenario A are summarized in Figure 7.

Using the KSIM model, an impact evaluation exercise was carried out with the workshop participants. Some of the themes most representative of the regional conditions were taken and Guayule was included among these with the possible impacts it could cause, starting with those specified in the scenario. The use of KSIM allows the incorporation of the perceptions that the group of experts have on the problem.

## Policy Analysis

The policy analysis is the last stage of the TA. It is an attempt to identify policy alternatives and institutional options for the achievement of proposed operational goals (42). In a sense it seeks to generate a "menu" of policy options for preliminary selection of policies, as well as the determination of which general options should be detailed, studied and evaluated. The policy analysis identifies those existing and non-existing policy instruments (laws, regulations, rules, plans, studies, etc.) which affect the planning, instrumentation and operation of the Guayule Project. Policy analysis is the principal analytical tool to support decision-making which invariably, and particularly in this case, is accompanied by great uncertainty and risk.

The planning, implementation and operation of new agroindustrial concepts, such as the Guayule case, have vast and intricate relationships with the social, economic and political frameworks. The social nature of the development projects, their transectorial character and their multiple objectives make this type of analysis very necessary.

| ISSUES | Principal Promotor | Public Sector | | Others | | | |
|---|---|---|---|---|---|---|---|
| | CONAZA/ Guayulmex | CIQA | Others | Small-holders | Tyre Industry | Ejidatarios | Agronomic University |
| ECONOMIC FEASIBILITY<br>Uncertainty re the price of rubber; vague criteria; profitability in the public sector; costs depending on organization | 7,12, ■ (P)<br>1, ■ (I) | | 3, □ (P) | | | | |
| RESOURCE SUSTAINABILITY<br>Inventory; sustained production without management, 5,000 tons of rubber per year; recuperation 10-15 years; sustainability depending on organization and cutting strategy | 4,5,7, ■ (I)<br>13, ■ (P)<br>1, □ (O) | 5, ■ (I)<br>4, □ (P) | 1, □ (O)<br>4, □ (P) | | | | 4, □ (I)<br>7, ■ (I) |
| REGIONAL DEVELOPMENT<br>Development plan lacking; Guayule alone not sufficient for regional development; organization decisive in regional development; conflicts if current structure is maintained | | 15, ■ (P) | 1,2,3, ■ (P)<br>5, ■ (P)<br>10, ■ (P)<br>9, ■ (P) | | | | |
| DISTRIBUTION OF BENEFITS<br>Guaranteed only through fixed employment, price policies, land rights; need for agreements between government agencies such as COPLAMAR, IMSS, CONASUPO, SAHOP | | | 6,17, ■ (P)<br>3, ■ (P)<br>4, ■ (P)<br>11, ■ (P)<br>2, ■ (P) | 2, ■ (P) | | 6, ■ (P) | |
| LAND OWNERSHIP<br>Conflicts between ejidos and small-holders depending on the organization; Agricultural Promotion Law favours productive units and appropriate organization | | | | 2, ■ (P)<br>9, ■ (O) | | 3, ■ (P)<br>2, ■ (P) | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| MIGRATION, MANPOWER AND EMPLOYMENT<br>Partially avoid emigration; restrictions on manpower availability favour alternative 3: 800 jobs generated, 80% permanent in primary and secondary sectors constitute important regional impact. Work force tends to concentrate in harvesting centres and industrial plant settlement. | | | 1,2,9, ■ (P)<br>11, ■ (P)<br>10, ■ (O) | | | 17, ■ (P)<br>11, ■ (O) | |
| ROLE OF LABOUR ORGANIZATIONS<br>Conflicts with ixtle or candelilla workers' leaders or organizations; labour organizations for peasants, harvesters and plant workers. Alternative 3 - promotion of new characteristics in regional labour organizations. | | | 5, ■ (P)<br>9, ■ (O)<br>11, ■ (P)<br>10, ■ (P) | | | 5, □ (P) | |
| DEVELOPMENT OF INFRASTRUCTURE<br>Especially water and roads; inter-institutional coordination between Guayulmex, SAHOP & SARH very important. | 1, ■ (O)<br>3, □ (P)<br>6, □ (O) | 6, □ (O) | 1, ■ (O) | | | | |
| CAPACITY & STRUCTURE OF THE ORGANIZATION<br>Three alternatives each with different constraints; slowness and imprecision of the public sector to define them; lack of specific organization policies. | 1, □ (P) | | 1, □ (P)<br>2, □ (P) | | | 2, □ (I)<br>3, □ (I) | |
| INTER-INSTITUTIONAL COORDINATION<br>Numerous institutions and groups involved. Constraints and inexperience in long-term planning; state instruments not considered. | 6,17, ■ (P) | | 9, ■ (P) | | | | |
| INTEGRATION OF GUAYULE WITH OTHER RESOURCE ACTIVITIES<br>Slight competition from animal husbandry and agriculture, considerable competition from candelilla and ixtle; no competition from mining. | | | 9, ■ (O) | | | 10, ■ (O) | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| ENVIRONMENTAL POLLUTION<br>50,000 tons of cellulosic waste annually. Technology exists for its utilization (energy and forrage). Waste water with treatable contaminants; negligible solvent vapour; considerable accident risks; no adverse affects on harvesters. | 1,2,3, ■ (O) | 3, ■ (O) | 17, ■ (P) | | | | |
| ECOLOGY<br>No precise information available. Less ecological risk than current activities (agriculture, animal husbandry, candelilla). Depends on institutional organization. Requires permanent monitoring. | | | 8, ■ (I)<br>16, ■ (P) | | | | |
| WATER RESOURCES<br>Risk in sustainability of water supply over 10 years. Slight pollution risks; waste waters only industrial. Potable water required in collection centres. | | | 1, ■ (O) | | | | |
| SCIENCE AND TECHNOLOGY<br>Fundamentally of an ecological nature; eminently practical. Inventory control, monitoring of effects, development of preventative measures and constant analysis of ecological risk. Intense development of norms, not much development of products. Optimization of water and industrial process; technological development of the use of subproducts. Integration of germplasm. | | | 5,7,8, ■ (O) | | 5,6, □ (O) | | 4, ■ (O)<br>2, □ (O) |

KEY

1,2,3 etc. indicates the policy instrument described on following page
■ Existing instrument
□ Non-existing instrument
(P), (I), (O) - Planning, Implementation, Operation

FIGURE 7. Policy Instruments for Scenario A

KEY TO FIGURE 7.

| POLICY INSTRUMENTS | |
|---|---|
| EXISTING | NON-EXISTING |
| **PLANNING (P)** | |
| 1. National Plan for Agro-industrial Development | 1. Guayulmex organic and administrative structure |
| 2. Agricultural Promotion Law | 2. Decree on the creation of Guayulmex |
| 3. Agrarian Reform Law | 3. Financing and administrative operation norms for the Guayule Agroindustrial System |
| 4. Para-state Organism Law | |
| 5. Cooperatives Law | |
| 6. Decree on the creation of COPLAMAR | 4. System for the integral management of Guayule |
| 7. Decree on the creation of CONAZA | 5. Proceedures for the buying of Guayule |
| 8. Decree on the creation of FIDHULE | |
| 9. Unique Agreements on Federal-State Coordination | |
| 10. Statutes of Candelilla and Ixtle Organizations | |
| 11. Federal Labour Law | |
| 12. Preinvestment and Feasibility Study | |
| 13. Guayule Inventory Study | |
| 14. Study on Macrolocalization of the Industrial Plant | |
| 15. Socio-Economic Study of the Guayule Region | |
| 16. National Plan to Combat Desertification | |
| 17. Agreements COPLAMAR-Agencies | |

KEY TO FIGURE 7 (cont'd)

| POLICY INSTRUMENTS | |
|---|---|
| EXISTING | NON-EXISTING |
| IMPLEMENTATION (I) | |
| 1. Detailed Engineering of the Guayule Factory Study<br>2. Minimum Salary Law<br>3. Agricultural Promotion Law<br>4. Ecological Study of the Guayule Region<br>5. Documented estimate of the sustainability of the Guayule harvest<br>6. Guayule transportation system<br>7. Guayule cutting and collection methodology<br>8. National Land Clearing Program<br>9. Agrarian Reform Law | 1. Study on the maximum sustained capacity of the regional resources (water, energy, manpower)<br>2. Program and procedures for the training of personnel<br>3. Integral system for the cutting and transportation of Guayule<br>4. Guayule harvest and conservation norms<br>5. Internal labour regulations for Guayulmex |
| OPERATION (O) | |
| 1. Soil and Water Conservation Law<br>2. Environmental Protection Law<br>3. Manual for residual water treatment<br>4. Development and evaluation studies for rubber and derivatives<br>5. Product quality norms<br>6. Study on commercialization channels (market)<br>7. Patents and trademarks Law<br>8. Cooperatives Law<br>9. Statutes of La Forestal and Fondo Candelillero<br>10. National Agroindustrial Development Plan<br>11. Regional Policy on Human Settlements | 1. Inventory control system<br>2. Integral system for the utilization and destiny of subproducts, residues and contaminants<br>3. Study of the impact of urbanization on the region<br>4. Program for sensitization of the tyre sector |

Policy Framework. The Guayule Project, depending on the scenario, is immersed in a complex policy framework which could change in some aspects during the time-span of each one of the scenarios. Table 5 shows, in a general way, the political and institutional frameworks and their relationships with each one of the scenarios. From this table it can be seen that each scenario has a slightly different policy framework and this, of course, implies different actors in each one.

Policy Analysis of the Scenarios. By means of the study, a set of policy instruments required to partially resolve operative aspects and conflicts detected were identified. In each of the scenarios, Guayule has the characteristic of being fundamentally a Project of an inter-institutional nature and it cannot be conceived of in any other way. To a great extent, this is the cause of the great constraints, uncertainties and complexities of an organizative type which are manifested. The space available for this article prohibits a detailed analysis, but Table 6 summarizes the policy characteristics of each of the scenarios.

This table is complemented by Figure 7 which shows the issues of the "slow growth" scenario, the points of conflict in each one and how they relate to the general policy instruments such as laws (environmental, organizational, etc.) or the specific ones for each scenario. This figure is a "map" of policy instruments which permits the identification of the most relevant actors. The complex inter-institutional pattern which has to be organized during the decision-making process can be observed.

It is important to point out that as a consequence of policy analyses one of the principal subproducts is the "explicitation" of the needs in the subject of scientific and technological information which should be integrated into a policy instrument specific to each scenario.

## CONCLUSIONS AND RECOMMENDATIONS

The carrying out of a TA study has important consequences, not only in aiding decision-making but as an enormous catalyst for learning about specific problems in the application of new technologies.

Some conclusions and recommendations of this study are presented under the following two headings:

TABLE 5.
Political and Institutional Frameworks for Scenarios A & B

| Level | Scenario A | Scenario B |
|---|---|---|
| NATIONAL | | |
| National Policy for Strategic Materials - non-existent | N | VI |
| Development in Arid Zones - implementation started in 1970 | VI | I |
| National Plan for Agroindustrial Development-systems approach initiated in 1977 | S | VI |
| National Plan for Industrial Development - projections to 1990 | N | VI |
| Natural rubber - Fidhule | S | VI |
| Agricultural Promotion Law (LFA) - from 1981 | I | VI |
| Food policy - development of Mexican Food System | S | I |
| Program against desertification - in design | I | I |
| Employment policy - especially through COPLAMAR | I | S |
| REGIONAL | | |
| Decentralization of planning through the establishment of state committees (COPLADES) | I | VI |
| Food policy - managed by the Ministry for Agriculture and Hydraulic Resources and the Mexican Food System (SAM) | I | VI |
| Industrial development - mining plans and the Saltillo industrial corridor | I | VI |
| Human Settlement Policy | I | I |
| Renewable Resources Forestry Policy - carried out by 2 government agencies - La Forestal & Foncan | VI | S |
| Policy against margination - COPLAMAR agreements | VI | S |
| LOCAL | | |
| Strengthening of the municipalities | I | I |
| Policy for the use of aquifer resources | S | VI |
| Soil Use Policy | S | VI |

Key: VI = very intense, I = intense, S = scarce, N = nil

TABLE 6.
General Policy Characteristics for Scenarios A and B

| Scenario A | Scenario B |
|---|---|
| **Economic** | |
| Of a regional nature, framed within the development policies in marginal regions. In particular, the actions of the Ministry for Programming and Budget, CONAZA and other government agencies like COPLAMAR are identified as well as the role of the Governor of Zacatecas. Fundamental objectives of raising the regional product through the production of 5,000 tons of rubber. Occasional subsidy policies. | The general political framework is national and international and is immersed within a national policy on natural rubber. It seeks the economic specialization of the region in the production of Guayule under cultivation in order to achieve goals of around 50,000 tons of natural rubber in 1995. National policies on prices & the formation & implementation of a national strategy combined with Hevea and synthetic rubber for the production of polyisoprene rubber. The roles of SEPAFIN, SPP, Banrural and SARH as actors will be important at this level together with the state governor. |
| **Social** | |
| With a high social content, seeking to promote the organization capacity and mechanisms for the generation of an employment structure which improves on the existing one. Risks as a consequence of the lack of organizative capacity to incorporate technology. Concern in such areas as reforestation, resource harvesting, transportation organization, etc. | A profound innovation is sought throughout the scenario, gradual technification in the crop and the need for social organization in productive units with possible constraints of a social type. Promotion of four important settlements and intensification of the migratory flow, both internal and external. Need for clear and well-coordinated policies in the services, especially in health and commerce. |

TABLE 6. (cont'd)

| Scenario A | Scenario B |
|---|---|
| **Political** | |
| Semi-official organization with integral control over supply, transfer and distribution. Development within a conflictive framework in which the predominance and influence of the current political organizations could represent a grave risk on the transfer of political control systems of the ixtle & candelilla workers' organizations. An indefined & conflictive political institutional framework & imprecise relationships with new legal instruments such as the Agricultural Promotion Law. An instrument is needed for the promotion of political & organizative innovations in the exploitation of renewable resources. | Profound links with national policies, especially those of industrial and commercial development and occasionally linked to governmental policies towards the transnational tyre producing companies. Important participation of the rubber industry associations. Need for a clear policy framework in agroindustry, intensification of the technified productive units and serious conflicts between the production policies of grains and cattle with their respective actors. Definate displacement of the traditional policies in the exploitation of renewable resources. |
| **Environmental** | |
| Risk for the sustainability of the resource which requires the support of revegetation programs. Need to plan for 7-10 years as without means of reforestation the economic availability of the resource will fall. This notably influences the type of organization and exploitation schemes of the natural stands. It is indispensable to establish integrated resource exploitation systems in which the economic species, mainly Guayule, Candelilla and Lechuguilla, are exploited under integral policies. | The initiation of this scenario with the exploitation of wild stands requires a policy of resource maintenance and of preparation via revegetation. Soil conservation plays an important role in this scenario through the identified policies such as the plans for clearing of land and combating desertification and state policies which occasionally emerge. Policies for the establishment of germplasm, nurseries, etc. |

TABLE 6. (cont'd)

| Scenario A | Scenario B |
|---|---|
| **Research** | |
| Studies oriented to revegetation, maintenance of germplasm, ecology, transport optimization, and monitoring of the evolution of the wild populations collected. The design of tools and of organization systems for collection which gradually increase productivity. Utilization of satellite images for permanent monitoring both of collection and revegetation. Need for a normative research plan, although decentralized in various agencies coordinated by the company. The size of the project will not permit internal research & development work and this will have to be supported by already existing centres. | Establishment of an intense program in dryland and irrigated cultivation, genetic improvement, use of bioregulators, machinery and strategic design of innovation in the crop. Innovation in the industrial process oriented to the optimization of water use, utilization of wastes, development of diverse products from rubber, especially thermoplastics. The magnitude of this scenario requires an intense R&D effort via the establishment of professional research units geared to the necessities of optimization in the resource use (water and soil mainly). Design of a long-term plan in which institutions specializing in diverse areas of the problem would participate. |

On the TA:

- The carrying out of the TA has made it possible to initiate the training of human resources in the area of technology assessment, in the integration of methodologies and in the organizative capacity for the discussion of technological problems;
- The carrying out of a TA in the area of arid zone technologies is an important social learning exercise which should be intensely promoted;
- It is recommended that regional projects be integrated for their submission as exercises for assessment studies;
- In the medium-term, an evaluation of the legislation at a national and state level is recommended for the gradual incorporation of assessment techniques, especially in the case of ecological and environmental evaluation of arid zone projects;

- The creation of suitable groups for the study of relevant development issues in arid zones and the application of TA methods is proposed.

On Guayule:

- The Guayule Project is a high risk one but no more so than existing projects;
- In either of the two scenarios, Guayule could be an important project of national and regional characteristics, through which, with adequate planning and organization, the necessary capacity can be acquired for the carrying out of technological innovation projects in arid zones;
- The Guayule Project has shown up numerous faults, the products of inexperience and institutional conflict, which have impeded integral planning;
- For the Guayule Project, in either of the two scenarios, the only route to success is via integral long-term planning, with the taking of many decisions by the President of the Republic and the Governor of the State;
- It is possible to take the first decision to initiate the planning of the Project, in either scenario. This planning requires new methodological skills which are often not found in the bureaucratic agencies;
- It is necessary to form a technological company oriented to the planning of Guayule development, in either of the two scenarios. This company should integrate all the policy instruments, including R&D, and the taking of decisions in the implementation and the promotion of the Project in various regions;
- The Guayule Project cannot proceed at the margin of the political processes of the other renewable resource exploitation schemes of candelilla and ixtle. A national policy is essential for the planning of the exploitation of renewable resources with resource sustainability, economic, environmental and political criteria. Without this integral planning, the existing conflicts and political and administrative habits will hinder any innovation;
- The research and development plans should be congruent with the needs of each development scenario.

ACKNOWLEDGMENTS

We would like to thank CONACYT, CONAZA and the National Science Foundation of the USA for supporting this Project and all the people who participated in the workshops, especially W. McGinnies, M. Jamail, A. Torres and B. Motomochi.

REFERENCES


1. Kunreuther, H. and Linnerooth, J., Risk Analysis and Decision Processes, Preliminary Draft, IIASA, Laxenburg, Austria, March 1982.
2. Majone, G., Technology Assessment and Policy Analysis, Policy Sciences 8, 173-175, (1977).
3. Nehnevajsa, J. and Menkes, J., Technology Assessment and Risk Analysis, Technological Forecasting and Social Change 19, 245-255, (1981).
4. Technology: Processes of Assessment and Choice, National Academy of Sciences, Washington, D.C., July (1969).
5. Coates, Joseph F., Technology Assessment - A Tool Kit, Chemtech, 372-383, June (1976).
6. Technology Assessment for Development, Report of the United Nations Seminar, Bangalore, India, 30 Oct. - 10 Nov., 1978, New York, (1979).
7. Linstone, H.A., The Use of Structural Modeling for Technology Assessment, Vol. 1, prepared for the National Science Foundation/RANN, Portland State University, Portland, Oregon, (1978).
8. Hetman, F., Social Assessment of Technology, Chapter 19 in this book.
9. Several articles in Technology Assessment, Vol. 1, No. 1, (1972).
10. Dobrov, G.M., Systems Assessment of New Technology for Decision-Making in Government and Industry, Technological Forecasting and Social Change, 12, 73-87, (1978).
11. Gvishiani, J.M., The Scientific-Technological Revolutions and some Current Problems of a Scientific and Technological Policy, in Organization for Forecasting and Planning: Experiences in the Soviet Union and U.S.A., W.R. Dill and G. Popov (eds.), IIASA, John Wiley and Sons, (1979).
12. Relatorio de Atividades, CNPq, Consetho Nacional de Desenvolvimento Cientifico e Tecnologico, Brasilia, Brazil, (1979).
13. Sistema Nacional de Desarrollo y Prospectiva Tecnologica Industrial, SEPAFIN, Mexico, March (1982).
14. Porter, A.L. et al., A Guidebook for Technology Assessment and Impact Analysis, Elsevier North Holland, New York and Oxford, (1980).
15. Holling, C.S. (ed), Adaptive Environmental Assessment and Management, Chapter 4, IIASA, John Wiley and Sons, Chichester, (1978).
16. IIASA, Expect the Unexpected: Adaptive Approach to Environmental Management, Executive Report IIASA, Laxenburg, Austria, (1979).
17. CIQA, Evaluación de los Impactos de la Comercialización de Guayule en México, CIQA Report presented to CONACYT and CONAZA, (1982).

18. McGregor, E.A. and Gonzalez, R.L., Perspectivas del Hule Natural en México, in El Hule Natural: Hacía el Año 2000, E. Campos and L. Mullins (eds.), CIQA, Mexico, in preparation.
19. Velazquez, M.A. et al., Chapter 2 in Guayule: Reencuentro en el Desierto, CIQA, Mexico, (1978).
20. Cinco Años de Investigación del CIQA en el Hule de Guayule, CIQA Report, in preparation.
21. Quero, E., CIQA.
22. Campos-Lopez, E., Un Sistema de Referencia en IADE de Recursos Renovables, Internal Report, CIQA,(1979).
23. OALS/MRI, A Sociotechnical Survey of Guayule Rubber Commercialization, A State of the Art Report, University of Arizona, Tucson, Arizona, (1976).
24. Quade, E. and Miser, H., Handbook of Systems Analysis, IIASA, John Wiley and Sons, Chichester, in press.
25. Häfele, Wolf, Energy in a Finite World: A Global Systems Analysis, IIASA, Ballinger, Cambridge, Mass. (1981).
26. Carr, A.B., Use of Scenario Writing in Assessing Technology, J. Int. Soc. Tech. Ass., 27-30, Fall, (1976).
27. Medellin-Leal, F., Mexico's Semi-Arid Zones, Chapter 2 in this book.
28. Narro Reyes, J.G., Un Intento de Regionalización de la Región Arida del Norte, CIQA internal report, (1980).
29. COPLAMAR, Mínimos de Bienestar, Vol. 6, Mexico, (1980).
30. McGinnies, William G., Chapter 1 in this book.
31. Fried, Jacob, Project COPLAMAR/ASZA, CIQA internal report, (1982).
32. Mier, A., CIQA internal report, (1980).
33. Landsat Inventory: An Inventory of the Distribution and Standing Crop of Guayule in Northern Mexico Using Remote Sensing Techniques, CIQA, Mexico, (1980).
34. CONAZA Inventory: Estudio Dasonómico de la Región Guayulera Circundante a Cedros, Zacatecas, Comisión Nacional de las Zonas Aridas, Mexico, (1981).
35. Roy, B., La Methode Electre II (Une Methode de Classment en Presence de Criteres Multiples, N.T. No. 142, Q.S., Group Metra, (1971).
36. McLean, M. and Shepherd, P., The Importance of Model Structure, Futures, 8-1, 40-51, (1976).
37. Kane, J., A Primer for a New Cross Impact Language - KSIM, Technological Forecasting and Social Change, Vol. 4, 129-142, (1972).
38. Wakeland, W., QSIM: A User Interactive Modeling Package, Paper 74-17, Systems Science PhD Program, Portland State University, Portland, Oregon, (1974).
39. Forrester, J.W., Industrial Dynamics, MIT Press, Cambridge, Mass., (1961).

40. Dalkey, N.C., An Elementary Cross-Impact Model, Technological Forecasting and Social Change, Vol. 3, 341-351, (1972).
41. Coates, J.F., What is a Public Policy Issue? Judgement and Decision in Public Policy Formation, p.33, AAAS, Selected Symposium 1, (1978).
42. Berg, M., Chen, K. and Lissis, G., A Value-Oriented Policy Generation Methodology for Technology Assessment, Technological Forecasting and Social Change, 8, 401-420, (1976).

# 21 Systems Analysis in Arid Zones (ASZA): Constructing an Interface Between Regional Public Policy and Science and Technology in Mexico*

*E. Campos, J. García, R. Anderson,*** 
*R. Ondarza,**** and R. Armijo*

## INTRODUCTION

About 30 percent of the world's land surface is desert and semi-arid grassland. Almost 40% of Mexico's two million square kilometers is arid or semi-arid. Global and national development increasingly require the wise utilization of these lands through a strong link between science and technology and planning.

As the scope of scientific and technological projects expands, these contrast more and more with the regional reality in which they will operate. A project may be supported by wide and rigorous research, but as it encounters regional reality other problems, heretofore hidden, arise. These may relate to land tenure, ecology, the social well-being, organization of work, transport systems, or to numerous other characteristics. The incorporation of new technologies desirable for development of arid regions is not merely a problem of natural resources or technology per se.

The imperviousness of many arid regions to technology is one of the most important reasons for the low standard of living and productivity widespread in these regions. There is a lack of analysis of this situation arising from several factors:

- Insufficient knowledge of specific technologies;
- Inadequate knowledge of the regional capacity (human, capital and natural resources, social and cultural factors);
- An institutional structure unable to assess complex problems and assist in the design and implementation of robust strategies, when they exist.

---

* Translated from Spanish

** Formerly with the International Institute for Applied Systems Analysis; presently with Mathtech Inc.

*** National Council for Science and Technology

Of course, these problems are not exclusive to arid regions; they are experienced in varying degrees of intensity in other regions as well.

Experience in Mexico emphasizes that a technological project, with a well-defined engineering background, institutes - deliberately or not - a process of regional transformation. Traditional evaluations of technologies, particularly those based on cost-benefit analysis, are limited in their usefulness. More comprehensive, far-seeing technology assessment has become an important challenge that cannot be met successfully by a disjointed combination of engineering and economics. A more systematic, interdisciplinary framework of multiple perspectives, criteria, and values is required.

One of the crucial deficiencies which has become apparent is the lack of mechanisms to encourage exchange of information between experts in the scientific and technical community on the one hand and government at all levels on the other. Real needs for development are not correctly transformed into programs of applied research and insights from research are not rapidly translated into programming and planning. At the same time, there is insufficient coordination within both the research and the government communities. The results are poor circulation of information, waste, and unnecessary antagonism between groups which in fact share common goals.

The construction of institutions which create a healthy interface between government and public policy and science and technology is a desperately-needed undertaking for the coming decade in Mexican arid land development, as well as in many other countries. Substantial progress in regional development will be the result of a sustained and intense effort, requiring:

- Improvement of skills for designing and assessing new technologies;
- Strengthening of the capacity to identify and implement effective courses of action. Where and when in a system is there special leverage to bring about beneficial change?
- Reinforcement of information flows between regional actors.

The Applied Chemistry Research Center (CIQA) was created by the Mexican government as a decentralized public institute during 1976 with a focus on special technical questions related to development of native biological resources in arid regions. A broader structuring of problems and accumulation of knowledge about the arid regions of northern Mexico were among the most important results of undertaking this research. Fed by its own experience and contacts with numerous individuals and institutions such as IIASA, CIQA began a more intensive and systems-oriented analysis in 1979. Two years later this process crystalized into the project "Systems Analysis in Arid Zones" (ASZA), supported by the National Council for Science and Technology (CONACYT), the Interamerican Development Bank, the National Commission for Arid Zones (CONAZA) and CIQA. The project focuses on the characteristics of innovation in arid zones and the design of strategies to stimulate this process. The first stage of the project concentrates on the design of a new regional forum for the analysis of problems of arid zones.

## THE ASZA PROJECT

### Characteristics

The ASZA project is intended to foster the interaction between science and technology and regional planning in arid zones. It has two principal goals:

- to promote new mechanisms to induce innovation;
- to apply systems analysis tools for policy design in the management of resources.

The project attempts to be:

- PROSPECTIVE - ASZA seeks the gradual development of individual and group capacities for the wise application of science and technology in long-term resource policies.
- ANALYTICAL - ASZA seeks to establish permanent foundations for the application of systems analysis tools in resource problems.
- INTEGRATIVE - ASZA will be integrative in the intellectual sense, in that it will bring together engineering descriptions of technological assessments. ASZA will also be integrative from the point of view of planning, in that it will seek to bring together representatives from the scientific, technical, and political spheres.
- INTERACTIVE - ASZA will seek to promote a work environment where technicians and decision-makers from governmental organizations regularly exchange experiences and perspectives with experts from national and international institutions, so that research activities adapt to changing regional reality.
- INNOVATIVE - ASZA will be innovative from an institutional viewpoint, at the same time that it seeks innovations in specific areas of science and technology.

Work Areas

The ASZA project is tentatively organized into four work areas. These are Technological Innovation, Resource Evaluation and Sustainability, Technology Assessment and Development and Methods and Communications.

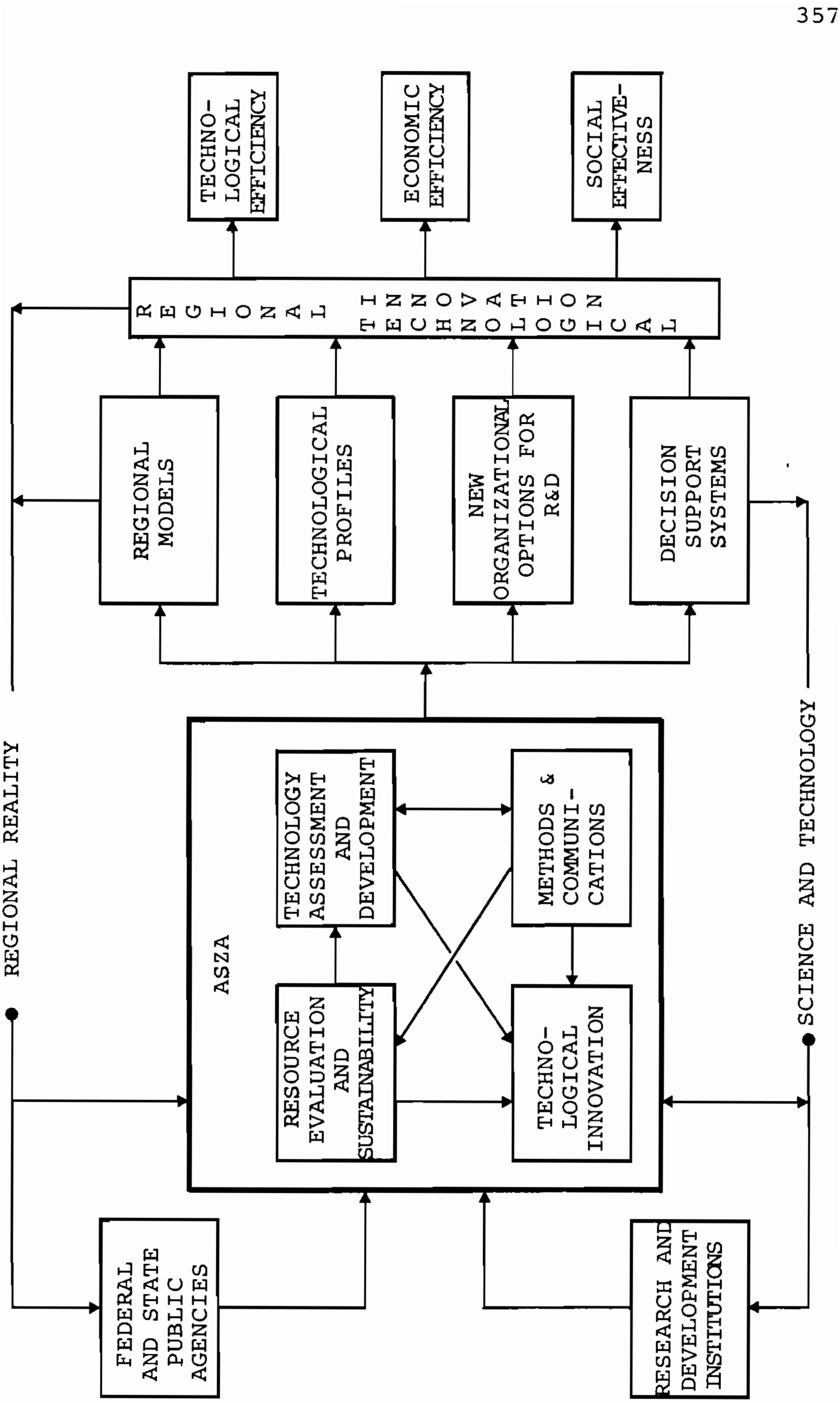
Technological Innovation. This area will analyze the stages and processes of technological innovation and its role in regional development. While the phenomenon of innovation has been carefully examined in various industrial sectors, at the regional level the process is less studied. It would be of great importance to understand the dynamics of the diffusion of technology and perhaps thus be able to accelerate the penetration of desirable technologies for the development of arid zones. Among the activities contemplated for this area are:

- Retrospective analysis of Mexican experience and experience in other countries with features similar to Mexico. For example, what are the time constants of diffusion for particular agricultural technologies such as plastic mulching?
- Management of innovation. Analysis of regional socio-economic restrictions on innovation and administrative and legal constraints on spread of technology.

Resource Evaluation and Sustainability. This area will assess the resource base of arid lands in a way such that information on particular subsystems may be incorporated into larger and dynamic analyses. More specifically, it will undertake evaluations of the following kind:

- Water resources. Actual and potential demand, supply and quality.
- Mineral resources. Recoverable reserves and potential resources of fuel and non-fuel minerals.
- Climate and soils.
- Vegetation cover. Native biological resources and their capacity to sustain grazing and forestry.
- Human resources. Population, availability of manpower, level of training, demographic dynamics.
- Institutions. Federal, state and municipal organizations; legal and financial structures; social and cultural features; scientific and technological infrastructure.

Technology Assessment and Development. This area will develop new technological concepts in accord with defined regional purposes, and assess possible impacts of adoption of technologies. Technology assessments will include evaluation of social and political compatibility,



REGIONAL REALITY
SCIENCE AND TECHNOLOGY
FEDERAL AND STATE PUBLIC AGENCIES
RESEARCH AND DEVELOPMENT INSTITUTIONS
ASZA
RESOURCE EVALUATION AND SUSTAINABILITY
TECHNOLOGY ASSESSMENT AND DEVELOPMENT
METHODS & COMMUNI-CATIONS
TECHNO-LOGICAL INNOVATION
REGIONAL MODELS
TECHNOLOGICAL PROFILES
NEW ORGANIZATIONAL OPTIONS FOR R&D
DECISION SUPPORT SYSTEMS
REGIONAL TECHNOLOGICAL INNOVATION
TECHNO-LOGICAL EFFICIENCY
ECONOMIC EFFICIENCY
SOCIAL EFFECTIVE-NESS

sustained availability of resources, and economic viability.

Technology assessment will proceed from the beginning with participation of interested federal, state, and local groups. While there will be a particular emphasis on planning, ASZA will also concentrate on the analysis of proper implementation, operation and monitoring.

Methods and Communications. This area will have three functions, one concerned with improvement of analytical tools, and two concerned with improvement of the information flow:

- Methods. One group, working closely with those involved in applications, will have responsibility for evaluation, adaptation, and development of tools for systems analysis. Among other activities this group will study suitability for various problems of approaches such as optimization, simulation and so forth, as well as credibility and verification of numerical models.
- Regional data systems. The ASZA project will require ongoing collection, storage, and retrieval of data. This activity has as its aim the design, demonstration, implementation, and operation of a system to facilitate analysis and use of data related to regional development of arid zones. It should build on existing systems, supplementing them as necessary for the aims of specific projects.
- Decision support systems. This activity will encourage the use of communication technologies helpful for exploring the implications of decisions and for facilitating individual and group decision-making. Computer-based approaches (interactive simulation models, teleconferencing, computer networks) will be used, along with non-computerized communication methods which promote exchange and development of concepts.

## Stages and Strategy

The project is structured in three stages; the first two constitute the phases of definition and initiation and will last three years (1982-84). Pending the success of the first two stages, the third will be the consolidation and operation of a new organization dedicated to the analysis and synthesis of scientific, technical, and socio-economic information, and the presentation of alternative solutions for the development of arid zones to public agencies. The first two stages are briefly described below:

- Structuring the idea (1982). Lasting one year, this stage will be concerned with evaluating alternative designs for the required institutional forum, identification of the most important problems for regional development of arid zones, and elaboration of corresponding studies. The vehicle for accomplishing these objectives will be permanent and ad-hoc working groups, which will also serve to begin the important process of bringing together the appropriate organizations and individuals.
- Institutional build-up (1983-1984). During this stage, the first steps will be taken towards the creation of an interdisciplinary institution functioning as an interface between science and technology and regional development. This stage will include the building-up of scientific and administrative staff, the modification of structure, and the detailing of a program.

### Working Groups and Participants

The early phases of the ASZA project will rely heavily on a set of working groups for formulation and evaluation of alternatives, and elaboration and implementation of a program. The working groups will be made up of people from a variety of different scientific disciplines and from different aspects of planning and development of arid zones. Members of the groups will come from public agencies of the state and federal governments, and national and international research and development institutions.

## CONCLUDING REMARKS

The ASZA project intends to fulfill its objectives by:

- Generating an intellectual focus on regional problems;
- Drawing on the experiences of other regions and countries in relation to arid zones;
- Bringing together representatives of both research and government to aid in the definition of problems and work toward their solution;
- Providing methods for the systematic analysis of regional problems which are consistent with information available; and
- Establishing an institutional structure which can maintain the appropriate research activities and continue to serve as an interface between science and technology and regional development of arid zones.

The creation of the new regional research organization will be complex, since it brings together diverse experiences, perspectives and values. While this paper presents a tentative design, the integration process sought by the project should be characterized by revision, re-design and adaptation. The intellectual and institutional tasks described here are examples of one of the most important challenges for Mexico's evolution during the 1980s.

## ACKNOWLEDGMENTS

We would like to thank E. Flores, General Director of CONACYT and R. Levien, Director of IIASA for encouragement and support and to J. Ausubel of IIASA for suggestions and fruitful discussions.

## BIBLIOGRAPHY

1. Haug, P.T., Social Synergism on Interdisciplinary Teams: Suggestions for Managing Integrated Adhocracies, Internal Report, School of Renewable Resources, Fort Collins, Colorado, 1977.
2. Houstein, H.D., Maier, H. and Ulfman, L., Innovation and Efficiency, IIASA, Laxenburg, Austria, May 1981
3. Levien, R.E., Interdisciplinary Science and Policy, IIASA, Laxenburg, Austria, February 1981.
4. Linstone, H.A., The Multiple Perspective Concept with Application to Technology Assessment and other Decision Areas, National Science Foundation Report 81-1, Futures Research Institute, Portland State University, Oregon, September 1981.
5. Majone, G. and Quade, E.S., Pitfalls of Analysis, John Wiley and Sons, (1980).

# Appendix: Contacts for Further Information

As an aid to readers who may want further information, recent addresses for one of the authors of each paper are given below.

*Rafael Almanza*, Instituto de Ingeniería, Universidad Nacional Autónoma de México, Ciudad Universitaria, México 20, D.F., Mexico

*Manuel Anaya-Garduño*, Centro de Edafología, Colegio de Postgraduados, Apdo. Postal No. 86, Chapingo, Mexico

*Robert J. Anderson*, Mathtech Inc., P.O. Box 2392, Princeton, N.J. 08540, U.S.A.

*Joseph Barnea*, United Nations Institute for Training and Research (UNITAR), 801 United Nations Plaza, New York, N.Y. 10017, U.S.A.

*Russell A. Buchanan*, Route 2, Washington, Illinois 61571, U.S.A.

*Enrique Campos-López*, ASZA, Centro de Investigación en Química Aplicada (CIQA), Apdo. Postal 379 Centro, C.P. 25000, Saltillo, Coahuila, Mexico

*K.J. Dalsted*, Remote Sensing Institute, South Dakota State University, Brookings, South Dakota 57007, U.S.A.

*H.E. Dregne*, International Center for Arid and Semi-Arid Land Studies, Texas Tech University, P.O. Box 4620, Lubbock, Texas 79409, U.S.A.

*Enriqueta García*, Instituto de Geografía, Universidad Nacional Autónoma de México, Ciudad Universitaria, México 20, D.F., Mexico

*D.O. Hall*, Dept. of Plant Sciences, University of London King's College, 68 Half Moon Lane, London SE24 9JF, England

*Francois Hetman*, Science Policy Division, Organization for Economic Cooperation and Development, 2 Rue Andre-Pascal, 75775 Paris Cedex 16, France

*Harold A. Linstone*. Futures Research Institute. Portland State University, P.O. Box 751, Portland, Oregon 97207, U.S.A.

*William G. McGinnies*, Office of Arid Lands Studies, University of Arizona, 845 N. Park, Tucson, Arizona 85719, U.S.A.
*Fernando Medellín-Leal*, Instituto de Investigación de Zonas Desérticas, Universidad Autónoma de San Luis Potosí, San Luis Potosí, Mexico
*David A. Mouat*, Applied Remote Sensing Program, Office of Arid Lands Studies, University of Arizona, 845 N. Park, Tucson, Arizona 85719, U.S.A.
*W.E. Ormerod*, Dept. of Medical Protozoology, London School of Hygiene and Tropical Medicine, Keppel St., London WC1 7HT, England
*Timothy R. Peoples*, Office of Arid Lands Studies, University of Arizona, 845 N. Park, Tucson, Arizona 85719, U.S.A.
*E. Quiñones-Garza*, Depto. de Edafología, DETENAL, San Antonio Abad No. 124, México 8, D.F., Mexico
*Merrill K. Ridd*, Center for Remote Sensing and Cartography, University of Utah Research Institute, Salt Lake City, Utah 84108, U.S.A.
*Robert H. Schmidt, Jr.*, Dept. of Geological Sciences, University of Texas at El Paso, El Paso, Texas 79968, U.S.A.
*J.I.B. Wilson*, Dept. of Physics, Heriot-Watt University, Riccarton, Currie, Edinburgh EH14 4AS, Scotland